Fluid Power Basics

Parker Training

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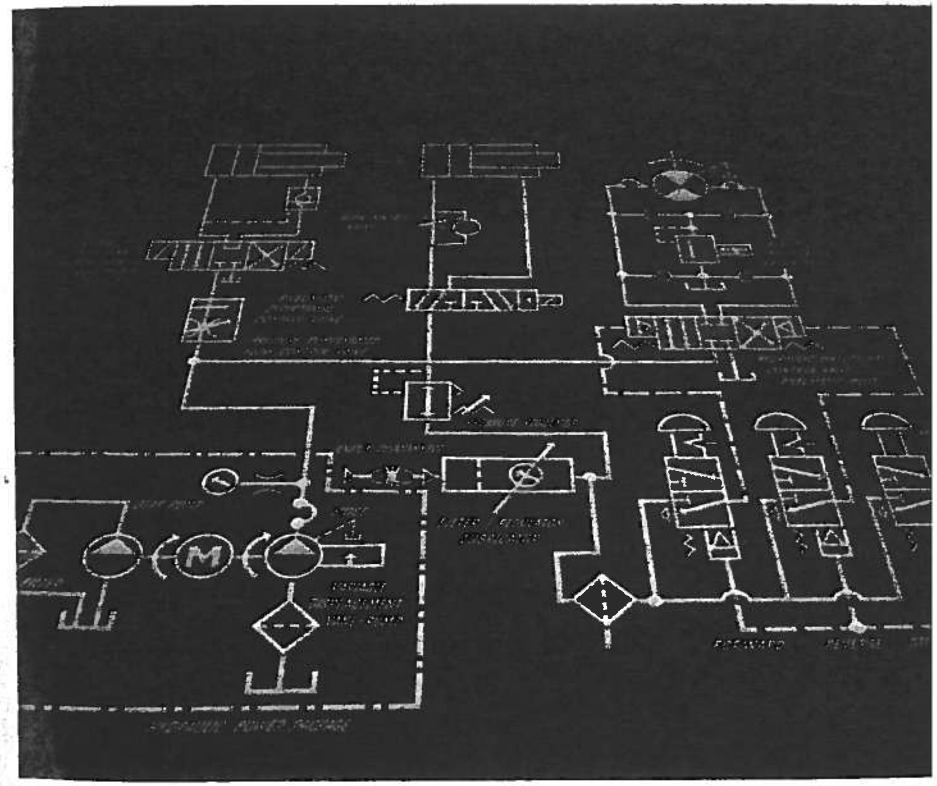

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Parker

Motion & Control
Training Department

Parker Hannifin Corporation
Motion Control Training Dept. W3MC01
6035 Parkland Blvd.
Cleveland, OH 44124-4141
Tel: (216) 896-2577
Fax: (216) 514-6738
Web site: http://www.parker.com

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Lesson 2

Force Transmission Through a Fluid

Pneumatic and hydraulic systems are fluid power systems. They use a fluid as the medium of energy transmission. Pneumatic systems use a highly compressible, gaseous fluid. Hydrualic systems use a relatively incompressible, liquid fluid.

Just as the other transmission systems (mechanical, electrical), fluid power systems are capable of transmitting a static force (potential energy) as well as kinetic energy. When a static force is transmitted through a fluid, it happens in a special way. To illustrate, we will compare how a force is transmitted through a solid with force transmission through a confined fluid.

force transmitted through a solid

A force transmitted through a solid is transmitted basically in one direction only.

If we pushed on a solid block, the force would be transmitted in the direction of the applied force, to the opposite side only.

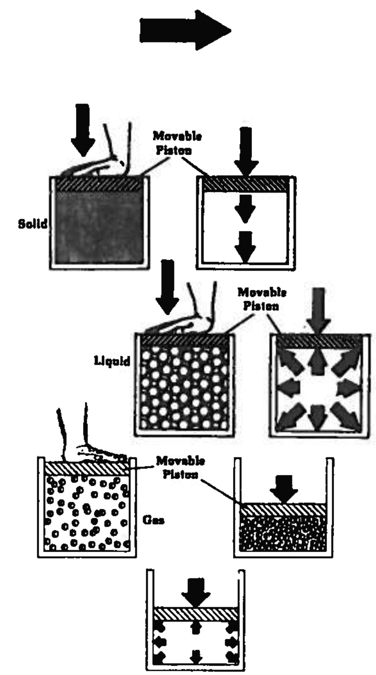
force transmitted through a fluid

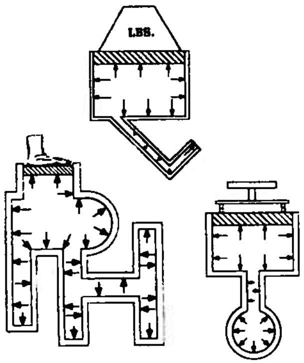
Unlike a solid, a force applied to a confined fluid (gas or liquid) is transmitted equally in all directions throughout the fluid in the form of fluid pressure.

If we pushed on a container filled with fluid, the pressure of the applied force would be transmitted equally throughout the fluid.

In the illustration, if the fluid were a liquid, the piston would not move when a force is applied.

In the case of a gaseous fluid, the applied force would push the piston down compressing the gas. Piston movement would continue until the intensity of the applied force were equalled by gas pressure. A gas absorbs the intensity of an applied force.





A confined gas or liquid will transmit pressure in a similar manner regardless of how it is generated. As far as a fluid is concerned, an applied force results in pressure whether the application of force comes from a hammer, by hand, weight, fixed or adjustable spring, or any combination of forces.

Fluids take the shape of their container. Consequently, pressure will be transmitted in all directions regardless of container shape.

pascal's law

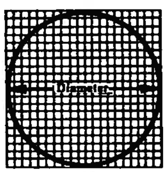
The property of a gas or liquid to transmit pressure equally in all directions throughout itself is known as Pascal's law in honor of Blaise Pascal who first defined the principle.

applying pressure

In transmitting pressure through a confined fluid, some sort of movable member has been used to apply the pressure. In the examples used so far, the movable member has been a piston.

To determine the intensity of a force, or pressure, being applied to a system, the force is divided by the area of the movable member. For example, if an applied force of 1000 lbs. were applied to a piston area of $10 in^2$, the resulting pressure would be 100 PSI.

$$\text{pressure} = \frac{\text{force}}{\text{area}} = \frac{1000 \text{ lbs.}}{10 \text{ in}^2} = 100 \text{ PSI}$$



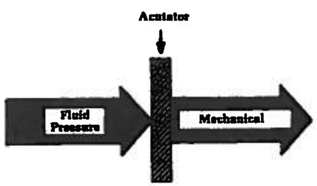
area of a circle

Many times, just the diameter or bore of a piston is known and the area must be calculated. This calculation is as easy to make as the area of a square.

We know that to determine an area of a square, a side of the square is simply multiplied by itself. It is a fact that the area of a circle is 78.54% of the area of a square whose sides are the length of its diameter.

To determine a circle area, multiply the circle diameter by itself and by .7854.

$$\text{circle area} = \text{diameter}^2 \times .7854$$



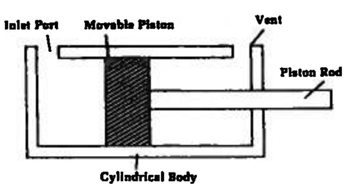
fluid pressure to mechanical force

Applying a force to a fluid and transmitting the resulting pressure throughout the fluid in various shaped containers does very little good for its own sake. Fluid pressure must be converted into mechanical force before work can be done. This is the function of a fluid power actuator—to accept fluid pressure and convert it into a mechanical force.

One very common type of actuator is the fluid power cylinder.

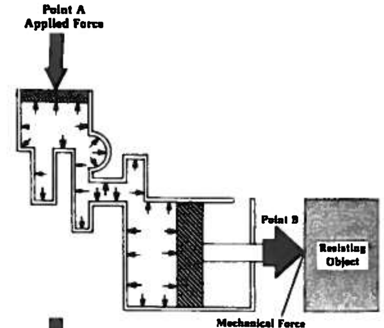
fluid power cylinder

A fluid power cylinder accepts fluid pressure and converts it into a straight-line, or linear, mechanical force.



what cylinders consist of

Fluid power cylinders basically consist of a cylindrical body, a closure at each end, a movable piston, and a rod attached to the piston. At one end of an elementary cylinder, the cylinder body has an inlet port by which fluid enters the body. The other end is vented.

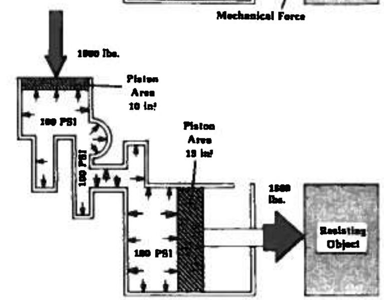


how cylinders work

With inlet port connected to the system, the cylinder becomes part of the system. In our illustration, when a force is applied at point A, the resulting pressure is transmitted throughout the system and acts on the piston in the cylinder. This results in a mechanical force at point B.

mechanical force multiplication

Mechanical forces can be multiplied using fluid power. The determining factor for force multiplication is the area on which pressure is applied. Since pressure is transmitted equally in all directions throughout a confined fluid, if a cylinder piston has more area than the movable member developing the pressure, output force will be greater than input force.

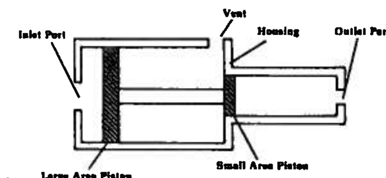


In our example, assume that the resisting object is stationary and will not move. A 1000 lb. force on the $10 in^2$ area piston results in a pressure of 100 PSI throughout the system. The 100 PSI acts on the cylinder piston with a $15 in^2$ area resulting in a mechanical force of 1500 lbs.

$$\text{force (lbs)} = \text{pressure} \frac{\text{lbs.}}{\text{in}^2} \times \text{area (in}^2\text{)}$$

intensifier

An intensifier multiplies fluid pressure.



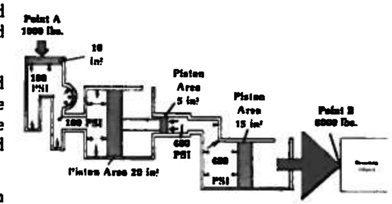
what intensifiers consist of

An intensifier basically consists of a housing with inlet and outlet ports, and a large area piston connected by a rod to a small area piston. The volume between the two pistons is vented.

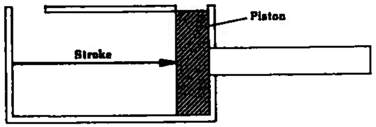
how intensifiers work

The inlet of an intensifier is connected to a source of fluid pressure either air or hydraulic. Intensifier outlet is connected to part of the system containing hydraulic fluid.

An intensifier multiplies, or intensifiers, an existing fluid pressure by accepting an air or hydraulic pressure at the large area piston and applying the resultant force to the small area piston. Fluid pressure is therefore intensified or multiplied at the actuator.



In our example, assume that the object is to be clamped. An input pressure of 100 PSI at intensifier inlet ultimately results in a high output clamping force of 6000 lbs.

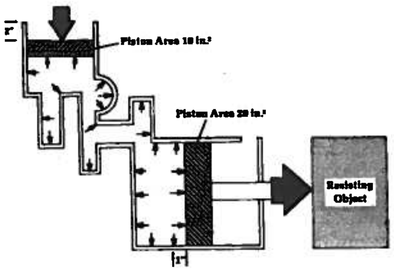


movement sacrificed

It has been illustrated that a cylinder can be used to multiply a force by the action of fluid pressure acting on a piston area.

When multiplying a force with fluid pressure, it may have appeared that something was received for nothing. It appeared that a smaller force could generate a larger force under the right circumstances, and nothing was sacrificed. This is relatively true in a static system. But if the force were to be multiplied and moved at the same time, something would be sacrificed—movement.

Each cylinder has a stroke and volume. The stroke of a cylinder is the distance through which a piston and piston rod travel.

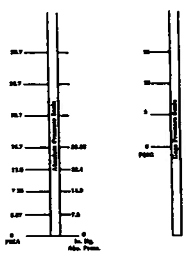


A cylinder volume is the piston's displacement. It is calculated by multiplying its stroke in inches by piston area in square inches. This will give a volume in cubic inches.

$$\underset{(in^3)}{\text{cylinder volume}} = \underset{(in^2)}{\text{piston area}} \times \underset{(in)}{\text{stroke}}$$

In the illustration, the system is filled with hydraulic fluid. The top piston must move through a distance of 2 in. to make the cylinder piston move 1 in. In both cases the work done is the same. The top piston displaces 20in³ of liquid, and the lower piston is displaced by 20 in³ of liquid.

When forces are multiplied with fluid pressure, movement is sacrificed.



pressure scales

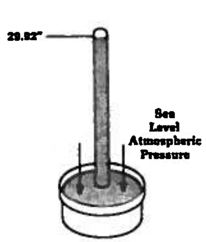
Either of two pressure scales are used to measure pressure in a fluid power system—an absolute scale or a gage scale.

gage pressure scale

The gage pressure scale begins at the point of atmospheric pressure. The units of measure are PSI. An ordinary pressure gage that we find in a fluid power system operates on this scale.

The gage scale measures fluid pressure in a system and does not include the pressure exerted by the atmosphere. To measure atmospheric pressure, the absolute pressure scale is used.

Barometer



measuring atmospheric pressure

Up to this point we have been measuring pressure in pounds per square inch (PSI). But, it is not uncommon to express low pressures by the height of a liquid column. This is how we measure the pressure exerted by the atmosphere.

We generally think of air as being weightless. But, the ocean of air surrounding the earth has weight and thus exerts a pressure.

Back in the 17th century, a physicist named Torricelli determined that atmospheric pressure could be measured by a column of mercury (Hg). Filling a tube with mercury and inverting it in a pan of mercury, he discovered that a standard atmosphere at sea level could support a column of mercury 29.92 inches high. Sea level atmospheric pressure therefore measures, or exerts the same pressure as, 29.92 inches of mercury. Any elevation above sea level would of course measure less than this.

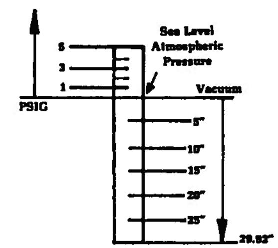
Altitude Above Sea Level In Feet	Barometer Reading — Inches of Mercury	Atmospheric Pressure — Pounds Per Square Inch
0	29.92	14.7
1000	28.8	14.2
2000	27.7	13.6
3000	26.7	13.1
4000	25.7	12.6
5000	24.7	12.1
6000	23.8	11.7
7000	22.9	11.2
8000	22.1	10.8
9000	21.2	10.4
10000	20.4	10.0

Torricelli's atmospheric measuring device is known as a barometer.

Sometimes it is desirable to change pressure from inches of mercury to PSI. Since one inch of mercury exerts a pressure of .491 PSI, multiplying a mercury column height by .491 changes inches of mercury to PSI. For instance, to convert a pressure of 29.92 inches of mercury to PSI, 29.92 is multiplied by .491 yielding 14.7 PSI. Therefore, 29.92 inches of mercury (standard sea level atmospheric pressure) is the same as 14.7 PSI.

absolute pressure scale

The absolute pressure scale begins at the point where there is a complete absence of pressure. It can measure and does include atmospheric pressure. The customary unit of measure for the absolute scale in the United States can be either PSI or inches of mercury.



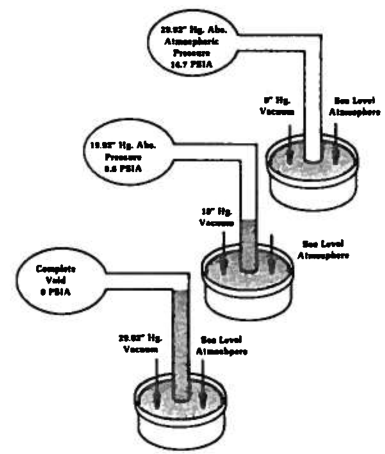
To differentiate between the two pressure scales, PSIG is used to denote gage pressure, and PSIA is used for absolute pressure.

vacuum pressure scale

A vacuum is any pressure less than atmospheric. Vacuum pressure is a source of confusion many times because the scale begins at atomospheric pressure, just as gage pressure, but works its way down in units of inches of mercury.

how vacuum is determined

In the illustration, a pan of mercury open to the atmosphere is connected by means of a tube to a flask which has the same pressure as the atmosphere. Since the pressure inside the flask is the same as the pressure acting on the pan of mercury, a column of mercury cannot be supported in the tube. Atmospheric pressure is balanced by the pressure in the flask.

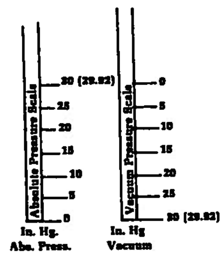


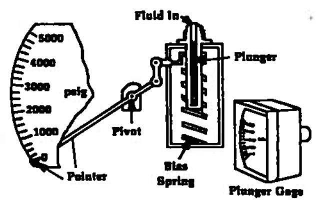
Zero inches of mercury (Hg) in the tube indicates a no-vacuum condition in the flask.

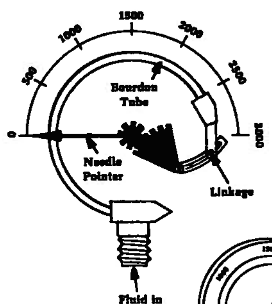
If the flask were evacuated so that the pressure inside were reduced by 10 inches of mercury, atmospheric pressure acting on the mercury in the pan would support a column of mercury 10 inches high. Atmospheric pressure is balanced by the pressure in the flask plus the pressure exerted by 10 inches of mercury. The vacuum would measure 10 in. Hg.

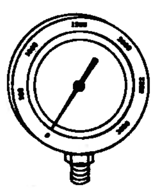
If the flask were evacuated so that no pressure remained and a complete void existed, atmospheric pressure could support a column of mercury 29.92 inches high at sea level. The vacuum would measure 29.92 in. Hg.

Zero inches of mercury vacuum is atmospheric pressure or









the absence of vacuum. 29.92 inches mercury vacuum indicates zero absolute pressure or a high vacuum at sea level.

Vacuum pressure has an equivalent point on the absolute pressure scale as can be seen when the two scales are compared. For example, at sea level a vacuum of 12 In. Hg. is the same as an absolute pressure of 18 in. Hg. Sometimes it is helpful to convert vacuum pressure to an absolute pressure.

pressure gages

A pressure gage is a device which measures the intensity of a force applied to a fluid. Two types of pressure gages are most commonly used in fluid power systems—the bourdon tube gage and the plunger gage.

plunger pressure gage

A plunger pressure gage consists of a plunger connected to system pressure, a bias spring, pointer, and a scale calibrated in units of PSI.

how a plunger gage works

As pressure in a system rises, the plunger is moved by the pressure acting against the force of the bias spring. This movement causes the pointer attached to the plunger to indicate the appropriate pressure on the scale.

Plunger gages are primarily found in hydraulic fluid power systems. They are a durable, economical means of measuring system pressure.

bourdon tube pressure gage

A bourdon tube gage basically consists of a dial face calibrated in units of PSI, and needle pointer attached through a linkage to a flexible metal curved tube, called a bourdon tube. The bourdon tube is connected to system pressure.

how a bourdon tube gage works

As pressure in a system rises, the bourdon tube tends to straighten out. This action causes the pointer to move and indicate the appropriate pressure on the dial face.

Bourdon tube gages are generally precision instruments. They are frequently used for laboratory purposes and on systems where pressure determination is relatively important.

Pressure gages, either plunger or bourdon tube type, measure system pressure which is above atmospheric. The units are in PSI and the scale is gage pressure or PSIG. To determine an absolute pressure from a gage reading, add the atmospheric pressure to the gage reading. For example, if a machine were operating at sea level and system pressure were 122 PSIG, the absolute pressure would be 136.7 PSIA (122 PSIG + 14.7 PSI).

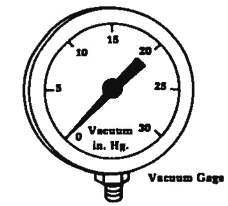
vacuum gage

A vacuum gage is a bourdon tube gage which measures

pressures below atmospheric. A vacuum gage is generally calibrated from 0 - 30. (The number 30 is actually 29.92 rounded off.)

Each division represents the pressure exerted by one inch of mercury.

At sea level, to determine an absolute pressure from a vacuum gage reading, subtract the vacuum in inches of mercury from 30. For instance, a vacuum reading of 7 in. Hg. at sea level is actually an absolute pressure of 23 in. Hg.



lesson review

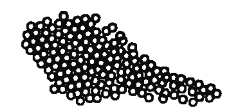
In this lesson of force transmission through a fluid we have seen that:

- The intensity of a force applied to a confined liquid or gas is transmitted equally in all directions throughout the fluid in the form of hydraulic or pneumatic pressure. This is Pascal's law.
- A fluid power cylinder converts fluid pressure into straight-line, or linear, mechanical force.
- The greater the pressure at a cylinder's piston or the larger the piston area, the greater the mechanical output force.
- An intensifier multiplies fluid pressure resulting in an increased output force at an actuator.
- When forces are multiplied with fluid pressure, movement is sacrificed.
- Either of two pressure scales are used to measure pressure in a fluid power system—an absolute scale or a gage scale.
- It is not uncommon to express low pressures by the height of a liquid column. Atmospheric pressure is measured by the height of a mercury column.
- A vacuum is an absolute pressure less than atmospheric. Vacuum is measured by the height of a mercury column.
- Two types of pressure gages are commonly used in fluid power systems—the bourdon tube gage and the plunger gage.
- A vacuum gage is a bourdon tube gage which measures pressures below atmospheric. A vacuum gage is calibrated from 0 - 30.

Lesson 3

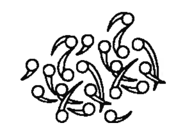
Energy Transmission Using a Hydraulic System

Before dealing with energy transmission through a liquid, it will help our understanding of hydraulics to first concentrate on some characteristics of a liquid.



liquids

Just as all substances, a liquid is made up of molecules. Unlike a gas, the molecules of a liquid are closely attracted to one another. Also, unlike a solid, these molecules are not so attracted to each other that they are in a relatively fixed position.



molecular energy

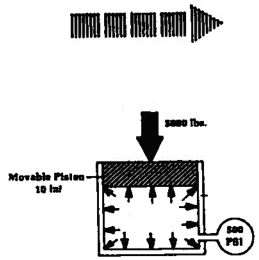
Liquid molecules are continuously moving. They randomly slip and slide past one another even when the liquid is apparently at rest. This movement of molecules is molecular energy.

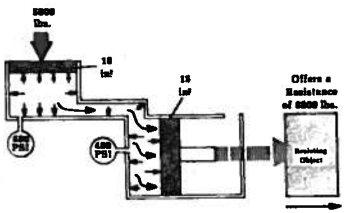
liquids take any shape

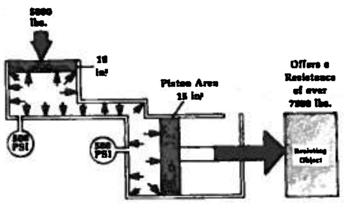
Since this slipping and sliding action is continuously taking place, a liquid is able to take the shape of any container.

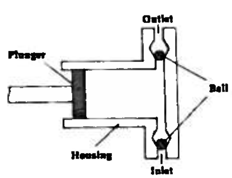
liquids are relatively incompressible

With molecules in close contact with one another, liquids exhibit a characteristic of solids. Liquids are relatively unable to be compressed. This is probably the reason a diver tries to "knife" his way into the water and avoid a belly smacker.









hydraulic transmission of energy

The reason for using hydraulics or any other type of energy transmission on a machine, is to perform work.

As illustrated previously, accomplishment of work requires the application of energy to a resisting object resulting in the object moving through a distance. To do any work then a hydraulic system requires something which can apply energy.

hydraulic accumulator

Up to this point, the device used to apply a pressure to a confined fluid has consisted of a movable piston on which the force is applied and a cylinder body to confine the fluid which in hydraulics is liquid. This device is called an accumulator.

An accumulator stores hydraulic pressure which is potential energy. This pressure can turn to working energy (flow and pressure).

In our illustration, the pressure stored in the accumulator is used to move the resisting object. 400 PSI of the 500 PSI accumulator pressure is used to overcome the resistance offered by the load. The remaining pressure is used to move the liquid.

An accumulator has its disadvantages when applying energy to a resisting object. If the resistance is large enough, there will be no movement and therefore no work.

In our example, the load offers a resistance of over 7500 lbs. The maximum force which can be generated by the 500 PSI accumulator pressure at the cylinder is 7500 lbs. Consequently, the cylinder and load will not move.

Another disadvantage of an accumulator is that once the volume of liquid stored in an accumulator is discharged, flow ceases.

A device is needed which can apply the necessary pressure to overcome a resistance and whose flow is continuous. This device is a positive displacement pump.

positive displacement pump

With constant cycling of its movable member, a positive displacement pump will deliver a constant flow of liquid, and will apply within limits of its prime mover whatever pressure is required.

In other words, a positive displacment pump develops working energy—kinetic energy (flow) and pressure.

what a positive displacement pump consists of

A positive displacement pump basically consists of a movable member inside a housing.

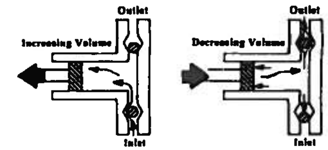
The pump in the illustration has a plunger for a movable member. The shaft of the plunger is connected to a prime mover (an engine or electric motor) which produces a constant reciprocating motion of the plunger. The inlet port is connected to fluid reservoir. At inlet and outlet ports, a ball allows liquid to flow only one way through the housing.

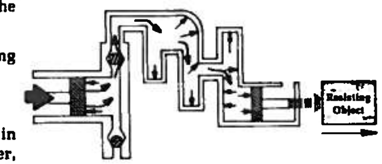
how a positive displacement pump works

As the plunger is pulled out, an increasing volume is formed within the housing. The ball at the inlet port allows fluid to enter filling the void.

After the housing is filled, the plunger is pushed in. The ball at the inlet closes and the ball at the outlet port unseats. A decreasing volume is formed within the housing. The plunger applies the pressure necessary to get the liquid out into the system.

The constant cycling of the plunger results in a pulsating rate of flow at whatever pressure is required.



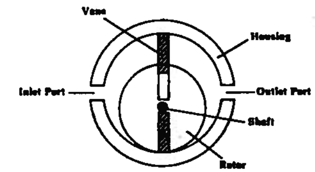


rotary positive displacement pump

The most commonly used positive displacement pump in a machine's hydraulic system is not a reciprocating plunger, but a rotary type. A rotary positive displacement pump develops a relatively smooth, pressurized flow of liquid, and it can be easily driven by an electric motor or internal combustion engine. For each revolution the pump is rotated, a definite volume of liquid is displaced.

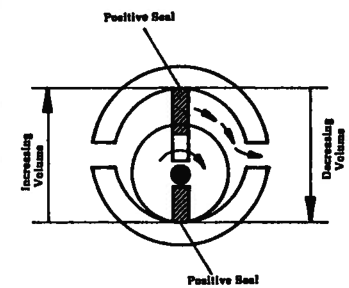
what rotary positive displacement pumps consist of

A rotary positive displacement pump basically consists of a housing with inlet and outlet ports, and a rotating group which develops fluid flow and pressure. One type of rotating group in the illustration consists of a rotor and vanes which are free to move in and out.



how rotary positive displacement pumps work

The rotating group of the pump is positioned off-center to the 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 housing forming a positive seal. The increasing volume at the inlet side allows liquid to fill the pump. The decreasing volume at the outlet forcefully pushes the liquid out into the system. The amount of pressure applied to the liquid by the pump will only be as great as the least resistance to flow in the system.



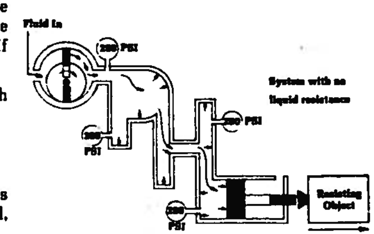
resistance vs. pressure

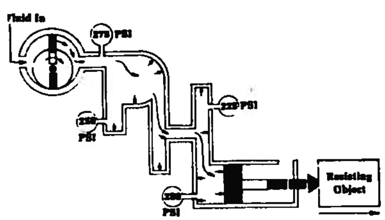
In a hydraulic system, there is a direct relationship between pressure and resistance. Pressure is applied by the pump in forcing fluid out into the system. The amount of pressure is determined by the degree of resistance. If the resistance is high, the pump must apply an equally high pressure. If the resistance is low, the pump applies a low pressure.

A pump applies pressure. Resistance determines how much pressure.

resistance to the flow of a positive displacement pump

Resistance to the flow of a positive displacment pump comes basically from two sources—the object resisting to be moved, and the liquid itself.





If the resistance of the liquid could be eliminated from the system illustrated, the only resistance to pump flow would be the resisting object, which can be overcome with a pressure of 200 PSI at the actuator. The pump would apply the required 200 PSI to get the liquid out into the system. This hydraulic working energy would be applied to the actuator and the object would move.

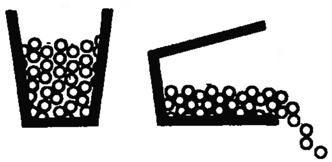
Resistance of a liquid to the pump's flow is always present. To discharge its flow against the liquid's resistance, the pump absorbs more energy from its prime mover, and applies an additional pressure to the liquid.

extra energy changes form

The additional energy applied by the pump does not result in additional hydraulic working energy at the actuator, because it is used up by a liquid's resistance. The working energy is "used up"—not in the sense of being destroyed, but it changes to heat energy. As was pointed out previously, this is the inefficiency in a system.

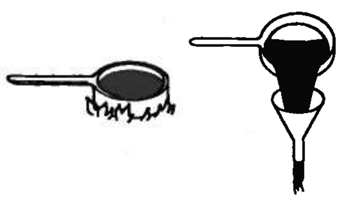
heat generation in a hydraulic system

Heat generation in a system is caused by a moving liquid's viscosity, friction, and changing direction. To find out how the heat is generated, we will now concentrate on some characteristics of liquids.



viscosity

Viscosity is a measure of the resistance of a liquid's molecules to flow or slide past each other. It is sort of an internal friction. An example of a high-viscosity liquid is honey or molasses. A low-viscosity liquid is water.

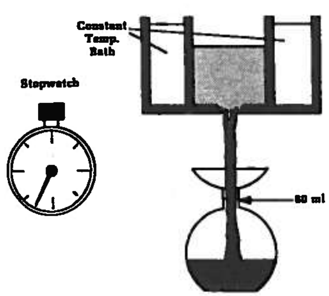


viscosity affected by temperature

A bottle of molasses taken from a refrigerator has a high resistance to flow. Trying to pour this liquid through a funnel would be a time-consuming task.

Heating the molasses in a sauce pan allows it to readily flow through the funnel. Heat causes the liquid molecules to flow past each other more easily.

As temperature increases, the viscosity of a liquid decreases.



saybolt universal seconds

One measure of a liquid's viscosity is the Saybolt Universal Second (abbreviated SUS or SSU). Professor Saybolt heated a liquid of a predetermined volume to a certain temperature and allowed the liquid to pass through an opening of a specific size. He timed the flow in seconds as it filled a 60 milliliter flask. The result was a measure of viscosity in Saybolt Universal Seconds.

viscosity generates heat

A high-viscosity liquid of 500 SUS, having more internal resistance to flow, will generate more heat in a system than a low viscosity liquid of 100 SUS.

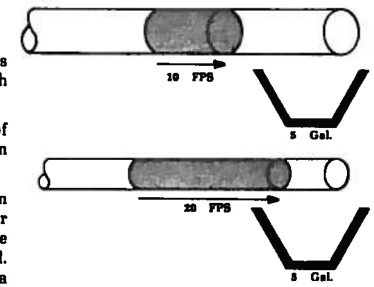
In many industrial applications, the viscosity of the oil

is 150 SUS at 100°F.

NOTE: All hydraulic systems do not use low viscosity fluid. Determination of the appropriate fluid viscosity for a hydraulic system incorporates other factors such as leakage and lubricity at high pressures.

friction

In any dynamic system, friction is present between parts which are moving in relation to one another. In hydraulics the liquid is moving, but the pipe is stationary.



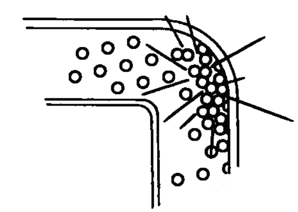
velocity vs. flow rate

In a dynamic system, fluid flowing through a pipe is traveling at a certain speed. This is the fluid's velocity which is usually measured in feet per second (FPS).

The volume of fluid flowing through a pipe in a period of time is a rate of flow. Flow rate is usually measured in gallons per minute (GPM).

The relationship between velocity and flow rate can be seen from the illustration. In order to fill the 5 gallon container in one minute, a 5 gallon volume of fluid in the large diameter pipe must travel at a speed of 10 feet per second. In the small diameter pipe, a 5 gallon volume must travel at a speed of 20 feet per second in order to fill the container in one minute.

In both cases the rate of flow is 5 GPM. The fluid velocities are different.



friction generates heat

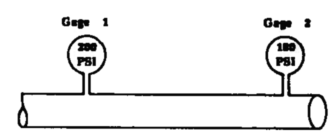
In a hydraulic system, friction, and therefore heat, is generated because of the liquid flowing through the pipe. The faster a liquid travels, the more heat is generated.

In industrial applications, the recommended maximum fluid velocity between pump and actuator is usually 15 FPS.

changing fluid direction generates heat

A mainstream of liquid flowing along in a straight line generates heat when it crashes into other liquid molecules while forced to change direction because of a pipe bend or elbow.

Depending on the pipe size, one 90° elbow could generate as much heat as several feet of pipe.



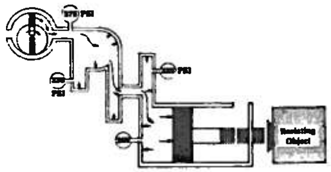
pressure differential

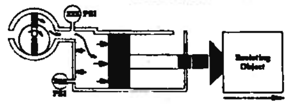
Pressure differential is simply the difference in pressure between any two points in a system.

It is a symptom of what is happening in a system:

1. By indicating that working energy in the form of a moving, pressurized liquid is present in the system.
2. By measuring the amount of working energy that changes to heat energy between the two points.

In our illustration, the pressure differential between the two





gage points is 20 PSI. This indicates that:

1. Working energy is moving from gage 1 toward gage 2.
2. While moving between the two gage points, 20 PSI of the working energy is transformed into heat energy because of liquid resistance.

hydraulic system designed to avoid generation of heat

The generation of heat by working energy traveling through a system to a point of work is system inefficiency. To make a hydraulic system more efficient, a designer chooses oil with the appropriate viscosity, uses piping of a proper size, and keeps bends to a minimum.

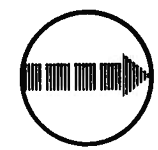
lesson review

In this lesson dealing with energy transmission using a hydraulic system, we have seen that:

- A liquid can take the shape of any container since its molecules are continuously slipping and sliding past one another.
- A liquid is relatively incompressible.
- Accumulators store hydraulic fluid under pressure as a source of potential energy.
- A positive displacement pump delivers a constant flow of liquid at a required pressure.
- Pumps operate by forming increasing and decreasing volumes within their housings.
- The amount of pressure applied to the liquid by a pump will only be as great as the least resistance to flow in the system.
- Resistance to the flow of a positive displacement pump comes from the load and the liquid.
- Liquid resistance is the result of viscosity, friction, and changing direction.
- Viscosity of a hydraulic fluid is its internal resistance to flow. A measure of viscosity is the Saybolt Universal Second (SUS).
- Flow rate in a hydraulic system is generally measured in gallons per minute (GPM).
- Fluid velocity in a hydraulic system is generally measured in feet per second (FPS).
- Pressure differential in a hydraulic system is simply the difference in pressure energy between any two points of a system.

Lesson 4

Control of Hydraulic Energy

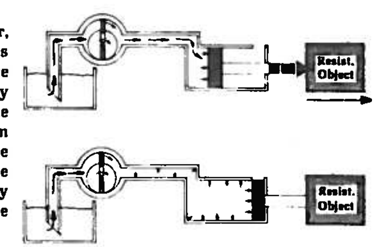


Working energy transmitted hydraulically must be directed and under complete control at all times. If not under control, no useful work will be done or a machine might be destroyed. One of the advantages of hydraulics is that energy can be controlled relatively easily by using valves.

valves

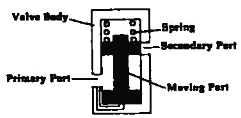
A valve is a mechanical device consisting of a body and an internal moving part which connects and disconnects passages within the body. The passages in hydraulic valves carry liquid. The action of the moving part controls maximum system pressure, direction of flow, and rate of flow.

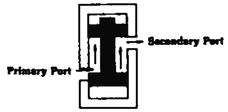
control of pressure

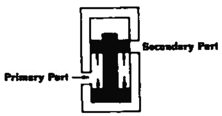


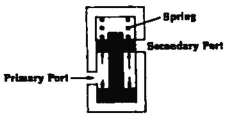
Hydraulic energy can be applied to a cylinder actuator, resulting in the performance of work. Once the cylinder is fully extended and the work is completed, a positive displacement pump will continue to absorb more energy from its prime mover and apply a higher pressure to the liquid. (Remember, the smallest resistance in the system signals the pump what pressure is to be applied.) With the cylinder fully extended, the smallest resistance becomes the physical strength of the system. The pump will try to apply a pressure to overcome this resistance which would be damaging.

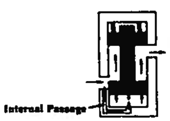
One use of a pressure valve is to limit system pressure to a safe level.











pressure control valve

A pressure control valve has an internal moving part which is operated by pressure. When the pressure in a system reaches a certain level, the internal moving part connects or disconnects passages in a valve body, allowing the liquid to follow another path.

what a pressure control valve consists of

A pressure control valve consists of a valve body with a primary and secondary passage and an internal moving part. The external openings of the passages are known as primary and secondary ports respectively.

how a pressure control valve works

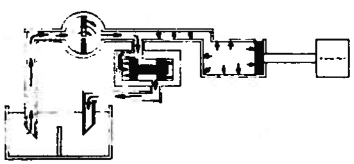
Many times, the internal moving part of a pressure control valve is a spool. In one extreme position, the spool connects the passages, allowing the fluid to flow through the valve. In the other extreme, the passages are disconnected and the flow path through the valve is blocked.

In pressure control valves, the spool is held biased in one extreme position by a spring. If the passages are disconnected and the flow path through the body is blocked in its normal condition, the valve is designated a normally closed pressure control.

Pressure is sensed at the bottom of the spool by an internal passage connected to the primary passage. When system pressure overcomes the force of the spring, the passages are connected. Fluid is free to flow through the valve.

(The fluid pressure used to operate the spool is known as pilot pressure. Pilot pressure is a common way of operating many types of hydraulic valves.)

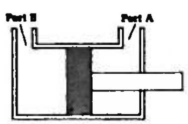
If the primary port of this type pressure valve were connected to system pressure, and the secondary port were connected to the tank, the flow from the pump could be directed back to tank when pressure applied by the pump becomes excessive. A normally closed pressure valve used in this manner is called a relief valve.



control of actuator direction

Once a cylinder is extended, it has to be retracted so that work can be done again.

To perform this task, a cylinder which is operated hydraulically in both directions is generally used, as well as something to change the direction of liquid flow.

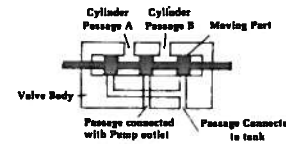


double-acting cylinder

A double-acting cylinder has a port at either end of the cylinder body by which fluid can enter and exit. This allows the piston rod to move in two directions (double-acting). To distinguish the ports on a double-acting cylinder, we will label one A the other B .

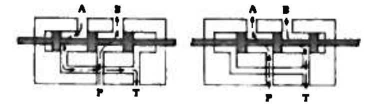
directional control valve

The moving part in a directional control valve connects and disconnects internal passages within the valve body, which action results in a control of fluid direction.



what a directional control valve consists of

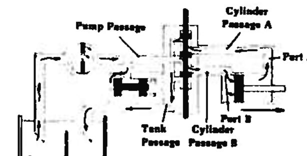
A typical directional control valve consists of a valve body with four internal passages and a sliding spool moving part which connects and disconnects the passages.



how a directional control valve works

With the spool in one extreme position, the pump passage is connected to cylinder passage B and tank passage is connected to cylinder passage A.

With the spool in the other extreme, the pump passage is connected to cylinder passage A and tank passage is connected to cylinder passage B.



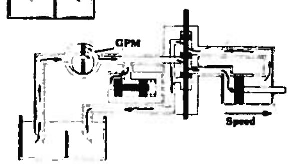
With a directional control valve in a circuit, the cylinder's piston rod can be extended and work performed.

By shifting the spool to the other extreme, flow is directed to the other side of the cylinder. The piston rod retracts.

control of actuator speed

In many applications, it is desirable and even necessary to control the speed at which an actuator does work.

The speed at which an actuator (cylinder) does work is the direct result of how quickly it is filled. In other words, actuator speed is the result of the GPM flowing to the actuator.

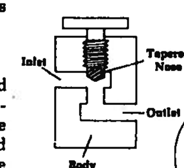


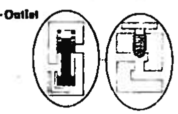
Since the pump in a hydraulic system is constant displacement, it would make sense to select a pump with the desired flow rate. This is usually the case when only one actuator is used in a system.

Many times in a hydraulic system, there is more than one actuator. If the system is designed for the cylinders to act individually, then the pump's flow rate is selected for the required speed of the largest cylinder. This means the smaller actuators will move more quickly, which may be undesirable. To reduce the flow rate to these or any actuator, a flow control valve is used.

flow control valve

A flow control valve, when properly used, always reduces the flow rate from a pump to an actuator.



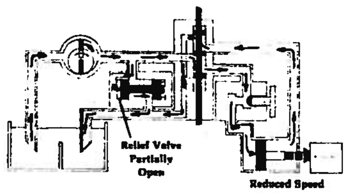


what a flow control valve consists of

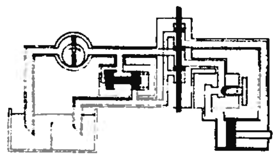
A typical flow control valve consists of a valve body and movable part. The movable part in our example is a "tapered-nose" rod which is threaded into the valve body. The movable part in our flow control valve is better described as "adjustable" since no movement takes place while the valve is operating.

how a flow control valve works

In a hydraulic system, there is many times a direct working relationship between a flow control valve and a pressure valve functioning as a relief valve.



The flow control valve is a resistance which results in a higher pressure being applied by the pump. This pressure partially opens the relief valve. The result is some flow goes over the relief valve and less flow through the flow control and to the actuator.

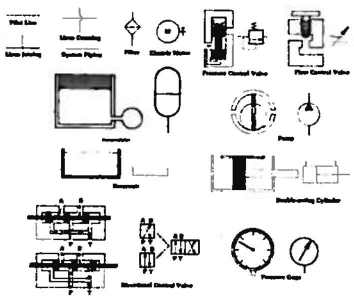


a simple hydraulic system

The components which have been described make up a simple hydraulic system. The system can perform useful work because hydraulic working energy in the system can be controlled.

Hydraulic systems are found in many diverse fields, from aerospace, aircraft, and military operations, to industrial, mobile, and steel mill applications. All hydraulic systems operate on the same principles which have been discussed up to now.

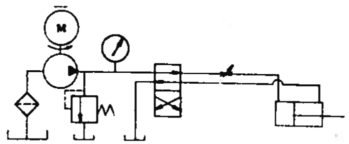
We shall in much of the remaining text material, concentrate on some of the various types of components which are available in industrial hydraulics.



hydraulic symbols

The hydraulic components and elementary systems which have been shown to this point, have been illustrated in a pictorial manner. System diagrams have been cut-away to illustrate internal component operation. This technique is beneficial from an instructional point of view, but it is impractical from a workaday standpoint.

In hydraulics, just as in other technologies, symbols are used to describe components and systems. The symbols for the components which have been discussed and the simple system which has been developed are illustrated using ANSI Y32.10 graphic symbols for fluid power.



NOTE: In addition to the components which have been discussed, the system also consists of an electric motor and a hydraulic filter. Hydraulic systems are generally equipped with a prime mover like an electric motor. And, in order to achieve a degree of reliability, hydraulic systems should be protected from dirt with a hydraulic filter.

• For additional fluid power symbols see Parker-Hannifin Design Engineers Handbook, Section k.

lesson review

In this lesson dealing with the control of hydraulic energy we have seen that:

- Valves consist of a body and internal moving part.
- Valves control maximum system pressure, direction of flow, and rate of flow.
- A relief valve is a normally closed pressure control valve which limits pressure in a system.
- A directional valve controls liquid flow to and from an actuator.
- A double-acting cylinder has a port at either end of the cylinder body by which pressurized fluid can enter and exit.
- A flow control valve, when properly used, always reduces the flow rate from a pump to an actuator.
- Symbols are a common way of depicting hydraulic components in a system.

Lesson 7

Hydraulic Pumps and Compressors

In this lesson, we will deal with the fluid power components which transform mechanical energy into fluid power energy.

hydraulic pumps

Hydraulic pumps convert the mechanical energy transmitted by a prime mover (electric motor, internal combustion engine) into hydraulic working energy or hydraulic horsepower.

$$\boxed{\text{hydraulic horsepower} = \text{GPM} \times \text{PSI} \times .000583}$$

Pumping action is the same for every pump. All pumps generate an increasing volume at the suction side and a decreasing volume at the pressure side. However, the elements which perform the pumping action are not the same in all pumps. And, they are more sophisticated than the simple two-vane pump which has been used in the illustrations to this point.

The type of pump used in an industrial hydraulic system is a positive displacement pump. There are many types of positive displacement pumps. For this reason, we must be selective and concentrate on the most popular. These are vane, gear, and piston pumps.

vane pumps

Vane pumps generate a pumping action by causing vanes to track along a ring.

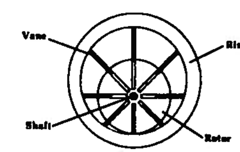
what a vane pump consists of

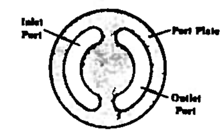
A pumping mechanism of a vane pump basically consists of rotor, vanes, ring, and a port plate with kidney-shaped inlet and outlet ports.

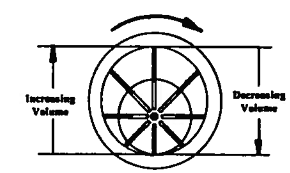
how a vane pump works

The rotor of a vane pump houses the vanes and it is

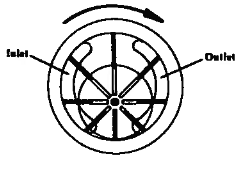
Hydraulic Pump Symbol

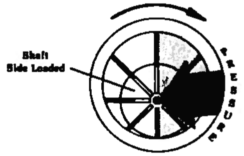


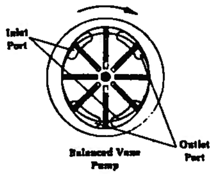




Note: Ring Does Not Rotate







attached to a shaft which is connected to a prime mover. As the rotor is turned, vanes are thrown out by centrifugal force and track along a ring. (The ring does not rotate.) As the vanes make contact, a positive seal is formed between vane tip and ring.

The rotor is positioned off-center to the ring. As the rotor is turned, an increasing and decreasing volume is formed within the ring.

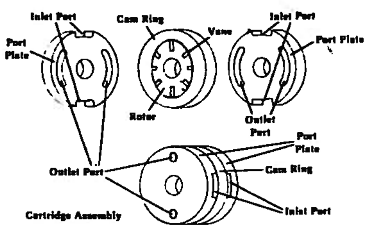
Since there are no ports in the ring, a port plate is used to separate incoming from outgoing fluid. The port plate fits over the ring, rotor, and vanes. The inlet port of the port plate is located where the increasing volume is formed. The port plate's outlet port is located where the decreasing volume is generated. All fluid enters and exits the pumping mechanism through the port plate. (The inlet and outlet ports in the port plate are, of course, connected respectively to the inlet and outlet ports in the pump housing.)

balanced vane pump design

In a pump, two very different pressures are involved-working pressure of a system at the outlet and less-than-atmospheric pressure at the inlet. In the vane pump which has been described, one half of the pumping mechanism is at less-than-atmospheric pressure. The other balf is subjected to full system pressure. This results in side loading the shaft which could be severe when high system pressures are encountered. To compensate for this condition, the ring is changed from circular to cam-shaped. With this arrangement, the two pressure quadrants oppose each other and the forces acting on the shaft are balanced. Shaft side loading is eliminated.

Therefore, a balanced vane pump, consists of a cam ring, rotor, vanes, and a port plate with inlet and outlet ports opposing each other. (Both inlet ports are connected together, as are the outlet ports, so that each can be served by one inlet or one outlet port in the pump housing.)

Constant volume, positive displacement vane pumps, used in industrial systems, are generally of the balanced design.



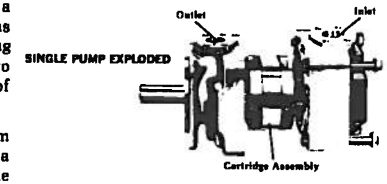
cartridge assembly

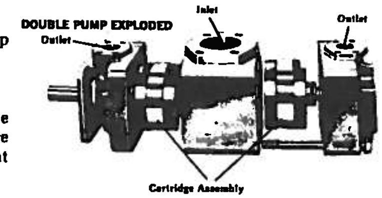
The pumping mechanism of industrial vane pumps is often an integral unit called a cartridge assembly. A cartridge assembly consists of vanes, rotor, and a cam ring sandwiched between two port plates. (Note that the port plates of the cartridge assembly are somewhat different in design than the port plates previously illustrated.)

An advantage of using a cartridge assembly is easy pump servicing. After a period of time when pump parts naturally wear, the pumping mechanism can be easily removed and replaced with a new cartridge assembly. Also, if for some reason the pump's volume must be increased or decreased, a cartridge assembly with the same outside dimension, but with the appropriate volume, can be quickly substituted for the original pumping mechanism.

double pumps

The vane pump which has been described is referred to as a single pump; that is, it consists of one inlet, one outlet, and a single cartridge assembly. Vane pumps are also available as a double pump. A double vane pump consists of a housing with two cartridge assemblies, one or two inlets, and two separate outlets. In other words, a double pump consists of two pumps in one housing.





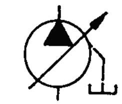
A double pump can discharge two different flow rates from each outlet. Since both pump cartridges are connected to a common shaft, one electric motor is used to drive the whole unit.

Double pumps give up to twice the flow of a single pump without an appreciably larger unit.

variable volume vane pumps

A positive displacement vane pump delivers the same volume of fluid for each revolution. Industrial pumps are generally operated at 1200 or 1800 RPM. This indicates that the pump flow rate remains constant.

In some cases, it is desirable that a pump's flow rate be variable. One way of accomplishing this is by varying the speed of the prime mover. This is usually economically impractical. The only other way, then, to vary the output of a pump is to change its displacement.

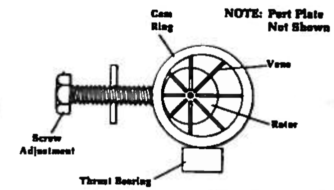


Variable Volume Pump Symbol

The amount of fluid which a vane pump displaces is determined by the difference between the maximum and minimum distances the vanes are extended and the width of the vanes. While the pump is operating, nothing can be done to change the width of a vane. But, a vane pump can be designed so that the distance the vanes are extended can be changed. This is known as a variable volume vane pump.

what a variable volume vane pump consists of

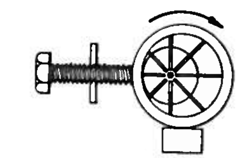
The pumping mechanism of a variable volume vane pump basically consists of a rotor, vanes, a cam ring which is free to move, a port plate, a thrust bearing to guide the cam ring, and something to vary the position of the cam ring. In our illustration, a screw adjustment is used.



Variable Volume Vane Pump

Variable volume vane pumps are unbalanced pumps. Their rings are circular and not cam-shaped. However, they are still referred to as cam rings.

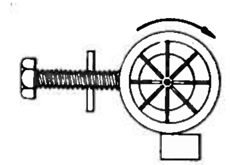
Since the cam ring in this type pump must be free to move, the pumping mechanism does not come as a cartridge assembly.



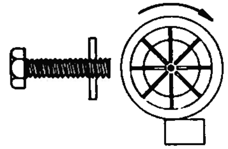
how a variable volume vane pump works

With the screw adjusted in, the rotor is held off center with regard to the cam ring.

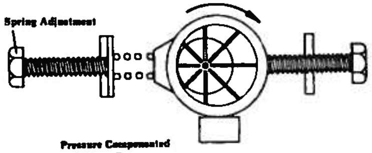
When the rotor is turned, an increasing and decreasing volume is generated. Pumping occurs.



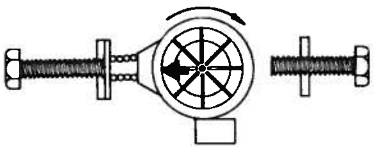
With the screw adjustment turned out slightly, the cam ring is not as off center to the rotor as before. An increasing and decreasing volume is still being generated, but not as much flow is being delivered by the pump. The exposed length of the vanes at full extension has decreased.



With the screw adjustment backed completely out, the cam ring naturally centers with the rotor. No increasing and decreasing volume is generated. No pumping occurs. With this arrangement a vane pump can change its output flow anywhere from full flow to zero flow by means of the screw adjustment.



Pressure Compensated Vane Pump

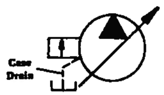


pressure compensated variable volume vane pumps

Generally, variable volume vane pumps are also pressure compensated. A pump which is pressure compensated stops pumping at a preset pressure level.

A pressure compensated vane pump consists of the same parts as a variable volume vane pump. But, in addition an adjustable spring is used to offset the cam ring. When the pressure acting on the inner contour of the cam ring is high enough to overcome the force of the spring, the ring centers and, except for leakage, pumping ceases.

System pressure is therefore limited by the setting of the compensator spring. This takes the place of a system's relief valve in effect.



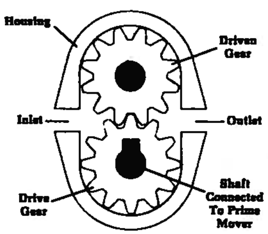
Variable Volume, Pressure Compensated Pump Symbol

case drain

While operating, a pumping mechanism leaks some fluid into its housing. For this reason, all variable volume, pressure compensated pumps must have their housings externally drained. The pumping mechanisms in these pumps move extremely fast when pressure compensation is required. Any buildup of fluid within the housing would hinder their movement.

Also, any leakage which accumulates in a pump housing is generally directed back to the pump's inlet side. The leakage from a variable volume pump, while it is compensating, is generally hot. If this were diverted to the inlet side, the fluid would get progressively hotter. Externally draining the housing alleviates the problem.

The external drain of a pump housing is commonly referred to as a case drain.



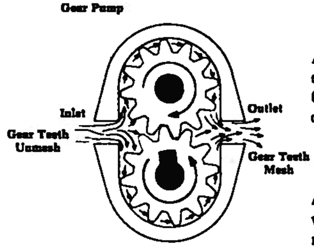
Gear Pump

gear pumps

Gear pumps generate a pumping action by causing gears to mesh and unmesh.

what a gear pump consists of

A gear pump basically consists of a housing with inlet and outlet ports, and a pumping mechanism made up of two gears. One gear, the drive gear, is attached to a shaft which is connected to a prime mover. The other gear is the driven gear.



how a gear pump works

As the drive gear is turned by a prime mover, it meshes with and rotates the driven gear. The action of teeth meshing and unmeshing generates an increasing and decreasing volume. At the inlet where gear teeth unmesh (increasing volume), fluid enters the housing. The fluid is then trapped between the gear teeth and housing, and carried to the other side of the gear.

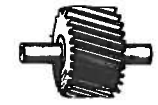
At this point, the gear teeth mesh (decreasing volume) and force the fluid out into the system.

A positive seal in this type pump is achieved between the teeth and the housing, and between the meshing teeth themselves.

Gear pumps are generally an unbalanced design.

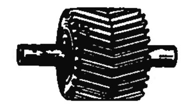
external gear pumps

The gear pump that has been described above is an external gear pump; that is, both meshing gears have teeth on their outer circumferences. These pumps are sometimes referred to as gear-on-gear pumps.



Helical Gear

Spur Gear

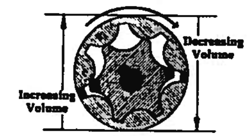


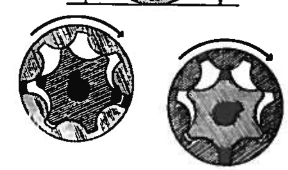
Herringbone Gear

There are basically three types of gears used in external gear pumps—spur, helical, and herringbone. Since the spur gear is the easiest to manufacture, this type pump is the most common and the least expensive of the three.

internal gear pump

An internal gear pump consists of one external gear which meshes with the teeth on the inside circumference of a larger gear. This type pump is sometimes referred to as a gear-within-gear pump. The most common type of internal gear pump in industrial systems is the gerotor pump.



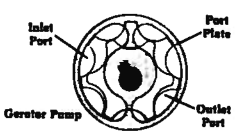


gerotor pump

A gerotor pump is an internal gear pump with an inner drive gear and an outer driven gear. The inner gear has one less tooth than the outer gear.

As the inner gear is turned by a prime mover, it rotates the larger outer gear. On one side of the pumping mechanism, an increasing volume is formed as gear teeth unmesh. On the other half of the pump, a decreasing volume is formed. A gerotor pump has an unbalanced design.

Fluid entering the pumping mechanism is separated from the discharge fluid by means of a port plate as in a vane pump.



Gerotor Pump

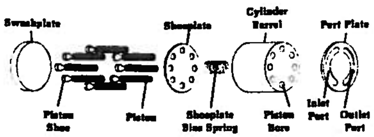
While fluid is carried from inlet to outlet, a positive seal is maintained as the inner gear teeth follow the contour of crests and valleys of the outer gear.

variable volume from a gear pump

The output volume of a gear pump is determined by the volume of fluid each gear displaces, and by the RPM at which the gears are turning. Consequently, the output volume of gear pumps can be altered by replacing the original gears with gears of different dimensions or by varying RPM.

Gear pumps, whether of the internal or external variety, do not lend themselves to a change in displacement while they are operating. There is nothing that can be done to vary the physical dimensions of a gear while it is turning.

One practical way, then, to vary the output flow from a gear pump is to vary the speed of its prime mover. This can many times be easily done when the pump is being driven by an internal combustion engine. It can also be accomplished electrically by using a variable speed electric motor.

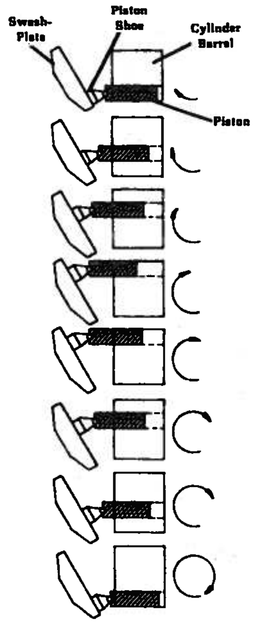


piston pumps

Piston pumps generate a pumping action by causing pistons to reciprocate within a piston bore.

what a piston pump consists of

The pumping mechanism of a piston pump basically consists of a cylinder barrel; pistons with shoes; swashplate; shoeplate; shoeplate bias spring; and port plate.



how a piston pump works

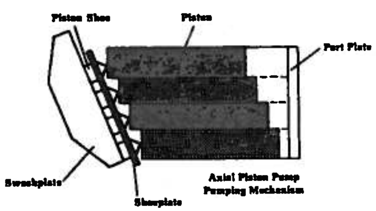
Earlier, we have seen one example of a piston pump. This pump generated an increasing and decreasing volume by means of a plunger being pulled and pushed, in and out of a cylinder body. It was pointed out that the disadvantages of this type of pump were that the pump developed a pulsating flow and that it could not be easily operated by an electric motor or internal combustion engine.

However, a piston can be made to reciprocate easily by the turning motion of a prime mover as well as develop a smooth flow.

In the example illustrated, a cylinder barrel with one piston bore is fitted with one piston. A swashplate is positioned at an angle. The shoe of the piston rides on the surface of the swashplate.

As the cylinder barrel is rotated, the piston shoe follows the surface of the swashplate. (The swashplate does not rotate.) Since the swashplate is at an angle, this results in the piston reciprocating within the bore. In 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 circle of rotation, this piston moves into the cylinder barrel and generates a decreasing volume.

In actual practice, the cylinder barrel is fitted with many pistons. The shoes of the pistons are forced against the swashplate surface by a shoeplate and bias spring. To separate the incoming fluid from the discharge fluid, a port plate is positioned at the end of the cylinder barrel opposite the swashplate.

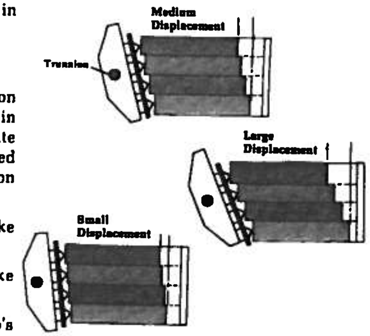


Axial Piston Pump Pumping Mechanism

A shaft is attached to the cylinder barrel which connects it with the prime mover. This shaft can be located at the end of the barrel where the porting is taking place. Or, more commonly, it can be positioned at the swashplate end. In this case, the swashplate and shoeplate have a hole in their centers to accept the shaft. If the shaft is positioned at the other end, the port plate has a shaft hole.

The piston pump which has been described above is known as an axial or in-line piston pump; that is, the pistons are rotated about the same axis as the pump shaft.

Axial piston pumps are a very popular piston pump in industrial applications.



variable volume axial piston pump

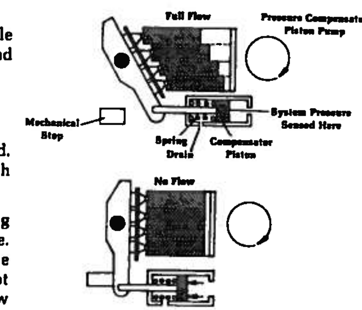
The displacement of an axial piston pump, or any piston pump, is determined by the distance the pistons are pulled in and pushed out of the cylinder barrel. Since the swashplate angle controls this distance in an axial piston pump, we need only to change the angle of the swashplate to alter the piston stroke and pump volume.

With a large swashplate angle, the pistons have a long stroke within the cylinder barrel.

With a small swashplate angle, the pistons have a short stroke within the cylinder barrel.

By varying the angle of the swashplate then, the pump's output flow can be changed.

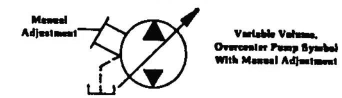
Several means of varying a swashplate angle are available from various manufacturers. These range from a simple hand lever device to a sophisticated servo valve.



pressure compensated axial piston pumps

Axial piston pumps can also be made pressure compensated. The swashplate of the pump is connected to a piston which senses system pressure.

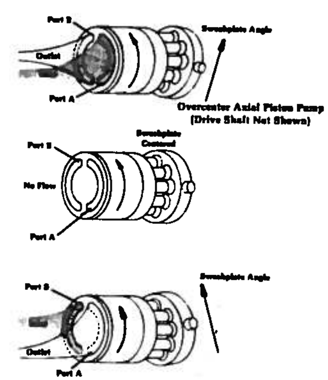
When system pressure becomes higher than the spring biasing the compensator piston, the piston moves the swashplate. When the swashplate hits the mechanical stop, the swashplate center is in line with the cylinder barrel. The pistons do not reciprocate in the cylinder barrel. This results in no flow to the system.



Variable Volume, Overcenter Pump Symbol With Manual Adjustment

overcenter axial piston pumps

As was illustrated, the displacement of an axial piston pump, and therefore its output volume, can be varied by changing the angle of the swashplate. It was also shown that the pump will develop no flow when the swashplate is centered with the cylinder barrel.



Overcenter Axial Piston Pump (Drive Shaft Not Shown)

Some swashplates of axial piston pumps have the capability of crossing over center. This results in the increasing and decreasing volumes being generated at opposite ports. Flow through the pump reverses.

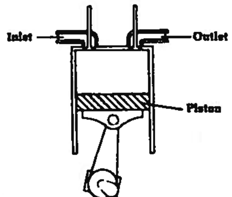
From the overcenter axial piston pump illustrated, it can be seen that ports A and B can be either an inlet or outlet port depending on the angle of the swashplate. This takes place with the cylinder barrel rotating in the same direction.

Overcenter axial piston pumps are often used in hydrostatic transmissions to control the direction of rotation and speed of hydraulic motors.

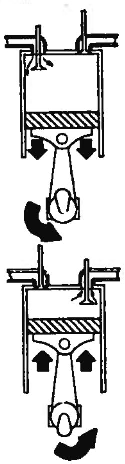
Axial piston pumps can be variable displacement, pressure compensated and variable displacement, or variable displacement and overcenter.

• For additional information regarding pump selection, operating characteristics, construction, calculations, application, and troubleshooting tips see Parker-Hannifin Design Engineers Handbook, Section i.

Compressor Symbol



Single-Stage Compressor



compressors

Compressors convert the mechanical energy transmitted by a prime mover (electric motor, internal combustion engine) into potential energy of compressed air.

To perform any appreciable amount of work with a pneumatic system, a device is needed which can supply a receiver tank with a sufficient amount of air at a desired pressure. This device is a positive displacement compressor.

piston compressors

The most common type of positive displacement compressor found in an industrial pneumatic system is a reciprocating piston compressor.

In a previous lesson, an example of a reciprocating piston compressor was illustrated. It was pointed out at that time that the compressor basically consisted of a piston inside of a bore. The piston was connected to a crankshaft which in turn was connected to a prime mover. At the top of the piston bore, two valves controlled inlet and outlet flow through the compressor.

how a reciprocating piston compressor works

As the crankshaft of a reciprocating piston compressor is rotated, the piston moves up and down within the bore. When the crankshaft pulls the piston down, an increasing volume is formed within the bore. With the resulting less-than-atmospheric pressure and the intake valve open, atmospheric air fills the chamber. At the end of the piston stroke, the chamber is filled with air and intake valve closes.

Starting its upward travel, the piston compresses the air. When air pressure in the bore reaches a high enough level, the outlet valve opens. Compressed air discharges from the compressor and ultimately ends up in an air receiver tank.

This describes the operation of a single-stage piston compressor, that is, a compressor which compresses air one time before it is discharged. Single-stage compressors are generally used in systems which require compressed air at 80 PSI or less.

We have seen earlier that when a gas is compressed, as with a compressor, the gas heats up. In a single-stage compressor, when air is compressed above 80 PSI, the heat of compression and the force required to compress the hot air become excessive. But, most industrial systems operate above 80 PSI. For this reason, two-stage compressors are usually found in industrial pneumatic systems.

two-stage piston compressor

A two-stage piston compressor compresses air in two separate steps.

what a two-stage piston compressor consists of

A two-stage piston compressor basically consists of a large and small piston each in their own cylinder bore and each connected to the same crankshaft; associated inlet and outlet valves; and an intercooler.

how a two-stage piston compressor works

In a two-stage compressor, the piston with the large diameter performs the first stage of compression. The smaller piston compresses air in the second stage.

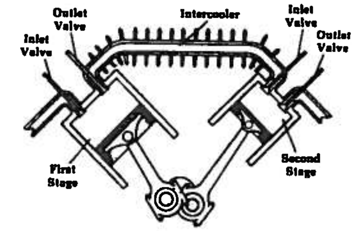
As the crankshaft is turned by its prime mover, the large diameter piston strokes downward. Air enters the chamber from the atmosphere through the open inlet valve. When the piston starts its upward movement, inlet valve closes. Air is compressed (and heated) until a certain pressure is reached. At which time, the outlet valve opens discharging hot, compressed air. If this air were discharged into an air receiver directly, the air would quickly cool to the temperature of the surrounding atmosphere. This cooling and subsequent reduction of pressure would result in much of the energy added to the air by the compressor to be wasted. In a two-stage compressor, after hot, compressed air discharges from the first stage, it is directed by means of a tube, called an intercooler, to the second stage piston. During the travel time from first to second stage, the air is cooled by means of air blowing over the tube or water flowing across the tube. By the time the air reaches the second stage piston, a great portion of the heat of first stage compression has been dissipated. The air is now cooler and ready to be compressed a second time.

With compressed air at its inlet, the smaller diameter piston is pulled downward. Compressed air fills the chamber and inlet valve closes. The piston is stroked upward, compressing the air further.

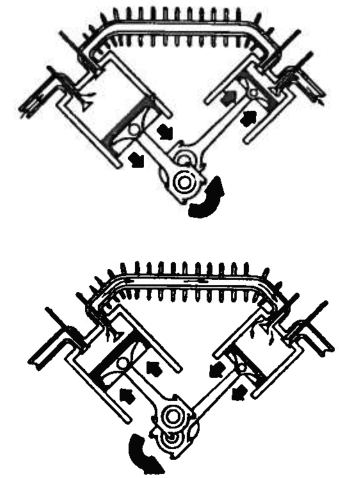
The compressed air, as it discharges from the compressor, is at an elevated temperature. But this excess temperature above the ambient is not nearly as great as if one stage were used in the compressing process.

Two-stage compressors do not waste as much energy in compressing air as single-stage units.

• For additional air compressor considerations, see Parker-Hannifin Design Engineers Handbook, Section g.



Two-Stage Compressor



lesson review

In this lesson dealing with hydraulic pumps and compressors, we have seen that:

- Hydraulic pumps convert mechanical energy transmitted by a prime mover into hydraulic working energy (flow and pressure).
- Vane, gear, and piston pumps are three of the most common types of pumps found in a hydraulic system.
- Vane pumps generate a pumping action by causing vanes to track along a ring.
- Vanes pumps can have a balanced or unbalanced design.
- The pumping mechanism of a vane pump is often an integral unit called a cartridge assembly.
- Vane pumps can be variable volume and pressure compensated.
- All variable volume, pressure compensated pumps have a case drain.
- Gear pumps generate a pumping action by causing gears to mesh and unmesh.
- Gear pumps can be external gear pumps or internal gear pumps.
- Spur, helical, and herringbone are examples of external gear pumps.
- A gerator design is an example of an internal gear pump.
- Gear pumps are not variable volume or pressure compensated.
- Piston pumps generate a pumping action by causing pistons to reciprocate within a piston bore.
- Axial piston pumps are a very popular type of piston pump.
- Axial piston pumps can be variable volume, pressure compensated, and overcenter.
- Compressors convert the mechanical energy transmitted by a prime mover into potential energy of compressed air.
- Piston compressors are the most common type compressor found in an industrial pneumatic system.
- Piston compressors can be single-stage, two-stage, or as many stages as required.

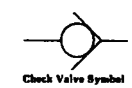
Lesson 8

Check Valves, Cylinders, and Motors

In this lesson, we will concentrate on check valves and the fluid power actuators of cylinders and motors.

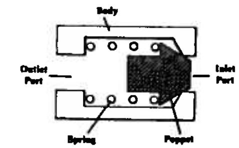
check valves

A check valve is seemingly small when compared to other hydraulic components, but it is a component which serves an important function.



what a check valve consists of

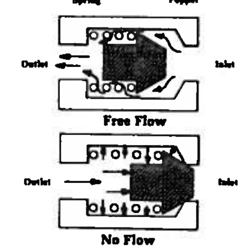
A check valve basically consists of a valve body with inlet and outlet ports and a movable member which is biased by spring pressure. The movable member can be a flapper, or plunger, but most often it is a ball or poppet.



how a check valve works

Fluid flow passes through a check valve in one direction only.

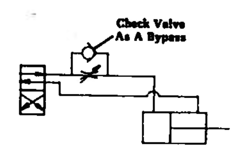
When system pressure at the check valve inlet is high enough to overcome the low spring pressure (5 PSI) biasing the poppet, the poppet is pushed off its seat. Flow passes through the valve. This is known as the check valve's free flow direction.

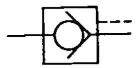


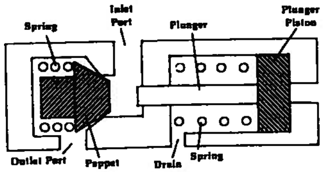
When fluid flow attempts to enter through the outlet, the poppet is pushed on its seat. Flow through the valve is blocked.

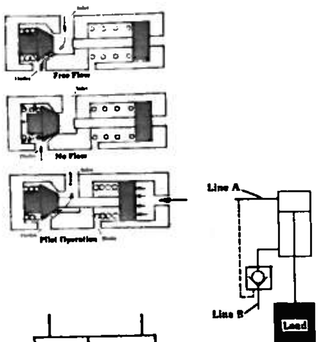
Check valves used in pneumatic systems generally use a resilient seal on the poppet. Hydraulic check valves usually have a metal-to-metal seal.

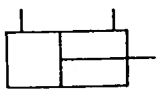
A check valve is often used in fluid power systems as a bypass valve. It allows flow to get around components, like flow control valves which would restrict flow in a reverse direction.

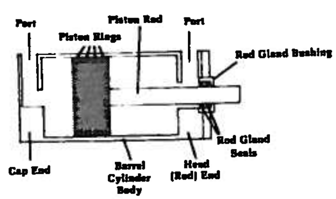












A check valve is also used to isolate sections of a system or a system component. For instance, in a hydraulic system, a check valve keeps an accumulator from dumping its flow over a relief valve or through a pump.

pilot operated check valve

A pilot operated check valve allows free flow in one direction. In the opposite direction flow may pass when pilot pressure unseats the valve's movable member.

what a pilot operated check valve consists of

A pilot operated check valve consists of a valve body with inlet and outlet ports and a poppet biased by a spring, just as an ordinary check valve. Directly opposite the check valve poppet is a plunger and plunger piston which is biased by a light spring. Pilot pressure is sensed at the plunger piston through the pilot port. The plunger spring chamber has a drain.

how a pilot operated check valve works

A pilot operated check valve allows free flow from its inlet port to its outlet port just as an ordinary check valve.

Fluid flow attempting to pass through the valve from outlet to inlet port will force the poppet on its seat. Flow through the valve is blocked.

When enough pilot pressure is sensed at the plunger piston, the plunger is moved and unseats the check valve poppet. Flow can pass through the valve from outlet to inlet as long as sufficient pilot pressure is acting on the plunger piston.

Pilot operated check valves are primarily used in hydraulic systems. A frequent application of pilot operated check valves is to "hold" a load attached to a hydraulic cylinder in mid-stroke.

fluid power cylinders

In all applications, fluid energy must be converted to mechanical energy before any useful work can be done. Cylinders convert fluid power energy into straight-line mechanical energy.

what a cylinder consists of

A cylinder consists of a cylinder body, a movable piston, and a piston rod attached to the piston. End caps are attached to the cylinder body barrel by threads, keeper rings, tie rods, or a weld. (Industrial cylinders use tie rods.)

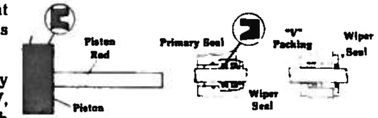
As the cylinder rod moves in and out, it is guided and supported by a removable bushing called a rod gland.

The side through which the rod protrudes is called the "head". The opposite side without the rod is termed the "cap". Inlet and outlet ports are located in the head and cap.

seals

For proper operation, a positive seal must exist across a cylinder's piston as well as at the rod gland.

Hydraulic cylinders many times use cast iron piston rings as a piston seal. Piston rings are a durable seal but they have a clearance flow of 1-3 in^3 per minute at 2000 PSI.



Pneumatic systems and hydraulic systems which cannot tolerate clearance flow, use a resilient piston seal. Resilient seals do not leak under normal conditions, but are less durable than piston rings.

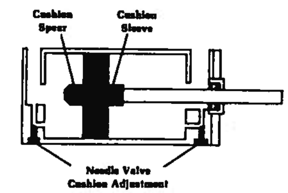
Rod gland seals come in several varieties and are generally resilient seals. Some cylinders are equipped with a U, V, multi-lip, or cupped shape primary seal and a rod wiper which prevents foreign materials from being drawn into the cylinder.

One popular type of rod gland seal has a primary seal with serrated edges along its inside surface. The edges contact the cylinder rod continuously to give a positive seal. This is used in conjunction with a wiper seal which collects any fluid which passes the primary seal during rod extension and wipes the rod clean during rod retraction.

cushions

As a cylinder piston completes its stroke, the piston runs into a cylinder end. If inertia is high enough at this point, the cylinder may experience a shock or concussion which could be damaging. As protection, cylinders can be equipped with cushions.

Cushions slow down a cylinder's piston movement just before reaching the end of its stroke. Cushions can be applied at either or both ends of a cylinder.

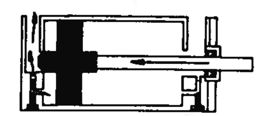


what a cushion consists of

A cushion consists of a needle valve flow control and a plug attached to the piston. The plug can be on the rod side, in which case it is called a cushion sleeve. Or, it can be on the cap end side, in which case it is called a cushion spear.

how a cushion works

As a cylinder piston approaches the end of its travel, the plug blocks the normal exit for a fluid and forces it to pass through a needle valve flow control. The needle valve restricts flow out of the cylinder retarding piston movement. The opening of the needle valve determines the rate of deceleration.



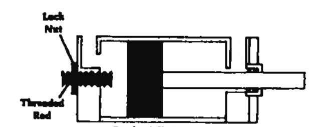
Cushioning

In the reverse direction, flow bypasses the needle valve by means of a check valve within the cylinder.

As a rule, cushions are applied to cylinders whose piston rod speed exceeds 20 feet per minute.

stroke adjusters

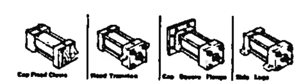
Sometimes the stroke of a cylinder must be externally controllable. Periodic adjustment is accomplished with a threaded rod which can be screwed in or out of the cylinder cap.

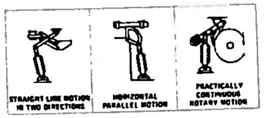


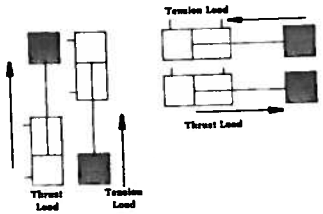
Stroke Adjuster

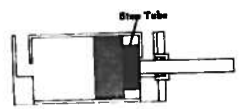
cylinder mounting styles

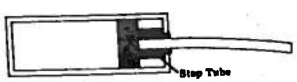
Cylinders can be mounted in a variety of ways, among which are flange, trunnion, side lug and side tapped, clevis, tie rod, and bolt mounting.











mechanical motions

Cylinders convert fluid energy into straight line, or linear, mechanical motion. But, depending on the way in which they are attached to mechanical linkages, cylinders provide many different mechanical motions.

types of cylinder loads

Cylinders can be used in an unlimited number of applications to move various types of loads. But, in general, a load which is pushed by a cylinder rod is termed a thrust load. A load which is pulled by a cylinder rod is called a tension load.

stop tube

A stop tube is a solid, metal collar which fits over the piston rod. A stop tube keeps the piston and rod gland bushing separated when a long-stroke cylinder is fully extended.

Since it is a bearing, a rod gland bushing is designed to take some loading when supporting the rod as it moves in and out of the cylinder.

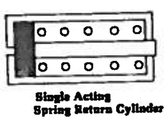
Along with being a bearing, a rod gland bushing is also a fulcrum for the piston rod. If the load attached to the piston rod of a long-stroke cylinder is not rigidly guided, then at full extension, the rod will tend to teeter-totter or jack-knife at the bushing causing excessive loading. A stop tube in effect protects the rod gland bushing by distributing any loading at full extension between both piston and bushing.

It may be difficult to believe, but the heavy, steel rods of long-stroke cylinders sag just because of their weight. A ⅝" diameter piston rod weights 1 lb. per foot and will sag over 1 in. at the center of a 10 ft. span.

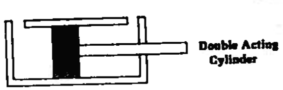
On long-stroke, horizontally mounted cylinders, undesirable bearing loads are generated at the rod gland bushing because of rod sag when the rod is fully extended. On these cylinders, a stop tube is used to separate bushing and piston when the rod is extended. This reduces the load on the rod gland bushing.

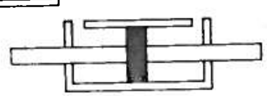
Most cylinders do not need stop tubes. To determine when a stop tube is required, or what the length of a stop tube should be, consult the cylinder manufacturer's catalog.

common types of cylinders


Single Acting Spring Return Cylinder


Ram


Double Acting Cylinder


Double Rod Cylinder

Single acting cylinder—a cylinder in which fluid pressure is applied to the movable element in only one direction.

Spring return cylinder—a cylinder in which a spring returns the piston assembly.

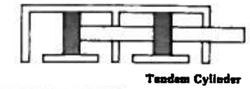
Ram cylinder—a cylinder in which the movable element has the same cross-sectional area as the piston rod.

Double acting cylinder—a cylinder in which fluid pressure is applied to the movable element in either direction.

Single rod cylinder—a cylinder with a piston rod extending from one end.

Double rod cylinder—a cylinder with a single piston and a piston rod extending from each end.


Telescoping Cylinder


Tandem Cylinder


Duplex Cylinder

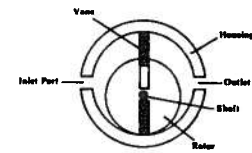
Telescoping cylinder—a cylinder with nested multiple tubular rod segments which provide a long working stroke in a short retracted envelope.

Tandem cylinder—consists of two or more cylinders mounted in line with pistons connected by a common piston rod; rod seals are installed between cylinders to permit double acting operation of each. A tandem cylinder gives increased output force when the bore size of a cylinder is limited, but not its stroke.

Duplex cylinder—consists of two cylinders mounted in line with pistons not connected; rod seals installed between cylinders to permit double-acting of each. Duplex cylinders give a 3-position capability.

- **For additional information concerning cylinder selection, consturction, accessories, applications, characteristics, and troubleshooting, see Parker-Hannifin Design Engineers Handbook, Section b.**

hydraulic motors

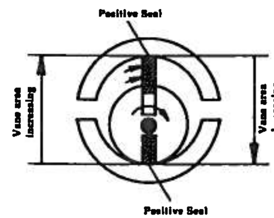


Hydraulic motors transform hydraulic working energy into rotary mechanical energy, which is applied to a resisting object by means of a shaft.

what motors consist of

All motors basically consist of a housing with inlet and outlet ports and a rotating group attached to a shaft. The rotating group in the particular vane type motor illustrated consists of a rotor and vanes which are free to slide in and out.

how motors operate

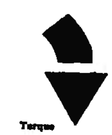


The rotating group of the motor is positioned off-center to the housing. The shaft in the rotor is connected to an object which offers a resistance. As fluid enters the inlet port, hydraulic working energy acts on any part of a vane exposed to the inlet port. Since the top vane has more area exposed to pressure, the force on the rotor is unbalanced and the rotor turns.

As the liquid reaches the outlet port where a decreasing volume is present, the liquid exits.

Before a motor of this type will operate, the vanes must be previously extended and a positive seal must exist between vanes and housing. Centrifugal force cannot be depended on as in a pump. This is usually done with springs or hydraulic pressure.

torque


Torque

Torque is a rotary or turning effort. Torque indicates a force is present at a distance from a motor shaft.

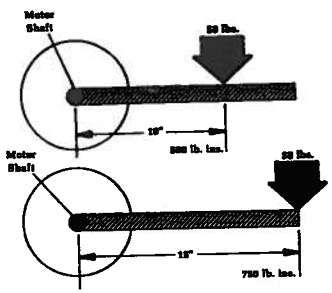
pound inch

One unit for measuring torque is a lb. in.

description of torque

Torque tells us where a force is in relation to the motor shaft. The expression which describes torque is:

torque = force x distance from shaft
(lb. in.) (lb.) (in.)

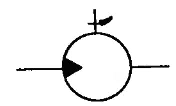


In the illustration, a force of 50 lbs. is positioned on a bar which is attached to a motor shaft. The distance between the shaft and the force is 10 inches. This results in a torque or turning effort at the shaft of 500 lb. ins. (50 lbs. x 10 ins.)

If the 50 lbs. were located 15 inches along the bar, the turning effort generated at the shaft would be equal to a twisting effort of 750 lbs. one inch from the shaft.

From these examples, we can see that the farther the force is from the shaft, the larger the torque at the shaft. It will also be noted that torque does not involve any movement.

A resisting object attached to a motor shaft generates a torque as described above. This, of course, is a resistance for the motor which must be overcome by hydraulic pressure acting on a motor's rotating group.



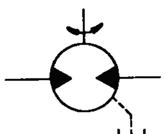
Uni-directional Motor Symbol

Hydraulic motors operate by causing an imbalance which results in the rotation of a shaft. This imbalance is generated in different ways depending on the motor type.

Hydraulic motors used in an industrial system can be divided into vane, gear, and piston types.

motor drains

Motors used in industrial hydraulic systems are almost exclusively designed to be bi-directional (operate in both directions). Even motors which operate in a system in only one direction (uni-directional) are probably bi-directional motors in design.

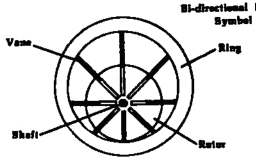


Bi-directional Motor Symbol

To protect its shaft seal, vane, gear, and piston bi-directional motors are generally externally drained.

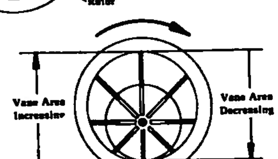
vane motors

A vane motor develops an output torque at its shaft by allowing hydraulic pressure to act on vanes which are extended.



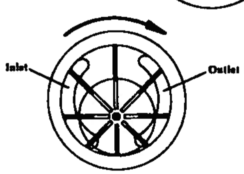
what a vane motor consists of

The rotating group of a vane motor basically consists of vanes, rotor, ring, shaft, and a port plate with kidney-shaped inlet and outlet ports.



how a vane motor works

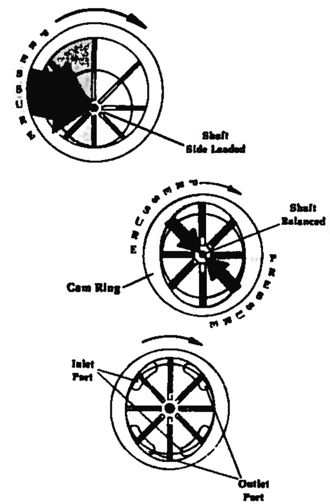
All hydraulic motors operate by causing an imbalance which results in the rotation of a shaft. In a vane motor, this imbalance is caused by the difference in vane area exposed to hydraulic pressure. In our illustration, with the rotor positioned off-center with respect to the ring, the area of the vanes exposed to pressure increases toward the top and decreases at the bottom. When pressurized fluid enters the inlet port, the unequal areas of the vanes result in a torque being developed at the motor shaft.



The larger the exposed area of the vanes, or the higher the pressure, the more torque will be developed at the shaft. If the torque developed is large enough, the rotor and shaft will turn.

balanced vane motor design

In a hydraulic motor, two different pressures are involved—system working pressure at the inlet and tank line pressure at the outlet. This results in side loading the shaft which could be severe at high system pressures. To avoid shaft side loading, the inner contour of the ring is changed from circular to cam-shaped. With this arrangement, the two pressure quadrants oppose each other and the forces acting on the shaft are balanced. Shaft side loading is eliminated.



Balanced Vane Motor

A balanced vane motor consists of a cam ring, rotor, vanes, and a port plate with inlet and outlet ports opposing each other. (Both inlet ports are connected together, as are the outlet ports, so that each can be served by one inlet or one outlet port in the pump housing.)

Vane motors used in industrial hydraulic systems are generally of the balanced design.

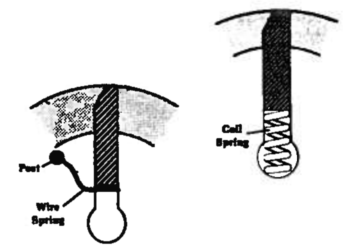
cartridge assembly

The rotating group of industrial vane motors is usually an integral cartridge assembly. The cartridge assembly consists of vanes, rotor, and a cam ring sandwiched between two port plates.

An advantage of using a cartridge assembly is easy motor servicing. After a period of time when motor parts naturally wear, the rotating group can be easily removed and replaced with a new cartridge assembly. Also, if the same motor is required to develop more torque at the same system pressure, a cartridge assembly with the same outside dimensions, but with a larger exposed vane area, can be quickly substituted for the original.

extending a motor's vanes

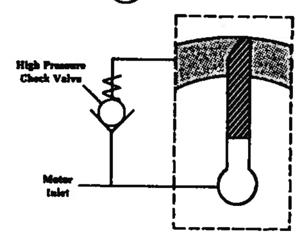
Before a vane motor will operate, its vanes must be extended. Unlike a vane pump, centrifugal force cannot be depended on to throw-out the vanes and create a positive seal between cam ring and vane tip. Some other way must be found.



There are two common means of extending the vanes in a vane motor. One method is spring loading the vanes so that they are extended continuously. The other method is directing hydraulic pressure to the underside of the vanes.

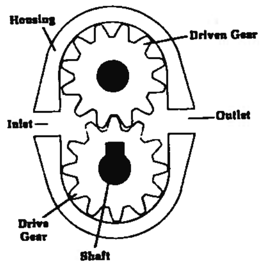
Spring loading is accomplished in some vane motors by positioning a coil spring in the vane chamber.

Another way of loading a vane is with the use of a small wire spring. The spring is attached to a post and moves with the vane as it travels in and out of the slot.



In both types of spring loading, fluid pressure is directed to the underside of the vane as soon as torque is developed.

Another means of extending a motor's vanes is with the use of fluid pressure. In this method, fluid is not allowed to enter the vane chamber area until the vane is fully extended and a positive seal exists at the vane tip. At this time, pressure is present under the vane. When fluid pressure is high



enough to overcome the spring force biasing the internal check valve, fluid will enter the vane chamber and develop a torque at the motor shaft.

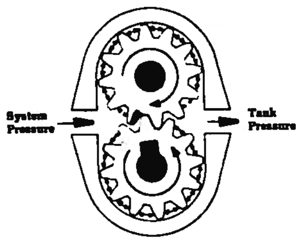
gear motors

A gear motor develops an output torque at its shaft by allowing hydraulic pressure to act on gear teeth.

what a gear motor consists of

A gear motor basically consists of a housing with inlet and outlet ports, and a rotating group made up of two gears. One gear, the drive gear, is attached to a shaft which is connected to a load. The other gear is the driven gear.

how a gear motor works



Hydraulic motors operate by causing an imbalance which results in the rotation of a shaft. In a gear motor, this imbalance is caused by gear teeth unmeshing.

In the illustration of the gear motor, the inlet is subjected to system pressure. The outlet is under tank pressure. As gear teeth unmesh, it can be seen that all teeth subjected to system pressure are hydraulically balanced except for one side of one tooth on one gear (shaded area). This is the point where torque is developed. Consequently, the torque developed by a gear motor of this type is a function of one side of one gear tooth. The larger the gear tooth or the higher the pressure, the more torque is produced.

You may wonder why, the gear teeth do not turn in the opposite direction. To rotate in the opposite direction, gear teeth would have to mesh instead of unmesh. Gears which mesh generate a decreasing volume which pushes fluid out of the housing. The gears have no other choice but to unmesh.

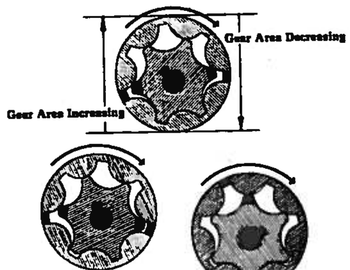
external gear motor

The gear motor which has been described above is an external gear motor; that is, both meshing gears have teeth on their outer circumferences. The type of gear used in this motor is a spur gear.

internal gear motor

An internal gear motor consists of one external gear which meshes with the teeth on the inside circumference of a larger gear. A popular type of internal gear motor in industrial systems is the gerotor motor.

gerotor motor

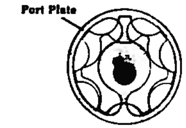


A gerotor motor is an internal gear motor with an inner drive gear and an outer driven gear which has one more tooth than the inner gear. The inner gear is attached to a shaft which is connected to a load.

The imbalance in a gerotor motor is caused by the difference in gear area exposed to hydraulic pressure at the motor inlet.

In the gerotor motor illustration, the exposed area of the inner gear increases at the inlet.

Fluid pressure acting on these unequally exposed teeth, results in a torque at the motor shaft. The larger the gear, or the higher the pressure, the more torque will be developed at the shaft.

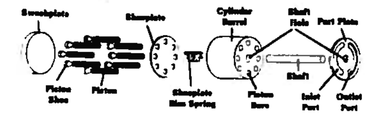


Fluid entering the rotating group of a gerotor motor is separated from the fluid exiting the motor by means of a port plate with kidney-shaped inlet and outlet ports.

piston motors

A piston motor develops an output torque at its shaft by allowing hydraulic pressure to act on pistons.

what a piston motor consists of

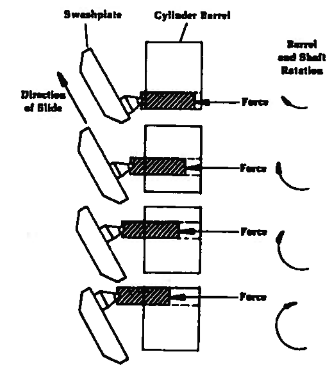


The rotating group of a piston motor basically consists of swashplate, cylinder barrel, pistons, shoeplate, shoeplate bias spring, port plate, and shaft.

The pistons fit inside the cylinder barrel. The swashplate is positioned at an angle and acts as a surface on which the shoe side of the piston travels. The piston shoes are held in contact with the swashplate by the shoeplate and bias spring. A port plate separates incoming fluid from the discharge fluid. A shaft is connected to the cylinder barrel. In our example, it is attached at the port plate end.

how a piston motor works

To illustrate how a piston motor works, let us observe the operation of one piston in a cylinder barrel of an axial piston motor.



With the swashplate positioned at an angle, the piston shoe does not have a very stable surface on which to position itself. When fluid pressure acts on the piston, a force is developed which pushes the piston out and causes the piston shoe to slide across the swashplate surface. As the piston shoe slides, it develops a torque at the shaft attached to the barrel. The amount of torque depends on the angle of slide caused by the swashplate and the pressure in the system. If the torque is large enough, the shaft will turn.

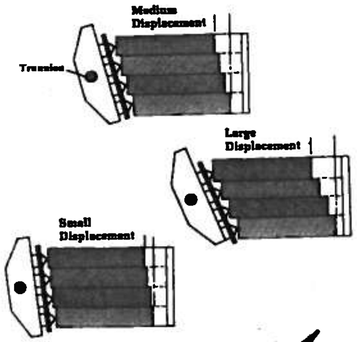
Torque continues to be developed by the piston as long as it is pushed out of the cylinder barrel by fluid pressure. Once the piston passes over the center of the circle, it is pushed back into the cylinder barrel by the swashplate. At this point, the piston bore will be open to the outlet port of the port plate.

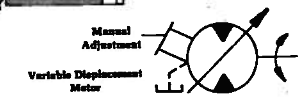
A single piston in a piston motor develops torque for only half of the full circle of rotation of the cylinder barrel and shaft. In actual practice, a cylinder barrel of a piston motor is fitted with many pistons. This allows the motor shaft to continuously rotate as well as obtain maximum torque.

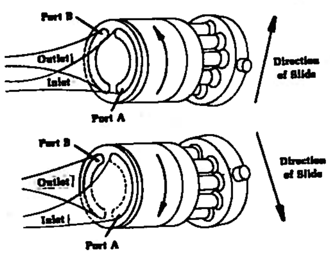
Of the vane, gear, and piston motors which have been described, only piston motors are available as variable displacement.

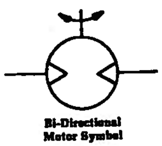
variable displacement axial piston motors

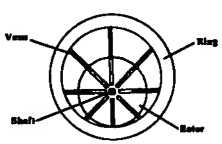
The displacement of an axial piston motor, or any piston











motor, is determined by the distance the pistons are reciprocated in the cylinder barrel.

Since the swashplate angle controls this distance in an axial piston motor, we need only to change the angle of the swashplate to alter the piston stroke and motor displacement.

With a large swashplate angle, the pistons have a long stroke within the cylinder barrel.

With a small swashplate angle, the pistons have a short stroke within the cylinder barrel.

By varying the angle of the swashplate then, the motor's displacement and consequently it's shaft speed and torque output can be changed.

overcenter axial piston motors

Some swashplates of axial piston motors have the capability of crossing over center. A motor of this type is able to reverse its shaft rotation without changing the direction of flow through the motor.

In the overcenter axial piston motor illustrated, the motor shaft is not shown. But, you can imagine it as being attached to the cylinder barrel at the port plate end or through the swashplate side. We can see from the illustration that changing the angle of the swashplate by crossing over center results in a different direction of slide for the pistons. Consequently, cylinder barrel and motor shaft rotate in the reverse direction. This takes place with fluid flow passing through the motor in the same direction.

- **For additional information concerning hydraulic motor selection, characteristics, and applications, see Parker-Hannifin Design Engineers Handbook, Section f.**

pneumatic motors

Pneumatic motors convert the potential energy of compressed air into rotary mechanical energy.

Pneumatic motors operate by causing an imbalance which results in the rotation of a shaft. This imbalance is generated in different ways depending on the motor type.

The most common type of motor found in an industrial pneumatic system is a vane motor.

vane motor

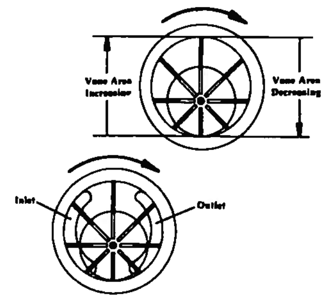
A vane motor develops an output torque at its shaft by allowing compressed air to act on vanes which are extended.

what a vane motor consists of

The rotating group of a vane motor basically consists of vanes, rotor, ring, shaft, and a port plate with inlet and exhaust ports.

how a vane motor works

All pneumatic motors operate by causing an imbalance which results in the rotation of a shaft. In a vane motor, this imbalance is caused by the difference in vane area exposed to air pressure. In our illustration, with the rotor positioned



off-center with respect to the ring, the area of the vanes exposed to pressure increases toward the top and decreases at the bottom. When compressed air enters the inlet port, the unequal areas of the vanes result in a torque being developed at the motor shaft.

The larger the exposed area of the vanes, or the higher the pressure, the more torque will be developed at the shaft. If the torque developed is high enough, the rotor and shaft will turn.

extending a motor's vanes

Before a vane motor will operate, its vanes must be extended. A positive seal must exist at the vane tip.

In a pneumatic vane motor, vanes are extended by continuously exposing the undersides of the vanes to air pressure. This is done by means of passages inside the motor.

Pneumatic vane motors are generally high speed and are frequently used in air tools.

lesson review

In this lesson dealing with check valves, cylinders, and motors, we have seen that:

- Fluid flow passes through a check valve in one direction only.
- A check valve is often used as a bypass valve or to isolate system parts.
- Pilot operated check valves are primarily found in hydraulic systems and are frequently used to "hold" a load in mid-stroke.
- Cylinders convert fluid energy into linear mechanical energy so that useful work can be done.
- Cushions protect a cylinder from concussion at the end of a piston's travel.
- A stop tube is a metal collar which keeps piston and rod gland bushing separated at full rod extension.
- Hydraulic motors transform hydraulic working energy into rotary mechanical energy.
- All motors operate by generating an imbalance.
- Torque is a rotary or turning effort which is measured in pound inches.
- Torque indicates that a force is present at a distance from a motor shaft.
- To overcome a torque resistance, hydraulic motors develop an opposing torque by applying hydraulic pressure to a motor's rotating group.
- Hydraulic motors used in an industrial system can be divided into vane, gear, and piston types.
- Bi-directional motors are generally externally drained.
- A vane motor develops an output torque at its shaft by allowing hydraulic pressure to act on vanes which are extended.
- Vane motors generally have a balanced design.
- The rotating group of industrial vane motors is usually an integral cartridge assembly.
- Motor vanes can be extended by springs or fluid pressure.
- A gear motor develops an output torque at its shaft by allowing hydraulic pressure to act on gear teeth.
- A spur gear motor is a common external gear motor.
- A gerotor motor is a common internal gear motor.
- A piston motor develops an output torque

at its shaft by allowing hydraulic pressure to act on pistons.

- Axial piston motors can be variable displacement and overcenter.
- Variable displacement piston motors can vary shaft speed and output torque.
- Overcenter axial piston motors can reverse barrel and shaft rotation without changing inlet and outlet ports.
- The most common type of motor found in pneumatic systems is a vane motor.
- A pneumatic vane motor develops an output torque at its shaft by allowing compressed air to act on vanes which are extended.