Chapter 2. Hydraulic Pumps and pneumatic compressors

2.1. Hydraulic pumps

2.1.1. Introduction

A hydraulic pump is a very important device to run the hydraulic power systems smoothly. The pump is attached either with a single-phase or a three-phase induction motor. The pump shaft and the motor shaft are coupled with gasket, nuts and bolts. In a positive half of the cycle, the pump creates the vacuum which in turn increases the volume and pulls the water from the source such as a lake, pond and river. Whereas in the negative half of the cycle, it discharges the water by reducing the volume. The necessary pipe fittings and accessories are used to control water flow through the piping system. Regarding pumps, some important points need to know. The pump generates flow, not pressure. However, the pressure is the result of resistance to the fluid flow and the pressure will be maximum if the resistance to the fluid flow is minimum. This chapter will discuss pump classification, construction, working principles, power and torque expressions.

2.1.2. Pump

A pump, which is the heart of a hydraulic system, converts mechanical energy into hydraulic energy. The mechanical energy is delivered to the pump via a prime mover such as an electric motor. Due to mechanical action, the pump creates a partial vacuum at its inlet. This permits atmospheric pressure to force the fluid through the inlet line and into the pump. The pump then pushes the fluid into the hydraulic system. However, the pump does not generate pressure.

A pump is a hydraulic machine that is used to import hydraulic energy to water and or liquid in the form of pressure energy or kinetic energy. In other words, a pump is a device used to move fluids (liquids or gases) from one place to another place. A pump is a hydraulic machine that converts mechanical energy to hydraulic energy (pressure energy). A hydraulic pump takes fluid (oil or water) from a tank and delivers it to the hydraulic distribution circuit. In doing so it raises the pressure of the fluid to the required level as shown in Fig. 2.1.

The pressure of the fluid at the pump outlet is zero if it is not connected to a system. This pressure rises from zero to a required level when it is connected to a system. A hydraulic pump speed depends on the three-phase induction motor shaft speed as shown in Fig. 2.2. The motor and pump must be rotated in a clockwise direction. Before coupling with a pump, the three-phase connection should be checked and tested the rotation. If the motor rotation is not clockwise direction, then any two supply lines need to be swapped.

The speed of a pump shaft depends on the motor shaft speed and the motor shaft speed is expressed as,

$$N_s = \frac{120\, f}{P}$$

where,

- f is the frequency in units of Hertz (Hz),
- P is the number of poles,
- N_s is the speed of the motor in units of revolution per minute (rpm).

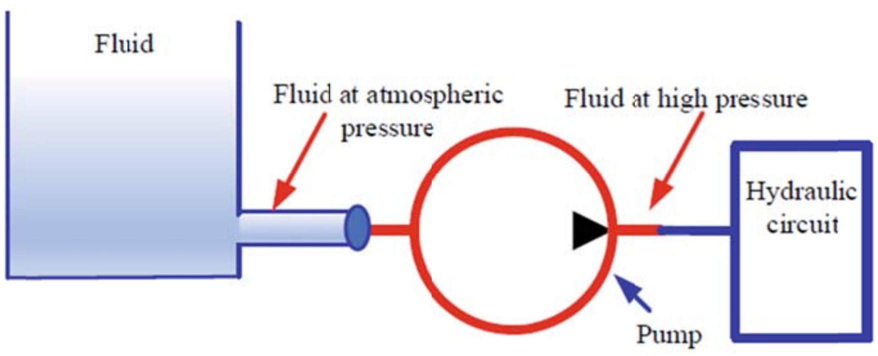

Fig. 2.1 A fluid tank with a pump

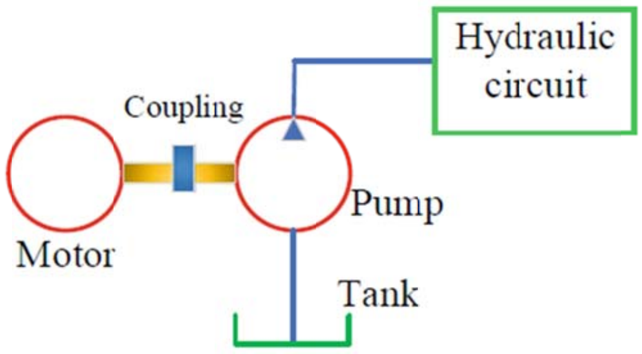

Fig. 2.2 A fluid tank with a pump

Example 2.1 The number of poles of a three-phase induction motor is 4. Find the speed of the pump if the frequency is 60 Hz.

Solution
The value of the pump speed is calculated as,

$$N_s = \frac{120f}{P} = \frac{120 \times 60}{4} = 1800\,\text{rpm}$$

Practice Problem 2.1
The speed of the is found to be 1200 rpm. Calculate the number of poles if the frequency is 60 Hz.

2.1.3. Pump Pressure and Flow Rate

Pressure and flow rate are very important for understanding the working principle of the pump. The pressure at the suction pipe (inlet) is very less and at the delivery pipe is high. This pressure is directly proportional to the system's applied force. A pump is conned to two cylinders *a* and *b*. The area and force of cylinder *a* are 2 in.^{2} and 1200 lb as shown in Fig. 2.1. The same parameters for cylinder *b* are 3 in.^{2} and 1500 lb. The pressure for cylinder *a* is calculated as,

$$P_a = \frac{F_a}{A_a} = \frac{1200}{2} = 600\ \text{psi}$$

The pressure for the second cylinder is calculated as,

$$P_B = \frac{F_B}{A_B} = \frac{1500}{23} = 500\ \text{psi}$$

From last Eqs, it is seen that the pump will first reach cylinder B and performs the work. After this, the remaining pressure will reach cylinder B (Fig. 2.3).

The amount (volume) of fluid that delivers per unit time through the discharge pipe is known as flow rate. All pumps are connected to the external power source. The three-phase or single-phase inductionmotor is used as the external power source. The speed of the motor depends on the number of poles and frequency. Therefore, the pump flow rate is related to the displacement per revolution and the motor speed revolution per min (rpm).Mathematically, the theoretical pump flowrate is expressed as,

$$Q_T = V_P.N$$

where,

- V_P is the pump displacement in the units of m^3/rev, in.^{3}/rev,
- N is the pump speed in the unit of rev/min,
- Q_T is the theoretical flow rate in the units of m^3/min, in.^{3}/min.

The theoretical pump flow rate in terms of a gallon per minute can be expressed using the factor 1 gallon equal to 231 in.^{3} as,

$$Q_T = \frac{V_P.\ N}{231}\ \text{gmp}$$

Similarly, the theoretical pump flow rate in terms of a litre per minute can be expressed using the factor 1 L equal to 1000 cm^3 as,

$$Q_T = \frac{V_P .\ N}{1000}\ \mathrm{lmp}$$

Example *2.2* The displacement of a pump is 3 in.^{3} per revolution. Find the theoretical flow rate if the pump is driven at 1800 rpm.

Solution

The pump flow rate is calculated as,

$$Q_T = V_P \times N = 3 \times 1800 = 5400\,\mathrm{in.}^3/\mathrm{min} = \frac{5400}{231} = 23.38\,\mathrm{gpm}$$

Practice Problem *. 2.2*

A pump is driven by a motor at a speed of 1200 rpm and the flow rate is 10 gpm. Calculate the pump displacement.

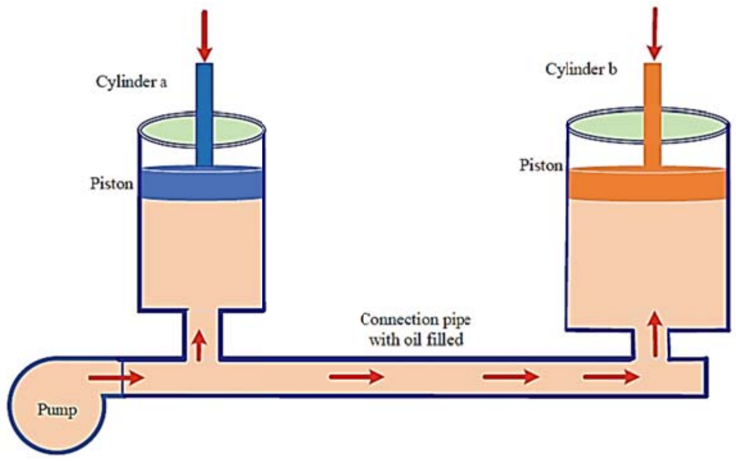

Fig. 2.3 Two cylinders with pump

2.1.4. Pump Power and Torque

An induction motor converts electrical power to mechanical power to drive or rotate the pump. This rotational speed reduces by the pressure at the delivery pipe. Therefore, the induction motor should have enough power to overcome this problem. The torque is produced when the pump-motor is rotating in a specified direction as shown in Fig. 2.4.

The circumference distance is expressed as,

$$d = 2\pi\, r\ (\mathrm{ft\ or\ m})$$

The energy is expressed as,

Energy = $F \times d$ (ft-lb or N-m or J)

Substituting yields,

$$Energy = F\ .\ 2\pi\, r\ (\mathrm{ft-b\ or\ N-m\ or\ J})$$

The torque that is generated at the shaft of the motor pump is defined as the product of force and distance. Mathematically, it is written as,

$T = F \times r$ (ft-lb or N-m)

Substituting yields,

$$Energy = 2\pi\, T\ (\mathrm{ft-b\ or\ N-m\ or\ J})$$

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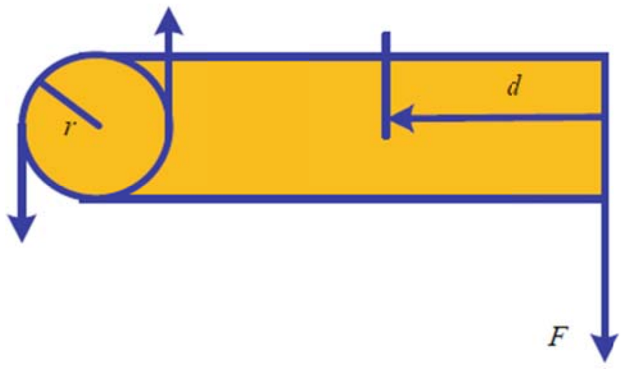


Fig. 2.4 A pump shaft with a force

The rate of receiving and delivering energy is known as power (*p*) and mathematically, it is expressed as,

$$P = \frac{dW}{dt}$$

In general, the power is expressed as,

$$P = \frac{dW}{dt} = \frac{\text{Energy}}{\text{time}}\ (\text{J/s})$$

Again, consider *N* is the rotation speed of the pump in revolution per minute (rpm). Last Equation can be rearranged as

$$P = \frac{\text{Energy}}{\text{rev}} = \frac{\text{rev}}{\text{time}}$$

Substituting yields,

$$p = 2\pi T\,.\,N$$

In the last Equation, the unit of speed is rpm. Therefore, it needs to convert rpm to rps to get the unit of power in ft-lb/s or N-m/s or J/s. it can be written as,

$$P = 2\pi T.N.\frac{1min}{60\ s}$$

$$P = \frac{T.N}{9.55}$$

If the torque is in ft lb and *N* is in rpm, then last Equation is modified by using the conversion factor 550 ft-lb/s equals to one HP as,

$$HP = \frac{T\,.\,N}{9.55\,.\,550} = \frac{T\,.\,N}{5252}$$

If the torque is in in lb and *N* is in rpm, then last Equation is modified as,

$$HP = \frac{T\,.\,N}{9.55\,.\,12} = \frac{T\,.\,N}{63024}$$

When SI units are used, then the power is calculated as,

$$P(kW) = \frac{T\,.\,N}{9.55\,.\,1000} = \frac{T\,.\,N}{9550}$$

The pump torque is fully dependent on the system pressure and pumps displacement. Mathematically, it is expressed as,

$$T = \frac{P.V_P}{2\pi}$$

where,

- *P* is the system pressure in units of psi,
- *Vp* is the pump displacement in units of in.^{3}/rev,
- *T* is the torque in units of lb. in.

Example 2.3 A hydraulic pump with a displacement of 2 in.^{3} per revolution is selected for a 1500 psi system. Calculate the value of the driving torque if the efficiency is 100%.

Solution

The value of the driving torque is calculated as,

$$T_d = \frac{P \times V_P}{2\pi} = \frac{1500 \times 2}{2\pi} = 477.46 \text{ in. lb}$$

Practice Problem *2.3*

A 500 N m is required to operate a system whose pressure is 125 Pa. Determine the pump displacement.

2.1.5. Pumps Classification

A hydraulic pump is used to pump when a certain volume of fluid is displaced and transferred from one place to another place. According to displacement, pumps are classified as positive displacement (hydrostatic) and non-positive (hydrodynamic or kinetic or dynamic pressure. When the pumping action displaces a specified amount of fluid per revolution is known as a positive displacement pump. There will be a definite amount of fluid discharge irrespective of an increase in pressure by a moving member such as a piston. Hence, only PDP can be used for the hydraulic system. The positive displacement pump is classified as a reciprocating and rotary pump.

The reciprocating pumps are classified based on the action of water on the piston and the number of cylinders uses.

Based on the action of water on the piston
- Single-acting pump
- Double-acting pump.

Based on the number of cylinders uses
- Single-cylinder pump
- Double cylinder pump
- Triple cylinder pump.

Rotary pumps are classified as
- Gear pump
- Vane pump
- Lobe pump
- Piston pump
- Screw pump.

Pumps that are using the inertia principle to push the fluid are known as non-positive displacement pumps or dynamic pressure pumps. The discharge reduces with an increase in pressure and the discharge becomes zero at the maximum pressure. Therefore, NPDP is not used for the hydraulic system. This type of pump is generally used for low-pressure (250–300 psi), high-volume flow applications. Dynamic pressure pumps are again classified as centrifugal, turbine, axial flow propeller pumps.

2.1.6. Working Principle of Pump

Initially, the motor converted electrical energy into mechanical energy. This mechanical action of a pump increases the volume which in turn creates a low-pressure vacuum at the inlet which allows the atmospheric pressure to force liquid from the main reservoir into the inlet line to the pump as shown in Fig. 2.5. It is also known as the suction side of the pump and the pressure of the liquid is lowest at the suction side.

Finally, the same mechanical action of a pump delivers this liquid to the pump outlet and forces it into the hydraulic system. The liquid leaves the pump through the outlet and this side is called the discharge side. The pressure of the liquid is highest at the discharge side.

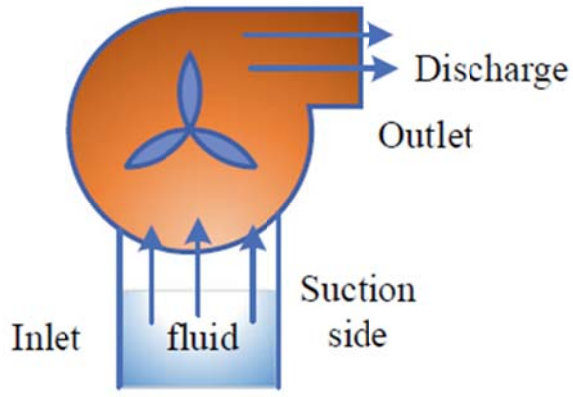


Fig. 2.5 A simple pump.

2.1.7. Rotary Pumps

All rotary pumps have rotating parts, which trap the fluid at the inlet port and force it, through the discharge port, into the fluid power systems. Gears, screws, lobes, and vanes are commonly used to move the fluid within the pump.

Rotary pumps are designed with very small clearances between their rotating and stationary parts to minimize slippage from the discharge side back to the suction side of the pump. They are designed to operate at relatively moderate speeds, normally below 1800 rpm. Operation at higher speeds can cause erosion and excessive wear. There are numerous types of rotary pumps and various methods of classification. They may be classified by the shaft position, the type of driver, their manufacturer's name, or their service application. However, the classification of rotary pumps is generally made according to the type of rotating element.

2.1.7.1. Gear Pump

A gear pump develops flow by carrying fluid between the teeth of two meshed gears as shown in Fig. 2.6. One gear is driven by the driveshaft and turns the other. The pumping chambers formed between the gear teeth are enclosed by the pump's housing and the side plates. A partial vacuum is created at the inlet as the gear teeth unmeshed. Fluid flows in to fill the space and is carried around the outside of the gears. As the
teeth mesh again at the outlet, the fluid is forced out. The high pressure at the pump's outlet might impose an unbalanced load on the gears and their associated bearing support structure.

The flow rate of this pump is calculated by considering the pump as a hollow cylinder of outside and inside diameters and the width of the gear teeth. According to Fig. 2.6, consider D_o is the outside diameter of gear teeth (in., m), D_i is the inside diameter of gear teeth (in., m), L is the width of gear teeth (in., m), V_d is the displacement volume of the pump (in^3/rev, m^3/rev), N is the rpm of the pump. The volumetric displacement is calculated as,

$$V_d = \frac{\pi}{4}\left(D_o^2 - D_i^2\right).L$$

According to last Equation, the theoretical pump flow rate in in.3/min and m3/min can be expressed as,

$$Q_T = V_d.N = \frac{\pi}{4}\left(D_o^2 - D_i^2\right).L.N$$

The value of the pump flow rate in gpm is calculated (1 gallon = 231 in.^{3}) as,

$$Q_T = \frac{\frac{\pi}{4}\left(D_o^2 - D_i^2\right).L.N}{231} \text{ gmp}$$

It is seen that the pump flow rate directly varies with the pump speed as explained in Fig. 2.7.

At a given speed, the pump theoretical flow rate is constant with respect to system pressure that is explained in Fig. 4.8. Whereas the actual flow rate is less than the theoretical flow rate due to frictional losses or internal losses.

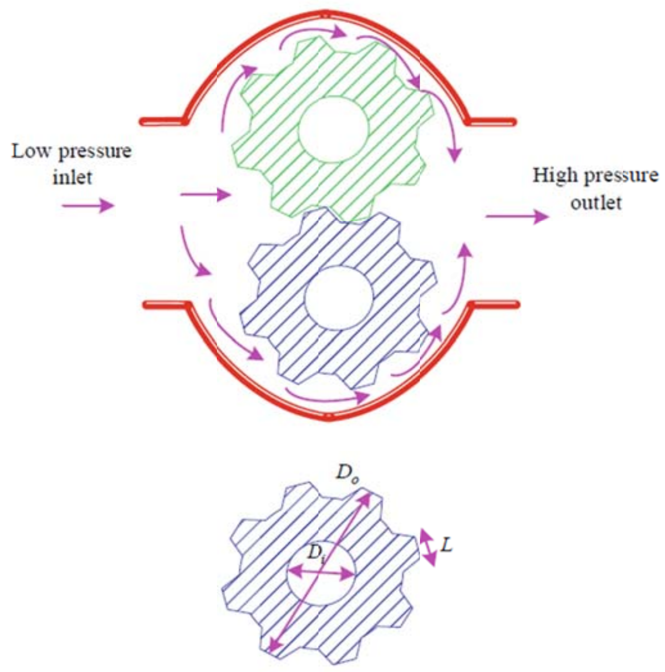


Fig. 2.6 A simple gear pump

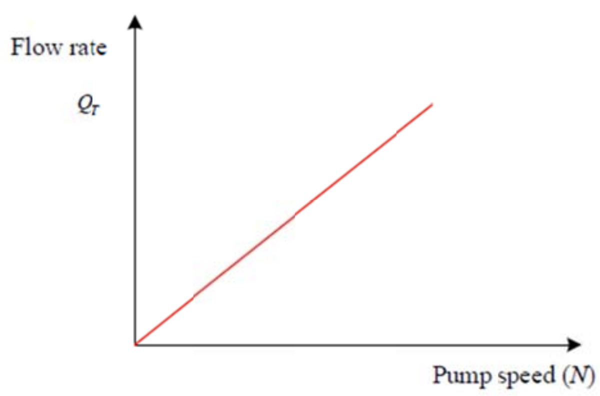


Fig. 2.7 Flow rate versus pump speed

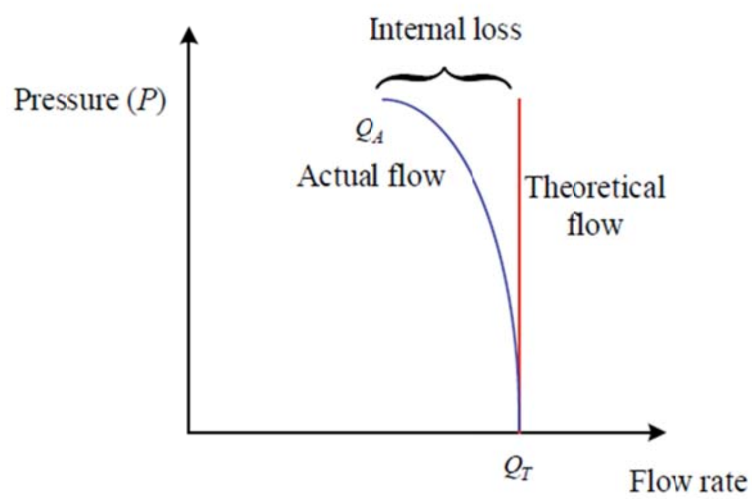


Fig. 2.8 Flow rate with pressure and a given pump speed

2.1.7.2. Lobe Pump

The lobe pumps are considerably larger than gear teeth pumps, but there are only two or three lobes are used on each rotor. A three-lobed pump is illustrated in Fig. 2.9. The two elements of the lobe pump are rotated, one is directly driven by the power source, and the other is driven by timing gears. As the elements rotate, the liquid is trapped between two lobes of each rotor and the walls of the pump chamber. Then, the trapped liquid is carried from the suction side to the discharge side of the pump chamber.

As liquid leaves, the suction chamber, the pressure in the suction chamber is lowered and additional liquid is pulled into the chamber from the reservoir. Lobe pumps are used in a variety of industries such as pulp and paper, chemical, food, beverage, etc.

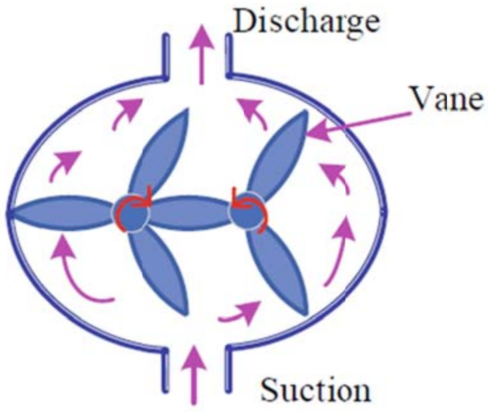


Fig. 2.9 A simple lobe pump

2.1.7.3. Vane Pump

The simplest vane pump consists of a circular rotor rotating inside of a larger circular cavity. The centers of the two circles are balanced, causing eccentricity as shown in Fig. 2.10. The leakage in a gear pump creates from the small gaps between the teeth as well as between teeth and pump housing. The vane pump reduces this leakage by using spring-loaded vanes slotted into a driven rotor.

The vanes of the pump can slide into and out of the rotor and seal on all edges. As a result, creating vane chambers for doing the pumping work. In the first half of the revolution (intake side of the pump), the volume between the rotor and the cam ring increases. These increasing volume vane chambers are filled with fluid forced in by the inlet pressure. This inlet pressure is the pressure from the system being pumped, often refer just to the atmosphere. As the rotation continues, the volume of the cavity is reduced. In the next half of the revolution, when the pumping chamber reaches the outlet port, the fluid is pushed out of the pump and into the system.

The relevant parameters of a vane pump are shown in Fig. 2.11. Consider the following parameters to derive the flow rate of a vane pump.

- D_r is the diameter of the rotor in m,
- D_c is the diameter of the cam ring in m.
- e is the eccentricity in m,
- L is the width of the rotor in mm.

From Fig. 2.11, the maximum possible eccentricity is expressed as,

$$e_{max} = \frac{D_c - D_r}{2}$$

This maximum value of eccentricity produces the maximum value of pump volumetric displacement and it can be expressed as,

$$V_{Dm} = \frac{\pi}{4}(D_c^2 - D_r^2).L$$
$$V_{Dm} = \frac{\pi}{4}(D_c + D_r)(D_c - D_r).L$$

Substituting yields,

$$V_{Dm} = \frac{\pi}{4}(D_c + D_r)(2e_m).L$$

$$V_{Dm} = \frac{\pi}{42}(D_c + D_r)(e_m).L$$

The actual volumetric displacement occurs when $e_{max} = e$ is gaian modified as,

$$V_{Dm} = \frac{\pi}{42}(D_c + D_r)(e).L$$

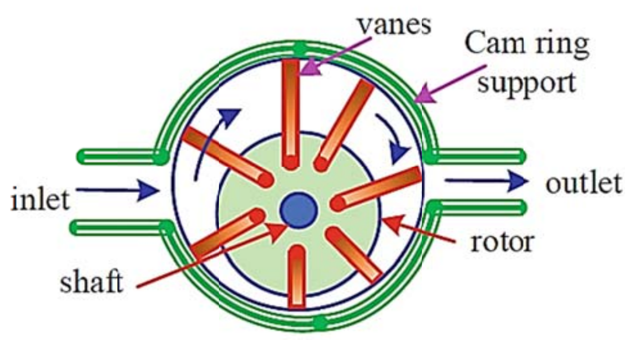
The eccentricity i.e. the deviation from the normal pattern is expressed as,

$$e = \frac{2Q_T}{\pi(D_c + D_r).L.N}$$

The eccentricity is expressed as,

$$e = \frac{2V_{dm}}{\pi(D_c + D_r).L}$$

The displacement and pressure ratings of a vane pump are generally lower than gear pumps. However, its volumetric efficiency is around 95%.



modified as,

Fig. 2.10 A simple vane pump

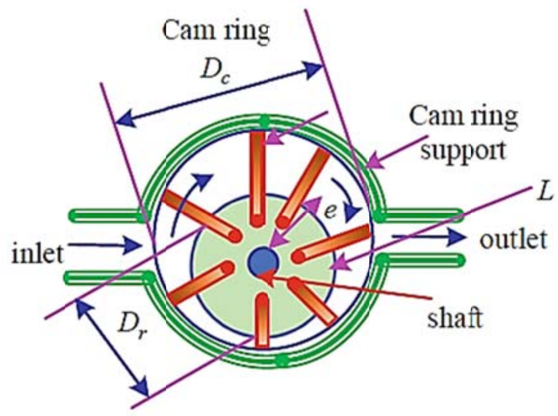


Fig. 2.11 Different diameters of a vane pump

2.1.7.4. Screw Pump

The screw pump is an axial flow positive displacement unit. The two shafts namely the driving shaft and driven shaft are attached to form meshing within a close-fitting housing as shown in Fig. 2.12. The blades are attached to the shafts.

The driving and driven shafts are connected by a timing gear. The driving shaft is coupled with a motor. The two screws are forming closed chambers that are moving in an axial direction during turning. This movement creates a vacuum at the inlet side and pressure at the outlet. The water through the inlets due to atmospheric pressure and delivers through the discharge pipe.

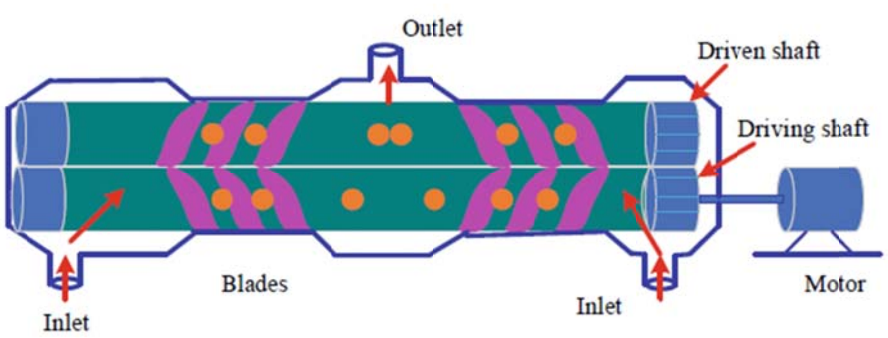


Fig. 2.12 A simple screw pump

2.1.7.5. Piston Pump

In a piston pump, the cylinder block and driveshaft are located on the same centerline as shown in Fig. 2.13. The piston usually moves backward direction to create the vacuum at the inlet pipe. This vacuum pressure allows atmospheric pressure to push fluid from the tank or reservoir into the pump. After that, the piston moves forward to expel fluid from the discharge pipe. The check valves are used in both the suction and delivery pipes to control the fluid. This type of pump is normally designed with a variable displacement capability. The maximum swash plate angle is limited to 17.5° by construction.

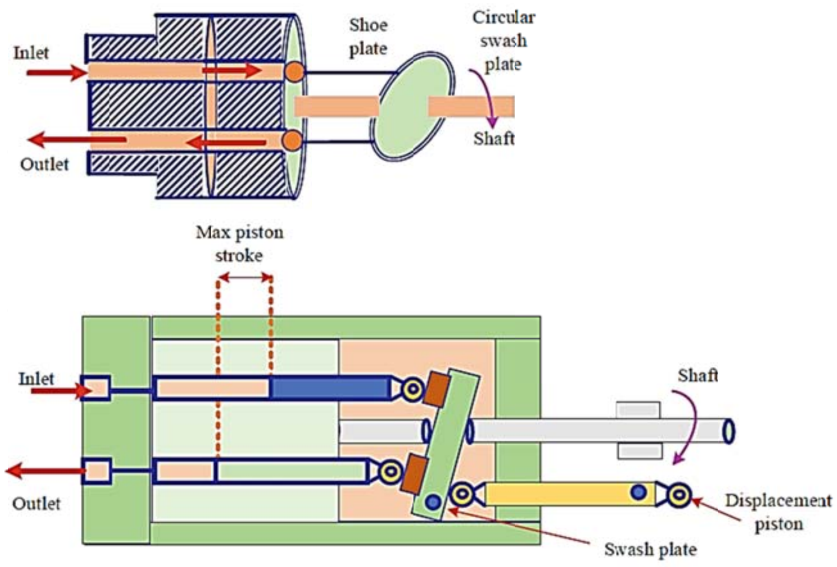


Fig. 2.13 A simple piston pump

2.1.8. Centrifugal Pump

Asimple schematic diagram of a centrifugal pump is shownin Fig. 2.14.The impeller, impeller vane, eye, shaft, casing, inlet pipe, outlet pipe, discharge valve, seat valve and strainer or filter are mentioned here. The function of the strainer allows fluid into the suction pipe without foreign materials. The seat valve allows fluid into the suction pipe. The static head of the pump is equal to the sum of the suction head and the discharge head.

Fluid enters the pump through the suction pipe and moves around the pump casing which creates the tangential velocity. The magnitude of this tangential velocity is low around the casing as the area is higher.Whereas this velocity is lower in the discharge pipe as the area is higher which satisfies the continuity equation ($Q=AV$ =constant).

Bernoulli's equation in energy form is used to explain the working principle and this equation is written as,

$$\text{Pressure energy} + \text{kinetic energy}\ \left(\frac{m\,v^2}{2}\right) + \text{potential head energy} = \text{constant}$$

$$gh\ \text{(potential energy)} + P_1/\rho(\ \text{pressure energy}) + (1/2)\ v^2\ \text{(kinetic energy)} = \ \text{constant}$$

The potential head energy is zero as the suction head constant with respect to the datum line. Therefore, it is revised as,

$$\text{Pressure energy} + \text{kinetic energy} = \text{constant}$$

In the discharge pipe, the velocity is low so that the kinetic energy is low. According to last Equation, pressure energy is high. As a result, the fluid discharged through the delivery pipe. Therefore, the fluid will discharge from the outlet with high pressure.

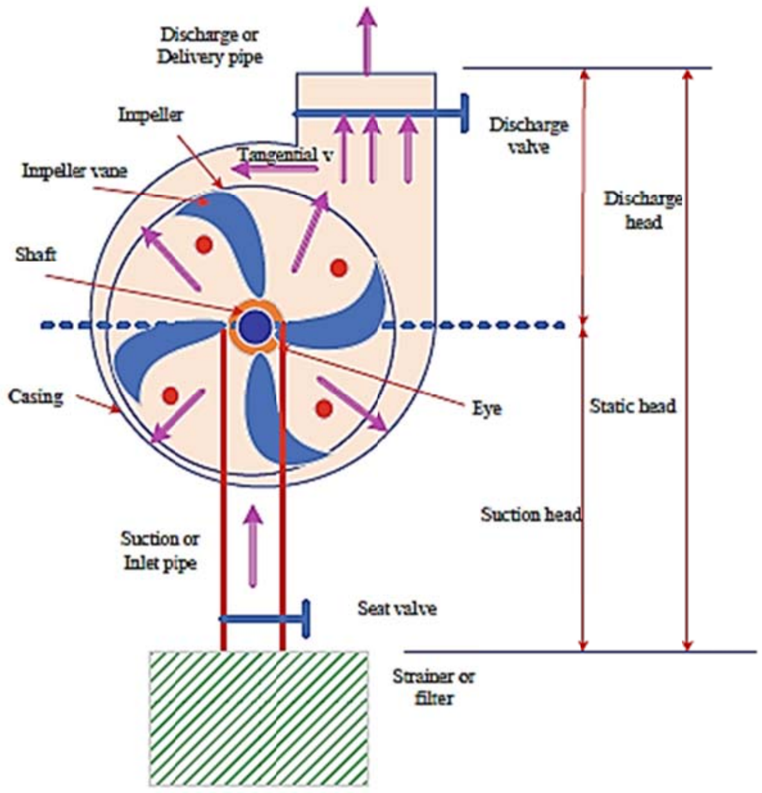


Fig. 2.14 A simple centrifugal pump

2.1.9. Graphic Symbols of Pump

The function of a hydraulic pump is to transform mechanical energy into hydraulic energy. Different types of pump symbols are used in hydraulic systems. These are fixed displace displacement, variable displacement, pressure compensated. The displacement of a pump is defined by the volume that the pump gears, vanes or pistons will displace in one revolution. The pump that has a fixed displacement per revolution is known as a fixed displacement pump or unidirectional pump. The unidirectional pump normally rotates in one direction. If rotating these motors in the wrong direction may result in a blown shaft seal and the motor drainage the fluid through the suction (inlet) port. In any case, blocking the outlet of a fixed displacement pump will send high flow to the tank through the pressure relief valve. The small solid triangle represents the direction of flow as shown in Fig. 2.15.

A pump that can increase or decrease the displacement either manually, hydraulically or electronically is known as a variable displacement pump as shown in Fig. 2.16. The flow rate can vary of a variable displacement pump at a constant speed. The pump that automatically reduces their displacement to prevent the pressure from rising from the preset level is known as the pressure compensated variable displacement pump.

The arrow that is parallel to the flow path indicates the pressure compensated as shown in Fig. 2.17.

The flow rate of a pressure compensated pump automatically decreases when pressure increases. This type of pump is only available in vane and piston designs.

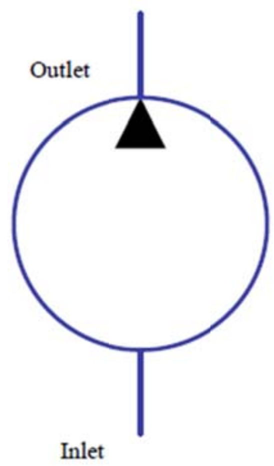


Fig. 4.15 A symbol of a fixed displacement pump

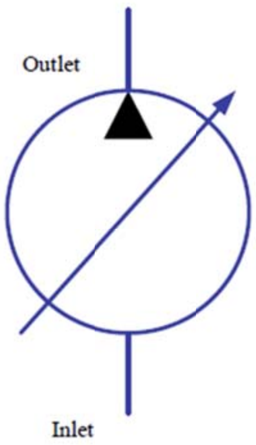


Fig. 4.16 A symbol of a variable displacement pump

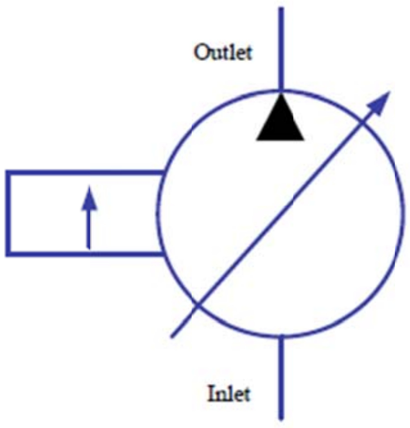


Fig. 4.17 A symbol of a pressure compensated variable displacement pump

The pump that has two energy triangles to show that the fluid is coming out from both ports is known as a bi-directional displacement pump. At a time, only one output is taken from one port while the opposite port is considered as an inlet as shown in Fig. 2.18. Variable flow rate can be obtained at a constant speed and this pump can rotate in either direction. Based on the requirement, this type of pump is used in a hydraulic system.

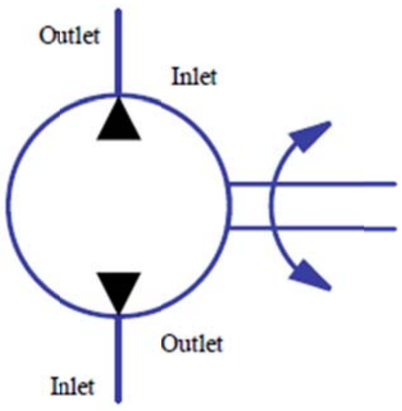


Fig. 2.18 A symbol of a bi-directional displacement pump

2.2. Basics of Pneumatics

2.2.1. Introduction

In Greek, the word 'Pneuma' means air. The system that is used gas to transmit power and control energy from one source to another source is known as a pneumatic system. The gas may be compressed air, nitrogen, or any other gases. The air is available in the atmosphere and compressed air is the air from the atmosphere which is reduced in volume by compression that increases its working pressure. Therefore, it is available everywhere without any cost and needs very little storage and delivery costs. Compressed air is used in every application as a safe gas media and it does not affect by temperature or radiation. It does not ignite any fire hazards and does not get hands dirty during application. It does not mess up the equipment and the working space if there is a leaking in the system. A reliable and large volume can be stored using a small container. There are many applications of a pneumatic system such as the manufacturing industry, construction sectors, material handling, airline industry, etc. In this chapter, components of a pneumatic system, comparison, absolute pressure and temperature, gas laws, compressor, and receiver size are discussed.

2.2.2. Components of Pneumatic System

The products or parts that are used compressed air as the medium for operation are called the components of the pneumatic system. A pneumatic system consists of an air compressor, electric-motor, filter, receiver, cooler, pressure switch, directional control valve, and cylinder. The filter is used to separate undesirable particles or contaminants from atmospheric air before entering the compressor. The electric motor transforms or converts electrical energy into mechanical energy. Later, this mechanical energy is used to run or drive the air compressor.

The compressor converts the mechanical energy into the potential energy of compressed air. The compressor decreases the volume of the incoming air and increases the temperature of the air. As the temperature increases, the pressure of the compressed air also increases. Practically, it is difficult to use compressed air at high temperatures. It needs to cool before using in any pneumatic system.

The cooler unit uses water to concentrate and banish excess heat from the compacted or compressed air. Another important component is the receiver or tank. The purpose of the receiver is to provide a smooth flow from the compressor as well as to cool and condense the moisture content. The receiver should be large in volume to hold all compressed air coming out from the compressor. The pressure in the receiver is always kept higher than the system operating pressure to compensate for the pressure loss in the pipe. Also, the larger area of the receiver helps to dissipate the heat of the compressed air. The pressure switch is used to start and stop the electric motor when the system pressure falls and reaches the required pressure level. The operation of a cylinder is controlled by a directional control valve (DCV).

The inputs of a DCV are connected to a pressure line and exhaust or silencer. The outputs (A and B terminals) of a DCV are connected to the cylinder. The components of a pneumatic system are shown in Fig.2.19.

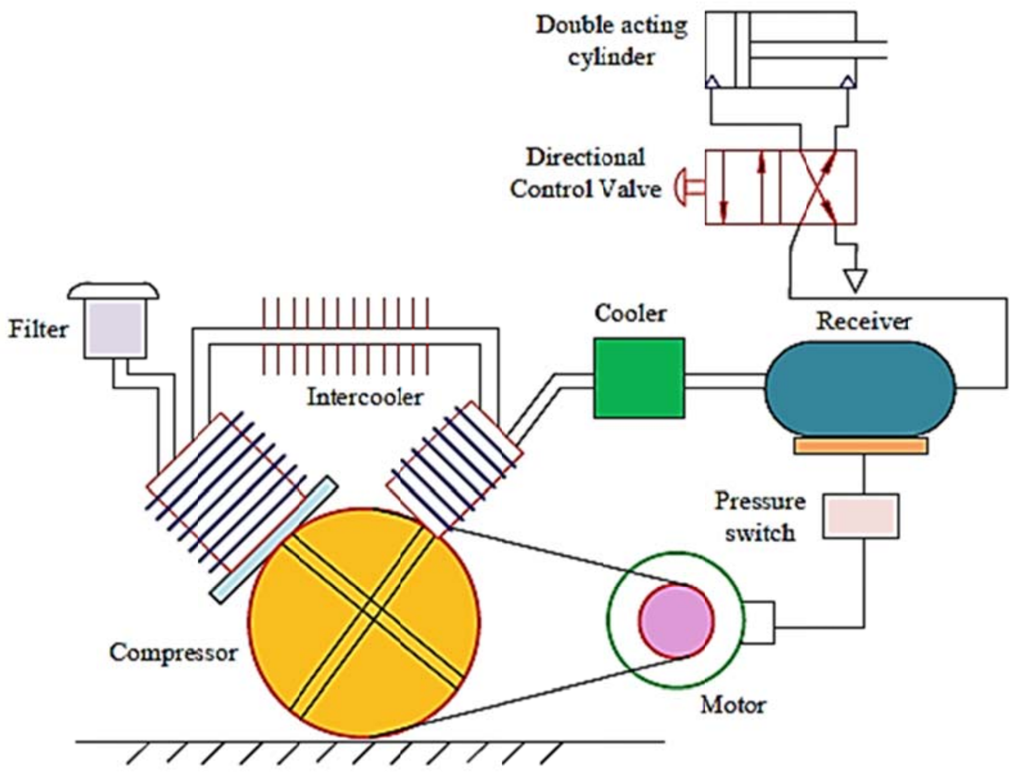


Fig. 2.19 A schematic of a pneumatic system

2.3. Comparison of Pneumatic Systems with Hydraulic Systems

The pneumatic system and hydraulic system are used based on the requirement. In an industry, there are some applications where the pneumatic is used in one part of the circuit and the part of the circuit used a hydraulic system to make the system more efficient and reliable. The comparisons of pneumatic and hydraulic systems are summarized in Table 2.1.

Table 2.1 Comparison of pneumatic system

Pneumatic system	Hydraulic system
It uses compressed gas (air) as fluid	It uses pressurized oil as the fluid
It is designed for an open system	It uses pressurized oil as the fluid
Leakage does not affect the system	Leakage slows down the system
The system is safe and free from fire hazards	The system is not safe as it is very sensitive to fire hazards
A special arrangement is required for lubrication	The system is self-lubricated
Pressures range from 80 to 100 psi	Pressures range from 1000 to 5000 psi

2.4. Pneumatic System Components

2.4.1. Introduction

The different types of pneumatic system components are usually used to operate and control any pneumatic system in a fluid power system. These are manifold, fluid conditioning units usually known as filter, regulator and lubricating (FRL), fluid control valve, directional control valve, connecting tubes and cylinders. These components are discussed in this section.

2.4.2. Pneumatic Cylinders

The pneumatic cylinders are very similar to hydraulic cylinders. The pneumatic cylinders are muscles of the pneumatic systems as they are used to move, lift and hold the objects based on the respective applications. The cylinders are the devices that produce the force with the help of compressed gas. A pneumatic cylinder with two eyes and ports is shown in Fig.2.20.

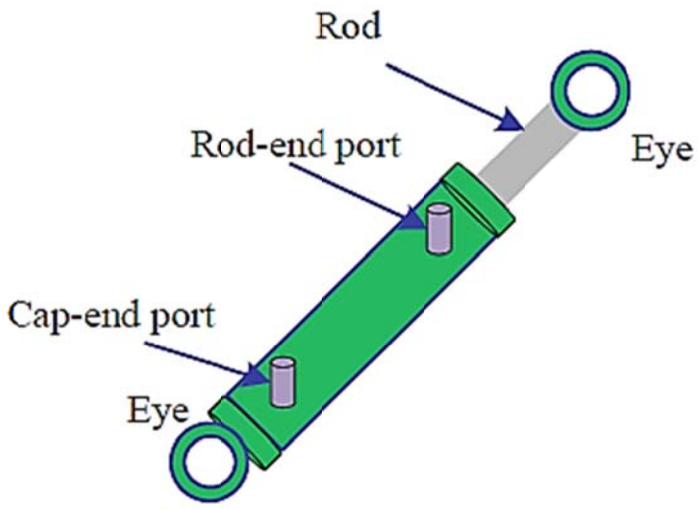


Fig. 2.20 A sample single-acting cylinder

The pneumatic cylinder converts the stored energy in the compressed gas into linear motion. Normally, the pressure is applied to the piston of the cylinder that moves in the linear direction. The mechanical generated by the cylinder is calculated by the fundamentals of Pascal's law that is the force is equal to the product of the compressed gas pressure and the area of the cylinder.

Each cylinder has two ends namely cap or blind end and rod end. The closed end of the cylinder is known as cap-end or dead-end or blind-end. Whereas the open end of the cylinder is known as head-end or rod-end or head-end and the cylinder rod normally comes through the rod end. The proper sealing (Dynamic and static) is used to make the cylinder leakproof. Static seals are used inside the barrel and dynamic seals are used with the piston. The wiper seals are also used at the rod-end to prevent the dirt, water and other unwanted contaminants from entering into the cylinder during retraction. The tube part of the cylinder is known as the barrel that provides the desired bore diameter during extension and retraction with zero leakings. The barrel also provides mechanical strength and protection during operation at a specific pressure. The main components of a real cylinder are shown in (Figs. 2.21 and 2.22).

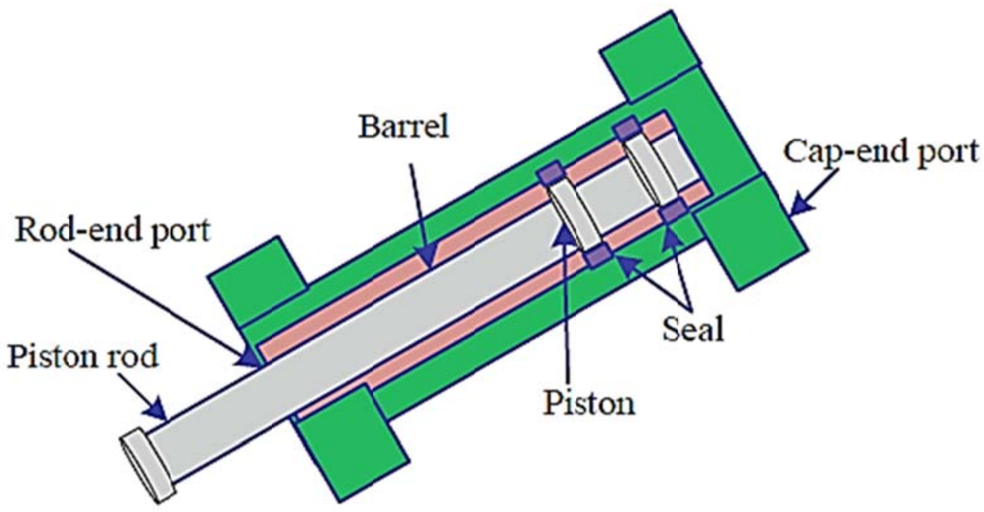


Fig. 2.21 Construction of a cylinder

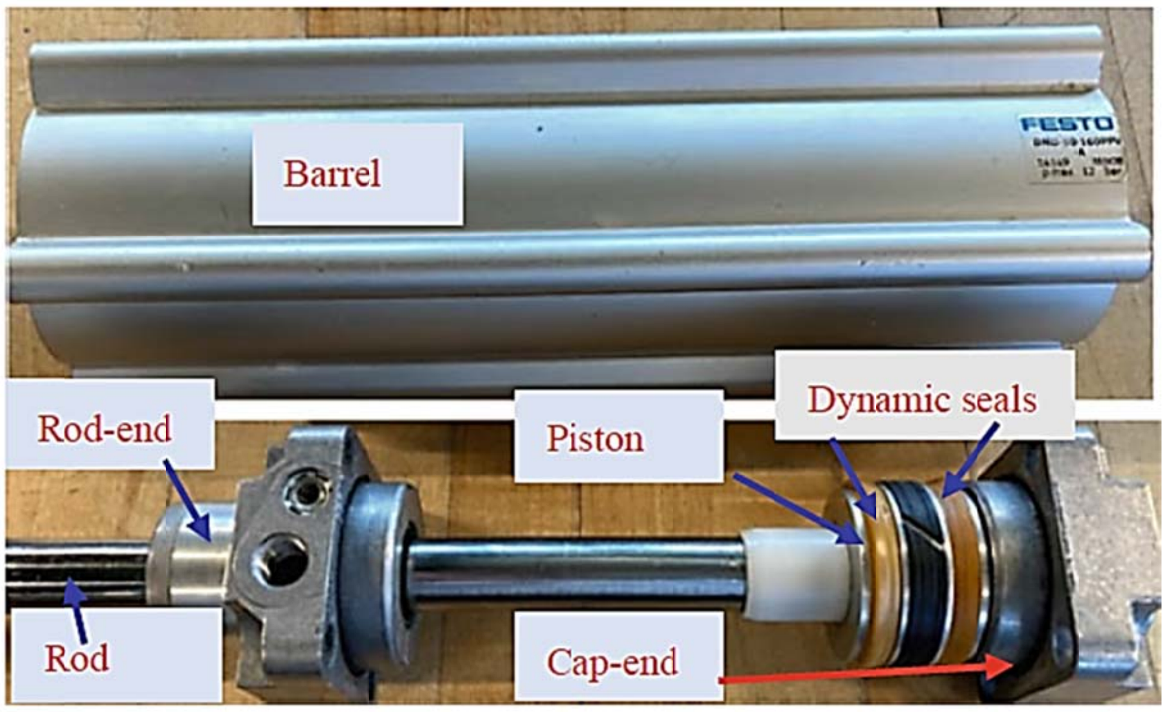


Fig. 2.22 Construction of a cylinder

Usually, the pneumatic cylinders operate at a much lower pressure than the hydraulic cylinders. Therefore, the pneumatic cylinders are made of aluminum. Based on applications, the pneumatic cylinders are classified as low-duty, medium-duty, and heavy-duty cylinders. In general, based on cylinder action, the pneumatic cylinders are classified as single-acting, double-acting (single-rod and double-rod), and telescopic or multistage.

2.4.2.1. *Sigle-Acting Cylinder*

There is one connection port in a single-acting cylinder where the compressed air supply is connected. A single-acting cylinder with and without spring is shown in Fig.2.23.. A compressed air supply is connected to a piston side port of a spring control single-acting cylinder as shown in Fig.2.24. As a result, the pressure of the compressed air will act on the piston of the cylinder and pushes the piston. If the force of the compressed air is higher than the spring force, then the piston rod will be fully outstroke.

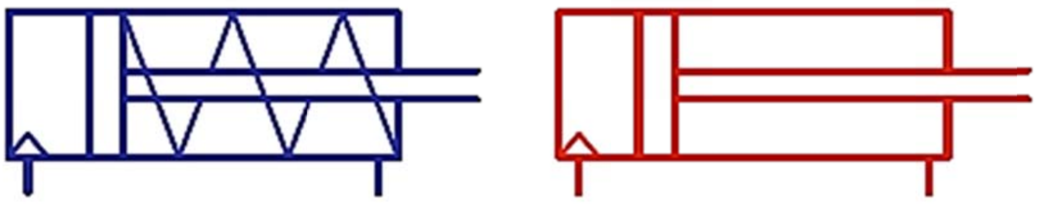


Fig. 2.23 A single-acting cylinder with and without spring

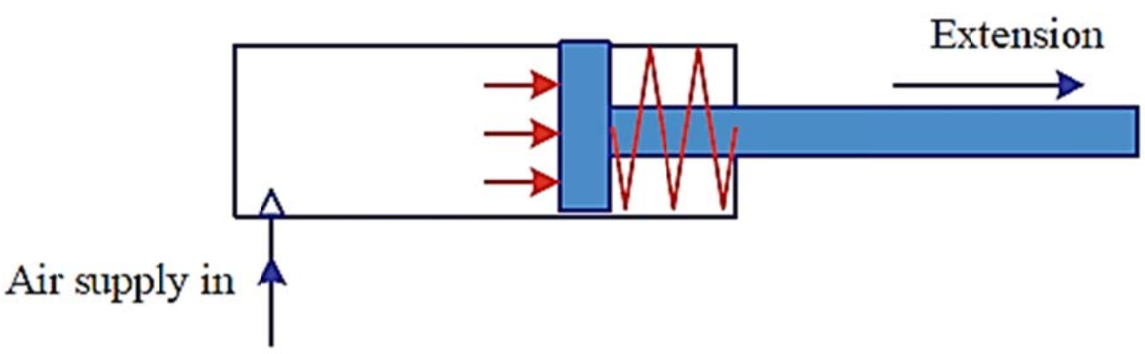


Fig. 2.24 A single-acting cylinder with extension

This position of the cylinder is known as an extension as shown in Fig.2.24. When the air supply is stopped, then the spring pressure will be higher than the supply pressure. As a result, the air from the cylinder will go out and it will be at a fully instroke position. This position of the cylinder is known as the retraction position as shown in Fig.2.25.

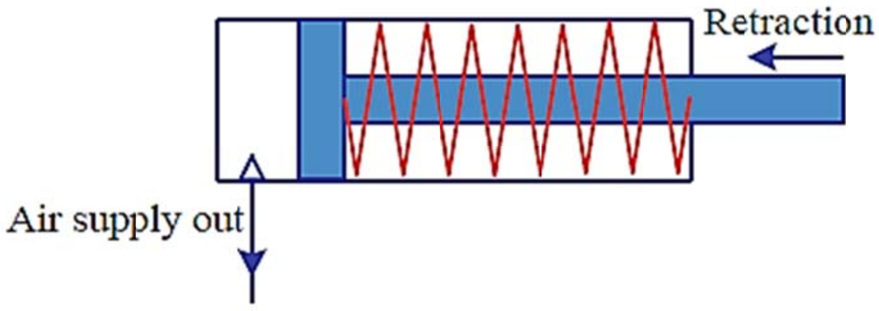


Fig. 2.25 A single-acting cylinder with retraction

The simulation of a single-acting cylinder is carried out using an air supply and a 3/2 normally closed directional control valve. The extension and retraction of a single-acting cylinder are shown in Fig.2.26.

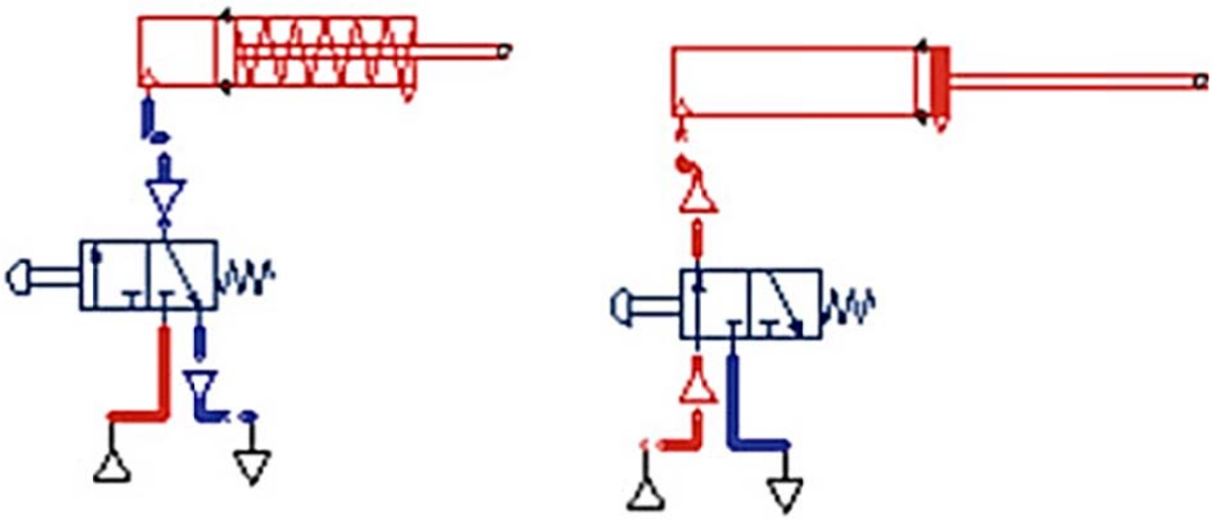


Fig. 2.26 A single-acting cylinder with retraction and attraction

2.4.2.2. ***Double-Acting Cylinder***

A double-acting cylinder has two connection ports as it does not have a spring. One connection port is near the cap-end terminal and the other port is near the rod-end terminal. During outstroke, the compressed air supply is connected to the cap-end port and the exhaust is connected to the rod-end port. In this case, the cylinder is fully outside of the barrel and this position is known as an extension of the cylinder as shown in Fig.2.27. Whereas in the return motion, the compressed air supply is connected to the rod-end port and the exhaust is connected to the cap-end. This position of the cylinder is known as retraction as shown in Fig.2.28. The doubleacting cylinder is used in a pneumatic system where a large magnitude of the force is required to move the workpiece.

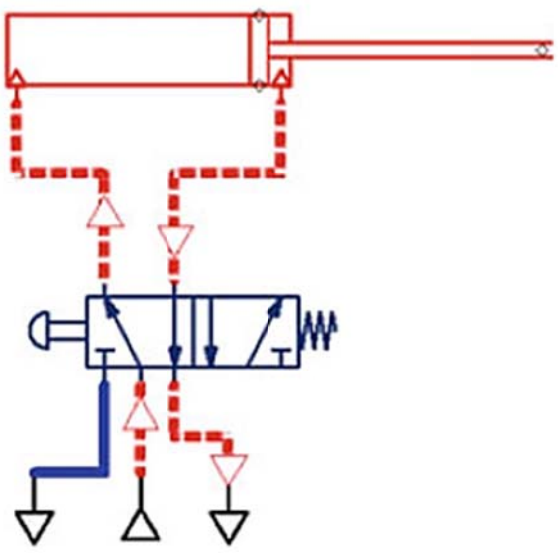


Fig. 2.27 A double-acting cylinder with an extended position

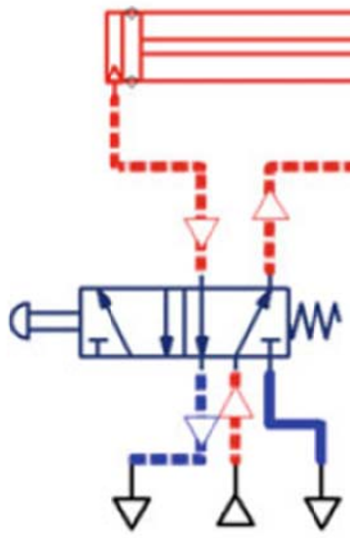


Fig. 2.28 A double-acting cylinder with the retracted position

There are some special applications where a double-acting cylinder with ended double rods is used. An example of such a load is simultaneous load. A given flow rate produces the same extension and retraction with equal area and volume on both sides of the cylinder.Asmall rod is placed in the center position of the piston to create the dead-end. This type of cylinder is used in a hydraulic system and the maximum pressure of 2500 psi can withstand during operation. The construction and graphic symbol of a double-acting ending with double rods are shown in Fig.2.29.a, b, respectively. The extension and retraction of double-acting double rods are shown in Fig.2.30 and Fig.2.31, respectively.

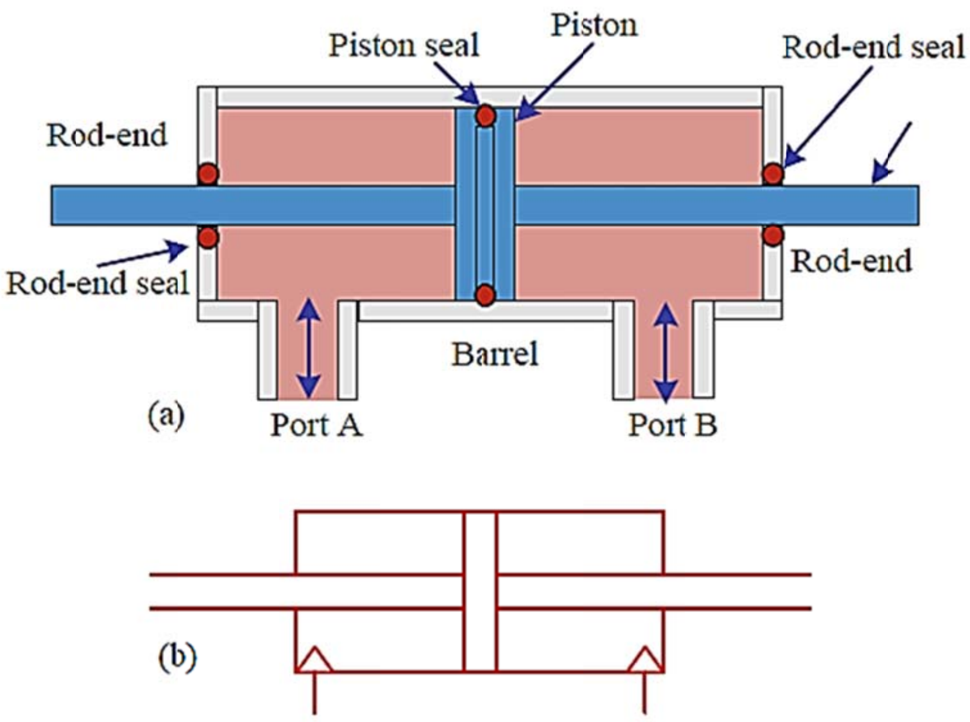


Fig. 2.29 A double-acting cylinder with ended double rods and graphic symbol

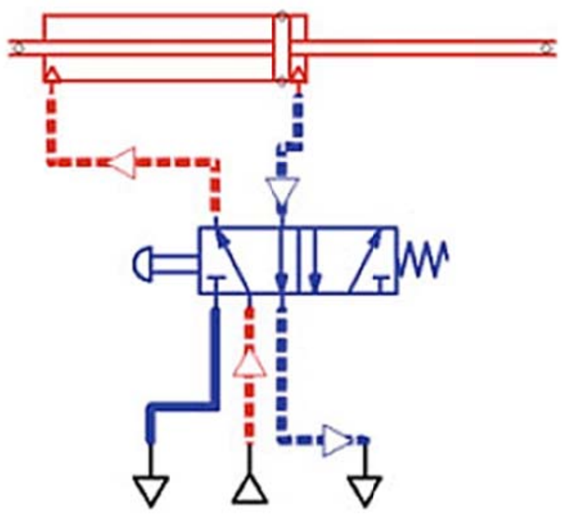


Fig. 2.30 A double-acting cylinder with ended double rods during extension

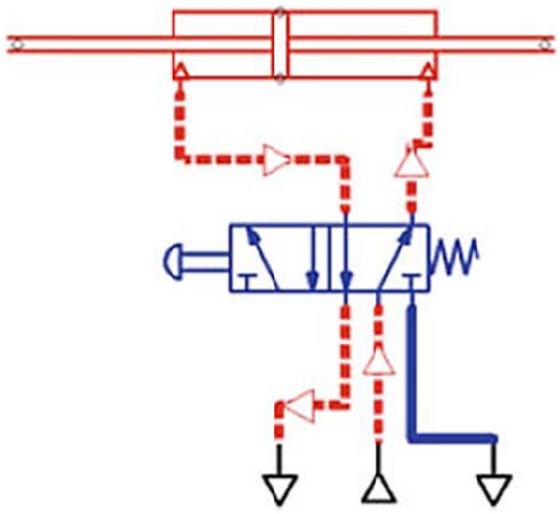


Fig. 2.31 A double-acting cylinder with ended double rods during retraction

2.4.2.3. *Telescopic Cylinder*

There are some industrial applications where a special design cylinder is required. In this type of application, a cylinder with a long stroke length and a short retracted length is required. This type of operation offered by a special cylinder is known as a telescopic cylinder. This type of cylinder is designed for high pressure that is around 2700 psi to carry a heavyweight load. There are many places where telescopic cylinders are used. These are dump trucks, amusement parks, during a long vehicle carrying new vehicles, etc. The extension and the retraction positions of a telescopic cylinder are shown in Fig.2.32.

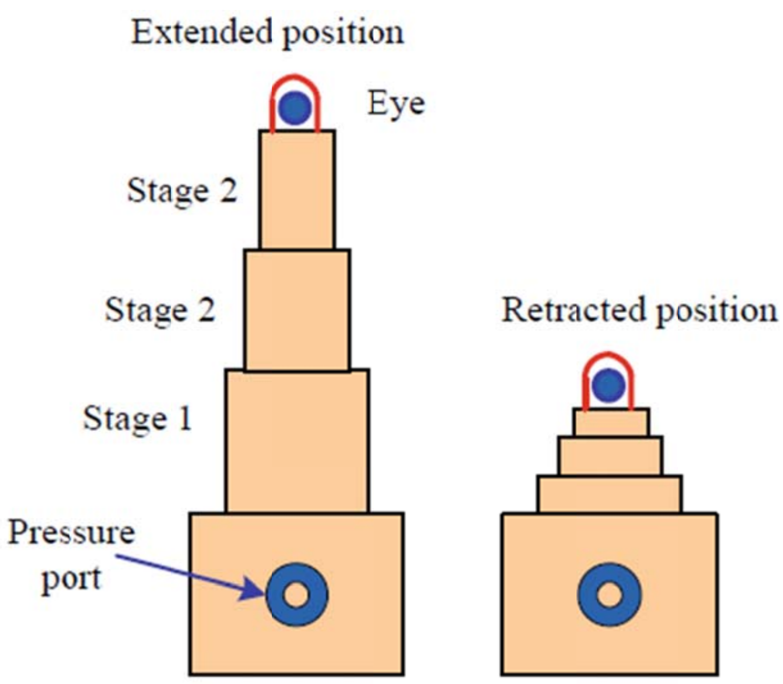


Fig. 2.32 An extension and a retracted position of a telescopic cylinder

Telescopic cylinders are more expensive than standard cylinders because of their complex construction. The graphic symbol of a single-acting telescopic cylinder is shown in Fig.2.33.

Fig. 2.33 A graphic symbol of a single-acting telescopic cylinder

Fig. 2.34 A graphic symbol of a double-acting telescopic cylinder

In Automation Studio software, the telescopic cylinder is only found under the hydraulic circuit. In this software, both double-acting and single-acting telescopic cylinders are available and can be designed with different stages. However, in MS Visio, the symbols of single-acting and double-acting telescopic cylinders are available. The graphic symbol of a double-acting telescopic cylinder is shown in Fig.2.34.

The hydraulic control valves, pressure relief valve, pump, reservoir, and tank are used to understand the operation of a telescopic cylinder. Under normal simulation, pushes the lever of the directional control valve and the piston of the telescopic cylinder will come out from the original position and extend as shown in Fig.2.32