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LECTURER NOTES

SUBECT- Hydraulic Machine & Industrial Fluid Power (**TH-3**)

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Hydraulic Turbines

The hydraulic turbine is a prime mover that uses the energy of flowing water and converts is into the mechanical energy in the form of rotation of the runner. (A prime mover is a machine which uses the raw energy of a substance and converts it into the mechanical energy.) Since the fluid medium is water, these turbines are also known as the ‘ water turbines’ . Hydraulic turbines coupled with hydro — generators form the so —called ‘ hydrounits’ which are widely used now a days for generating electrical power.

CLASSIFICATION OF TURBINES

Hydraulic turbines may be classified in the following ways:

i) According to the type of energy at inlet. a) Impulse turbine b) Reaction turbine.

ii) According to the direction of flow through runners. a) Tangential flow b) Radial flow c) Axial flow d) Mixed flow turbines.

iii) According to the head and quantity of water a) High head turbines —which work under high heads (above 250m) but with less

Classification of Hydraulic Turbines: Based on flow path

Water can pass through the Hydraulic Turbines in different flow paths. Based on the flow path of the liquid Hydraulic Turbines can be categorized into three types.

1. **Axial Flow Hydraulic Turbines:** This category of Hydraulic Turbines has the flow path of the liquid mainly parallel to the axis of rotation. Kaplan Turbines has liquid flow mainly in axial direction.
2. **Radial Flow Hydraulic Turbines:** Such Hydraulic Turbines has the liquid flowing mainly in a plane perpendicular to the axis of rotation.
3. **Mixed Flow Hydraulic Turbines:** For most of the Hydraulic Turbines used there is a significant component of both axial and radial flows. Such types of Hydraulic Turbines are called as Mixed Flow Turbines. Francis Turbine is an example of mixed flow type, in Francis Turbine water enters in radial direction and exits in axial direction.

Classification of Hydraulic Turbines: Based on pressure change

One more important criterion for classification of Hydraulic Turbines is whether the pressure of liquid changes or not while it flows through the rotor of the Hydraulic Turbines. Based on the pressure change Hydraulic Turbines can be classified as of two types.

1. **Impulse Turbine:** The pressure of liquid does not change while flowing through the rotor of the machine. In Impulse Turbines pressure change occur only in the nozzles of the machine. One such example of impulse turbine is Pelton Wheel.
2. **Reaction Turbine:** The pressure of liquid changes while it flows through the rotor of the machine. The change in fluid velocity and reduction in its pressure causes a reaction on the turbine blades; this is where from the name Reaction Turbine may have been derived. Francis and Kaplan Turbines fall in the category of Reaction Turbines.

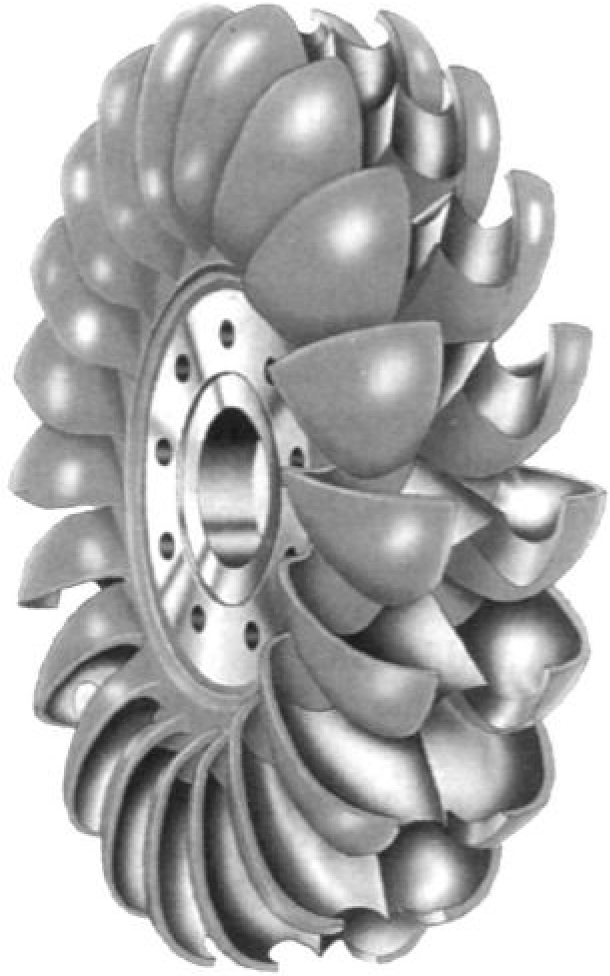
Design of Pelton Wheel Turbine

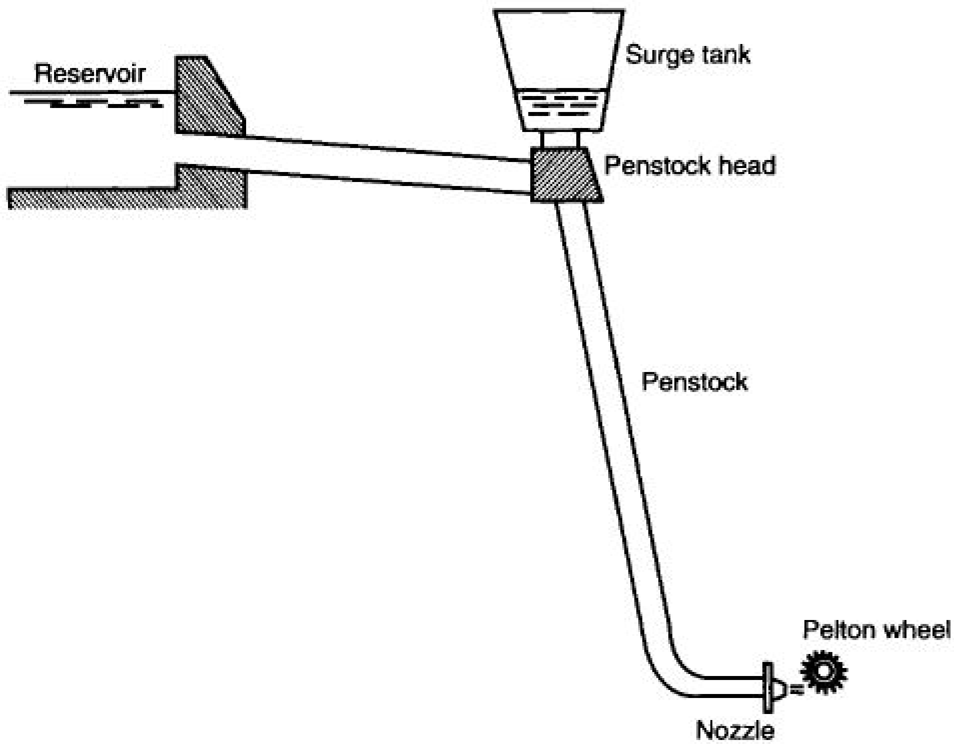
The Pelton Turbine has a circular disk mounted on the rotating shaft or rotor. This circular disk has cup shaped blades, called as buckets, placed at equal spacing around its circumference. Nozzles are arranged around the wheel such that the water jet emerging from a nozzle is tangential to the circumference of the wheel of Pelton Turbine. According to the available water head (pressure of water) and the operating requirements the shape and number of nozzles placed around the Pelton Wheel can vary.

Working Principle of Pelton Turbine

The high speed water jets emerging form the nozzles strike the buckets at splitters, placed at the middle of a bucket, from where jets are divided into two equal streams. These stream flow along the inner curve of the bucket and leave it in the direction opposite to that of incoming jet. The high speed water jets running the Pelton Wheel Turbine are obtained by expanding the high pressure water through nozzles to the atmospheric pressure. The high pressure water can be obtained from any water body situated at some height or streams of water flowing down the hills.

The change in momentum (direction as well as speed) of water stream produces an impulse on the blades of the wheel of Pelton Turbine. This impulse generates the torque and rotation in the shaft of Pelton Turbine. To obtain the optimum output from the Pelton Turbine the impulse received by the blades should be maximum. For that, change in momentum of the water stream should be maximum possible. That is obtained when the water stream is deflected in the direction opposite to which it strikes the buckets and with the same speed relative to the buckets.



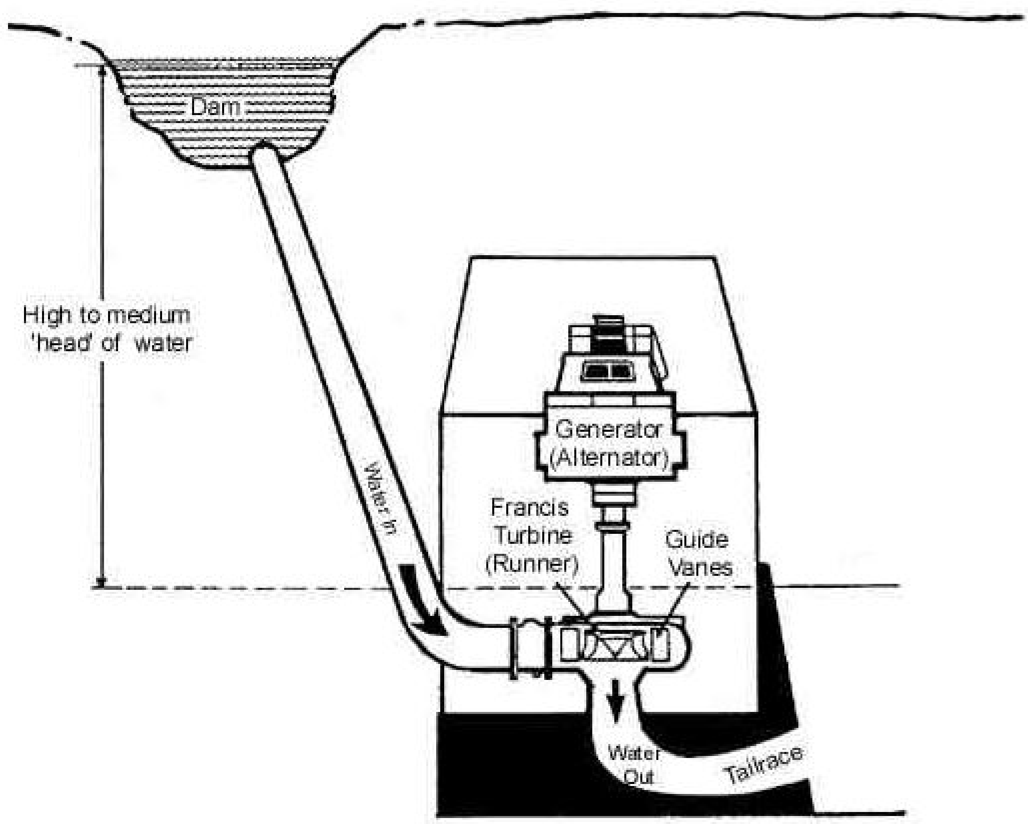


Francis Turbine

Francis Turbine is the first hydraulic turbine with radial inflow. It was designed by American scientist James Francis. Francis Turbine is a reaction turbine. Reaction Turbines have some primary features which differentiate them from Impulse Turbines. The major part of pressure drop occurs in the turbine itself, unlike the impulse turbine where complete pressure drop takes place up to the entry point and the turbine passage is completely filled by the water flow during the operation.

Working of Francis Turbine

Francis Turbines are generally installed with their axis vertical. Water with high head (pressure) enters the turbine through the spiral casing surrounding the guide vanes. The water looses a part of its pressure in the volute (spiral casing) to maintain its speed. Then water passes through guide vanes where it is directed to strike the blades on the runner at optimum angles. As the water flows through the runner its pressure and angular momentum reduces. This reduction imparts reaction on the runner and power is transferred to the turbine shaft.



For power generation using Francis Turbine the turbine is supplied with high pressure water which enters the turbine with radial inflow and leaves the turbine axially through the draft tube. The energy from water flow is transferred to the shaft of the turbine in form of torque and rotation. The turbine shaft is coupled with dynamos or alternators for power generation. For quality power generation speed of turbine should be maintained constant despite the changing loads. To maintain the runner speed constant even in reduced load condition the water flow rate is reduced by changing the guide vanes angle.

Kaplan Turbine

To generate substantial amount of power from small heads of water using Kaplan Turbine it is necessary to have large flow rates through the turbine. Kaplan Turbine is designed to accommodate the required large flow rates. Except the alignment of the blades the construction of the Kaplan Turbine is very much similar to that of the Francis Turbine. The overall path of flow of water through the Kaplan Turbine is from radial at the entrance to axial at the exit. Similar to the Francis Turbine, Kaplan Turbine also has a ring of fixed guide vanes at the inlet to the turbine.

Unlike the Francis Turbine which has guide vanes at the periphery of the turbine rotor (called as runner in the case of Francis Turbine), there is a passage between the guide vanes and the rotor of the Kaplan Turbine. The shape of the passage is such that the flow which enters the passage in the radial direction is forced to flow in axial direction. The rotor of the Kaplan Turbine is similar to the propeller of a ship. The rotor blades are attached to the central shaft of the turbine. The blades are connected to the shaft with moveable joints such that the blades can be swiveled according to the flow rate and water head available.

The blades of the Kaplan Turbine are not planer as any other axial flow turbine; instead they are designed with twist along the length so as to allow swirling flow at entry and axial flow at exit.

Working of the Kaplan Turbine

The working head of water is low so large flow rates are allowed in the Kaplan Turbine. The water enters the turbine through the guide vanes which are aligned such as to give the flow a suitable degree of swirl determined according to the rotor of the turbine. The flow from guide vanes pass through the curved passage which forces the radial flow to axial direction with the initial swirl imparted by the inlet guide vanes which is now in the form of free vortex.

The axial flow of water with a component of swirl applies force on the blades of the rotor and looses its momentum, both linear and angular, producing torque and rotation (their product is power) in the shaft. The scheme for production of hydroelectricity by Kaplan Turbine is same as that for Francis Turbine.

A Pelton wheel having semi-circular buckets functions under a head of 150m and consumes 0.06m³/s of water. If 750mm diameter wheel turns 800rpm, calculate the power available at the nozzle and hydraulic efficiency of the wheel. Assume the coefficient of velocity as unity.

Given data:

Net head, $H = 150m$

Discharge, $Q = 0.06m^3/s$

Diameter of wheel, $D = 750mm = 0.75m$

Speed of wheel, $N = 800rpm$

Coefficient of velocity, $C_v = 1$

☺ ***Solution:***

Power available at the nozzle, $P = w\,Q\,H = 9.81 \times 0.06 \times 150 =$ **88.29kW** **Ans.**

$$\text{Velocity of jet, } V_1 = C_v\,\sqrt{2\,g\,H}$$

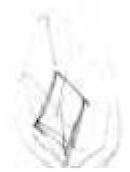
$$= 1 \times \sqrt{2 \times 9.81 \times 150} = 54.25m/s$$

$$\text{Tangential velocity of the wheel, } u = \frac{\pi D N}{60} = \frac{\pi \times 0.75 \times 800}{60} = 31.4m/s$$

Since, buckets are semi-circular, theoretically the jets get deflected through 180° and therefore, the blade angle $\phi = 0°$.

$$\text{Hydraulic efficiency, } \eta_h = \frac{2u\,(V_1 - u)\,(1 + Cos\phi)}{V_1^2}$$

$$= \frac{2 \times 31.4(54.25 - 31.4)\,(1 + Cos0)}{(54.25)^2}$$



$$\eta_h = 0.9751 = \mathbf{97.51\%}$$ **Ans.**

A Pelton wheel turbine runs under a head of 400m at a speed of 1000rpm. It develops a power of 5000kW. Find the least diameter of jet and the pitch circle diameter of wheel. Assume overall efficiency of turbine as 85%; $C_v = 0.99$ and speed ratio is 0.45. Also find the number of buckets. Assume any data, if required.

Given data:

Head, $H = 400m$

Speed, $N = 1000rpm$

Power, $P = 5000kW$

Overall efficiency $\eta_o = 85\%$

$C_v = 0.99$

Speed ratio, $K_u = 0.45$

Solution:

Velocity of jet, $V_1 = C_v\sqrt{2gH} = 0.99 \times \sqrt{2\times9.81\times400} = 87.7m/s$

Velocity of wheel, $u = K_u \times V_1 = K_u\sqrt{2gH}$

$= 0.45 \times \sqrt{2\times9.81\times400} = 39.87m/s$

Velocity of wheel, $u = \frac{\pi D N}{60}$

$39.87 = \frac{\pi\times D\times1000}{60}$

Diameter of wheel, $D = \mathbf{0.761m}$ **Ans.**

Overall efficiency, $\eta_o = \frac{P}{wQH}$

$0.85 = \frac{5000}{9.81\times Q\times400}$

$Q = 1.5m^3/s$

We know that, Discharge, Q = Area of jet × Velocity of jet

$Q = \frac{\pi}{4}d^2 \times V_1$

$1.5 = \frac{\pi}{4}d^2 \times 87.7$

$d^2 = 0.02178$

$d = \mathbf{0.1476m}$ **Ans.**

Number of buckets, $Z = 15 + \frac{D}{2d} = 15 + \frac{0.761}{2\times0.1476} = \mathbf{17.58 \approx 18}$ **Ans.**

A Pelton wheel is to develop 13,250kW under a net head of 800m while running at a speed of 600rpm. If the co-efficient of jet=0.97, speed ratio = 0.46 and the ratio of jet diameter is 1/15 of wheel diameter. Calculate (a) number of jets (b) Diameter of jets (c) Diameter of pitch circle (d) Quantity of water supplied to wheel. Assume overall efficiency as 85%.

Given data:

Power, $P = 13250 kW$

Head, $H = 800 m$

Speed, $N = 600 rpm$

$C_v = 0.97$

Speed ratio, $K_u = 0.46$

$\frac{d}{D} = \frac{1}{15}$

$\eta_o = 85\%$

Solution:

Velocity of jet, $V_1 = C_v \sqrt{2gH} = 0.97 \times \sqrt{2 \times 9.81 \times 800} = 121.53 m/s$

Velocity of wheel, $u = K_u \sqrt{2gH} = 0.46 \times \sqrt{2 \times 9.81 \times 800} = 57.63 m/s$

We know that, $u = \frac{\pi D N}{60}$

$$57.63 = \frac{\pi \times D \times 600}{60}$$

$D = \mathbf{1.834 m}$ **Ans.**

Ratio of jet diameter to wheel diameter

$$\frac{d}{D} = \frac{1}{15}$$

$d = \frac{1}{15} \times D = \frac{1}{15} \times 1.834 = \mathbf{0.122 m}$ **Ans.**

Overall efficiency, $\eta_o = \frac{P}{wQH}$

$$0.85 = \frac{13250}{9.81 \times Q \times 800}$$

$Q = \mathbf{1.986 m^3/s}$ **Ans.**

Discharge of one jet (q) = area of jet × velocity of jet

$$= \frac{\pi}{4} \times d^2 \times V_1 = \frac{\pi}{4} \times (0.122)^2 \times 121.53 = 1.42 m^3/s$$

$\therefore$ Number of jets required $= \frac{\text{Total discharge}}{\text{Discharge of one jet}} = \frac{1.986}{1.42} = \mathbf{1.4 \approx 2}$ **Ans.**

A Francis turbine has an inlet diameter of 2.0m and an outlet diameter of 1.2m. The breath of the blades is constant at 0.2m. The runner rotates at a speed of

250rpm with a discharge of 8m³ per sec. The vanes are radial at the inlet and the discharge is radially outwards at the outlet. Calculate the angle of guide vane at the inlet and blade angle at the outlet.

Given data:

Inlet diameter, $D_1 = 2.0m$

Outlet diameter, $D_2 = 1.2m$

Breath diameter, $B_1 = B_2 = 0.2m$

Speed, $N = 250rpm$

Discharge, $Q = 8m^3/s$

Solution:

Flow velocity at inlet, $V_{f_1} = \dfrac{Q}{K_t\ \pi D_1\ B_1} = \dfrac{8}{0.95\times\pi\times2\times0.2}$ ($\because$ Assume $K_t = 0.95$)

$$V_{f_1} = 6.7m/s$$

Also $V_{f_1} = K_f\ \sqrt{2gH}$

$6.7 = 0.25 \times \sqrt{2\times9.81\times H}$

($\because K_f$ value varies from 0.15 to 0.3 Assume = 0.2!

H=36.62m

Tangential velocity at inlet, $u_1 = \dfrac{\pi D_1 N}{60} = \dfrac{\pi\times2\times250}{60} = 26.18m/s$

We know that, Hydraulic efficiency

$$\eta_h = \frac{V_{w1}\,u_1}{gH}$$

Assume $\eta_h = 95\% = 0.95$

$$0.95 = \frac{V_{w_1}\times26.18}{9.81\times36.61}$$

$$V_{w_1} = 13.03m/s$$

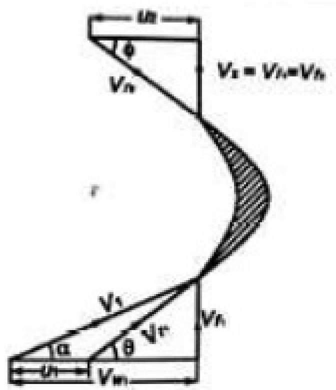


Figure 5.14

Angle of guide vane at inlet (α),

$$\tan\alpha = \frac{V_{f_1}}{V_{w_1}} = \frac{6.7}{13.03} = 0.514$$

$$\alpha = \tan^{-1}(0.514) = \mathbf{27.2^\circ}$$ **Ans.**

We know that $$\frac{V_{f_1}}{V_{f_2}} = \frac{K_{f_2}\,\pi D_2\,B_2}{K_{f_1}\,\pi D_1\,B_1}$$ ($\because$ Assume $K_{f_1} = K_{f_2}$)

Since, $B_1 = B_2$ and $K_{f_1} = K_{f_2}$

$$\frac{V_{f_1}}{V_{f_2}} = \frac{D_2}{D_1}$$

$$\frac{6.7}{V_{f_2}} = \frac{1.2}{2.0}$$

$$V_{f_2} = 11.167 m/s$$

Tangential velocity at outlet,

$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 1.2 \times 250}{60} = 15.71 m/s$$

Blade angle at the outlet (ϕ),

$$\tan\phi = \frac{V_{f_2}}{u_2} = \frac{11.167}{15.71} = 0.711$$

$$\phi = \tan^{-1}(0.711) = \mathbf{35.4^\circ}$$

5.

An inward flow turbine (Reaction turbine) with an overall efficiency of 80% is required to develop 150kW. Head is 8m. Peripheral velocity of wheel = 0.36 $\sqrt{2gH}$; Radial velocity of flow = 0.96 $\sqrt{2gH}$. Speed = 150rpm. Hydraulic losses = 22% of available energy. Assuming radial discharge determine (a) Guide blade angle at inlet. (b) Vane angle at outlet. (c) Diameter of wheel and (d) Width of wheel at inlet.

Given data:

Overall efficiency, $\eta_o = 80\% = 0.8$

Power developed, $P = 150kW$

Head, $H = 8m$

Speed, $N = 150rpm$

Hydraulic losses = 22% of available energy

Discharge at outlet = Radial

$\therefore V_{w_2} = 0;\ V_{f_1} = V_{f_2}$

☺ ***Solution:***

Peripheral velocity of wheel, $u_1 = 0.36\ \sqrt{2gH}$

$$= 0.36\ \sqrt{2 \times 9.81 \times 8} = 4.51 m/s$$

Radial velocity of flow, $V_{f_1} = 0.96\ \sqrt{2gH} = 0.96\ \sqrt{2 \times 9.81 \times 8} = 12 m/s$

Hydraulic efficiency, $\eta_h = \dfrac{\text{Head at inlet} - \text{Hydraulic losses}}{\text{Head at inlet}}$

$$= \frac{H - 0.22H}{H} = \frac{0.78H}{H} = 0.78 = 78\%$$

We know that $\eta_h = \dfrac{V_{w_1} u_1}{gH}$

$$0.78 = \frac{V_{w_1} \times 4.51}{9.81 \times 8}$$

$$V_{w_1} = 13.57 m/s$$

$$\tan\alpha = \frac{V_{f_1}}{V_{w_1}} = \frac{12}{13.57} = 0.884$$

The guide blade angle, $\alpha = \tan^{-1}(0.884) = \mathbf{41.48^\circ}$ **Ans.**

$$\tan\theta = \frac{V_{f_1}}{V_{w_1} - u_1} = \frac{12}{13.57 - 4.51} = 1.324$$

Vane angle at inlet, $\theta = \tan^{-1}(1.324) = \mathbf{53^\circ}$ **Ans.**

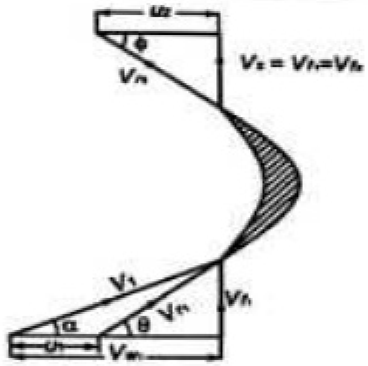


Figure 5.17

Velocity, $u_1 = \dfrac{\pi D_1 N}{60}$

$$4.51 = \frac{\pi \times D_1 \times 150}{60}$$

$$D_1 = 0.5742m = \mathbf{574.2mm}$$ **A**

Overall efficiency,

$$\eta_o = \frac{P}{wQH}$$

$$0.8 = \frac{150}{9.81 \times Q \times 8} \qquad (\because w = 9.81kN/m^3)$$

$$Q = 2.389m^3/s$$

We know that

$$Q = \pi D_1 B_1 V_{f_1}$$

$$2.389 = \pi \times 0.5742 \times B_1 \times 12$$

$$B_1 = 0.1103m = \mathbf{110.3mm}$$ A

A reaction turbine works at 450rpm under a head of 115m. The diameter of the inlet is 1.2m and the flow area is 0.4m². At the inlet, absolute and the relative velocities make angles of 20° and 60° respectively with the tangential velocity. Determine (i) The power developed (ii) Hydraulic efficiency. Assume the velocity of whirl at the outlet to be zero.

Given data:

Speed, $N = 450 rpm$

Head, $H = 115 m$

Diameter at inlet, $D_1 = 1.2 m$

Flow area, $A = 0.4 m^2$

Angle made by absolute velocity, $\alpha = 20°$

Angle made by relative velocity, $\theta = 60°$

Solution:

Tangential velocity of the turbine,

$$u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 1.2 \times 450}{60} = 28.27 m/s$$

From inlet velocity triangle,

$$\tan\alpha = \frac{V_{f_1}}{V_{w_1}}$$

$$\tan 20° = \frac{V_{f_1}}{V_{w_1}}$$

$$V_{f_1} = V_{w_1} \times \tan 20° = 0.364 V_{w_1}$$

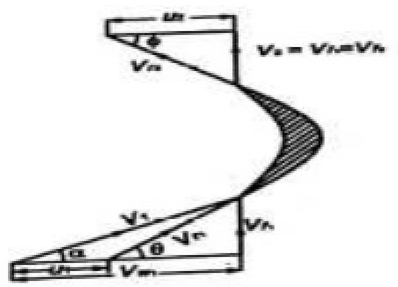


Figure 5.20

We know that, $\tan\theta = \dfrac{V_{f_1}}{V_{w_1} - u_1}$

$$\tan 60^\circ = \frac{0.364 V_{w_1}}{V_{w_1} - 28.27}$$

$$1.732 = \frac{0.364 V_{w_1}}{V_{w_1} - 28.27}$$

$$1.732 \left(V_{w_1} - 28.27\right) = 0.364 V_{w_1}$$

$$1.368\, V_{w_1} = 48.96$$

$$V_{w_1} = 35.789 m/s$$

$$\therefore\ V_{f_1} = 0.364 \times 35.789 = 13 m/s$$

Volume flow rate, $Q = A \times V_{f_1} - 0.4 \times 13 = 5.2 m^3/s$

Power developed, $P = w\,Q\,H$

$= 9.81 \times 5.2 \times 115 =$ **5866.38kW** **Ans.**

Hydraulic efficiency, $\eta_h = \dfrac{V_{w_1}\, u_1}{gH} = \dfrac{35.789 \times 28.27}{9.81 \times 115} = 0.897 =$ **89.7%** **Ans.**

TURBINES

1. **Define hydraulic machines.**

   Hydraulic machines which convert the energy of flowing water into mechanical energy.

2. **Give example for a low head, medium head and high head turbine.**

   Low head turbine – Kaplan turbine

   Medium head turbine – Modern Francis turbine High head turbine – Pelton wheel

3. **What is impulse turbine? Give example.**

   In impulse turbine all the energy converted into kinetic energy. From these the turbine will develop high kinetic energy power. This turbine is called impulse turbine. Example: Pelton turbine

4. **What is reaction turbine? Give example.**

   In a reaction turbine, the runner utilizes both potential and kinetic energies. Here portion of potential energy is converted into kinetic energy before entering into the turbine.

   Example: Francis and Kaplan turbine.

5. **What is axial flow turbine?**

   In axial flow turbine water flows parallel to the axis of the turbine shaft. Example: Kaplan turbine

6. **What is mixed flow turbine?**

   In mixed flow water enters the blades radially and comes out axially, parallel to the turbine shaft. Example: Modern Francis turbine.

7. **What is the function of spear and nozzle?**

The nozzle is used to convert whole hydraulic energy into kinetic energy. Thus the nozzle delivers high speed jet. To regulate the water flow through the nozzle and to obtain a good jet of water spear or nozzle is arranged.

8. Define gross head and net or effective head.

Gross Head: The gross head is the difference between the water level at the reservoir and the level at the tailstock.

Effective Head: The head available at the inlet of the turbine.

9. Define hydraulic efficiency.

It is defined as the ratio of power developed by the runner to the power supplied by the water

jet.

10. Define mechanical efficiency.

It is defined as the ratio of power available at the turbine shaft to the power developed by the turbine runner.

11. Define volumetric efficiency.

It is defied as the volume of water actually striking the buckets to the total water supplied by the jet.

12. Define over all efficiency.

It is defined as the ratio of power available at the turbine shaft to the power available from the water jet.

13. Define the terms

(a) Hydraulic machines (b) Turbines (c) Pumps. a. Hydraulic machines:

Hydraulic machines are defined as those machines which convert either hydraulic energy into mechanical energy or mechanical energy into hydraulic energy.

b. Turbines;

The hydraulic machines which convert hydraulic energy into mechanical energy are called turbines.

c. Pumps:
The hydraulic Machines which convert mechanical energy into hydraulic energy are called
pumps.

14. What do you mean by gross head?

The difference between the head race level and tail race level when no water is flowing is known as gross head. It is denoted by Hg.

15. What do you mean by net head?

Net head is also known as effective head and is defined as the head available at the inlet of te turbine. It is denoted as H

16. What is draft tube? why it is used in reaction turbine?

The pressure at exit of runner of a reaction turbine is generally less than the atmospheric pressure. The water at exit cannot be directly discharged to tail race. A tube or pipe of gradually increasing area is used for discharging water from exit of turbine to tail race. This tube of increasing area is called draft tube.

17. What is the significance of specific speed?

Specific speed plays an important role for selecting the type of turbine. Also the performance of turbine can be predicted by knowing the specific speed of turbine.

18.. What are unit quantities?

Unit quantities are the quantities which are obtained when the head on the turbine is unity. They are unit speed, unit power unit discharge.

19. Why unit quantities are important

If a turbine is working under different heads, the behavior of turbine can be easily known from the values of unit quantities.

20. What do you understand by characteristic curves of turbine?

Characteristic curves of a hydraulic turbine are the curves, with the help of which the exact behavior and performance of turbine under different working conditions can be known.

21. Define the term 'governing of turbine'.

Governing of turbine is defined as the operation by which the speed of the turbine is kept constant under all conditions of working. It is done by oil pressure governor.

22. What are the types of draft tubes?

The following are the important types of draft tubes which are commonly used.

a. Conical draft tubes
b. Simple elbow tubes
c. Moody spreading tubes and
d. Elbow draft tubes with circular inlet and rectangular outlet.

***Centrifugal Pump*:**

INTRODUCTION

While a turbine is a device to convert hydraulic energy into mechanical energy, a pump is a device to convert mechanical energy into hydraulic energy.
A centrifugal pump acts as a reversed turbine except that in this device special modifications are made to increase the efficiency. Centrifugal pumps are all of the outward flow type, where the radial velocity of water is increased by centrifugal action caused by the rotating vanes. It is necessary that the pump has to be full of water when starting it and hence, it should not be left to drain. External power is used to turn the vanes which gives a centrifugal head to the water collected in the pump.

This water is forced to leave the moving vanes at the outer periphery at a high velocity and pressure. This creates a partial vacuum in the centre of the pump and accordingly, the water from the suction pipe flows into it. It is the high pressure of the water leaving the vanes, which is utilized to overcome the delivery head of the pump. In the pumps made in the earlier years, the kinetic energy of the water leaving the vanes was not utilized and there used to be considerable loss of energy in the formation of eddies in the surrounding circular chamber.

In the later models, this defect has been rectified by converting the kinetic energy into pressure energy by making the water leaving the vanes, flow through a passage of gradually increasing area. The increase in the pressure head brought about in this manner is utilized in increasing the delivery head to the pump, thereby the efficiency of the pump is increased.
Generally, centrifugal pumps are made of the radial flow type only. But there are also axial flow or propeller pumps which are particularly adopted for low heads

A **Centrifugal Pump** is a hydraulic machine used to raise the liquids from a lower to a higher level by creating a required pressure by means of centrifugal action. These are the machines which increases the pressure energy of a fluid. These may either lift the fluid or just boost the pressure in a pipe line.

Component Parts of Centrifugal Pump:

- Impeller
- Casing
- Vortex
- Suction Pipe
- Delivery Pipe
- Delivery Pipe

Working of Centrifugal Pump:

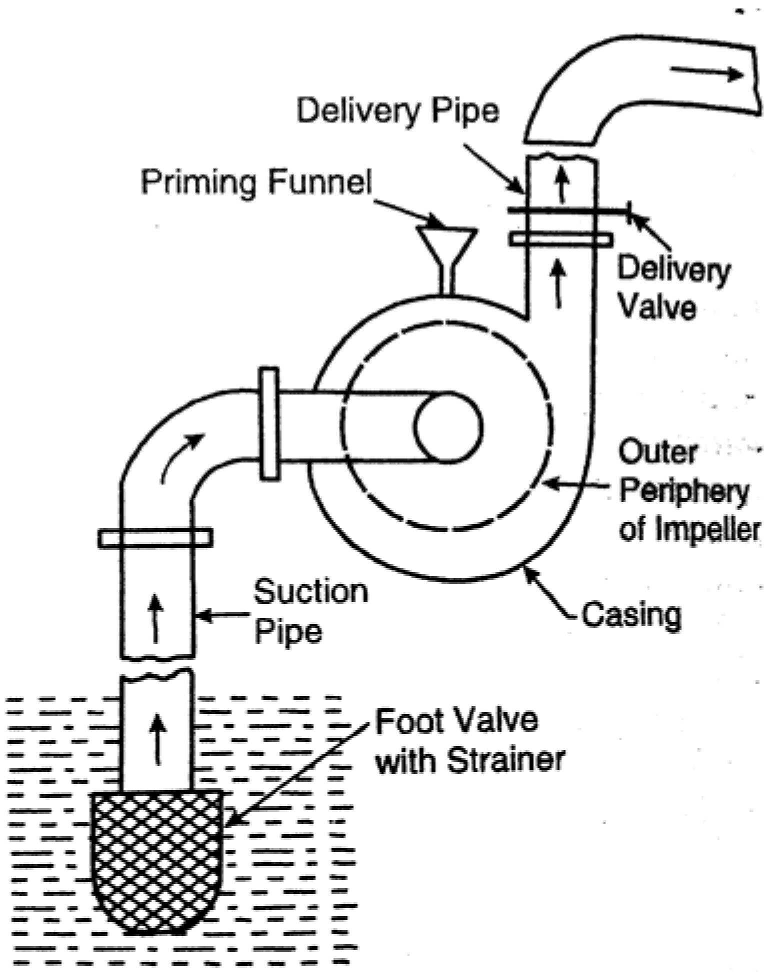
- Before starting pump, priming is done. In priming water is filled in suction pipe, casing and into a portion of delivery pipe up to delivery valve. This is done for the removal of air.
- If impeller is run in air, no liquid will be lifted by the pump.
- It should be noted that during priming, delivery valve is kept closed.
- After priming, the delivery valve is still kept closed and prime mover is started to rotate the impeller.
- The rotation of impeller in the casing full of liquid produces centrifugal head in the liquid and thus pressure in the whole of liquid is increased.
- After a short period, when pump attains a constant speed delivery valve is gradually opened and thus liquid is allowed to flow in a radially outward direction through the impeller vanes and attains higher velocity.
- The water at high pressure rises through the delivery pipe into a desired height.
- At the same time centrifugal action creates partial vacuum at the centre of impeller, known as 'EYE'.
- The partial vacuum cause the water to rush through the suction pipe towards the impeller eye, to take the place of water which has left the impeller vanes from the sump.

The following are the methods used to convert the kinetic energy of the water leaving the vanes into pressure energy:

(i) The Volute Chamber:

The volute chamber is a spiral casing surrounding the wheel which is also called the impeller. The water which leaves the vanes is directed to move in the volute chamber circumferentially. The area of the volute chamber increases gradually and hence, the velocity gets decreased accompanied by corresponding increase of pressure.

As the water reaches the delivery pipe, a considerable part of kinetic energy is converted into pressure energy. Observations however have shown that in this arrangement the efficiency of the pump is increased only slightly. This means eddies are not completely avoided and some loss of energy takes place in the eddies due to the continually increasing quantity of water passing through the volute chamber.



Vortex or Whirlpool Chamber:

This is an improvement over the ordinary volute chamber. In this case, the impeller is surrounded by a chamber by combining a circular chamber and a spiral chamber. See Fig. 24.2. In this arrangement the efficiency is increased considerably.

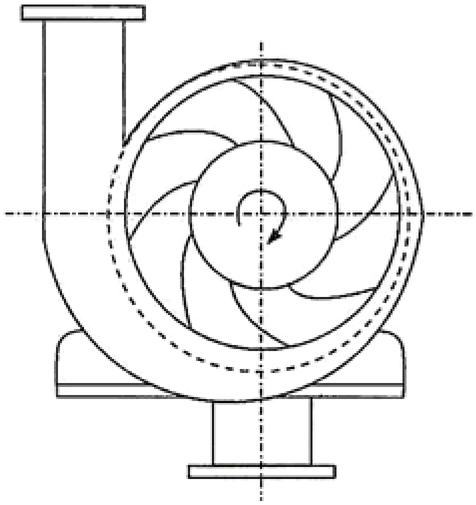


Fig. 24.2. Centrifugal pump with whirl pool chamber.

Guide Blades:

These are fixed vanes which receive the water leaving the moving vanes. The guide vanes provide a gradually increasing area of flow leading to decrease of kinetic energy and increase of pressure energy. A pump with such receiving guide vanes is called a turbine pump. The angles of the guide vanes at their receiving tips are such that the water enters the guides without shock. The guides are fixed over a circular ring. The ring with the guide blades is called a diffuser. The pump is also provided with a volute chamber which directs the water to the delivery pipe.

The Suction Pipe:

This is a pipe connecting the pump and the inlet of the pump. A non-return valve is provided at the lower end of this pipe. This valve does not allow the water to drain out of the pipe, when the pump is not running. By containing the water in the suction pipe, it assists in priming.

Generally, the lower end of the pipe is also provided with a strainer which allows only clear water into the pipe. The upper end of this pipe is connected to the inlet of the impeller and this section is called the eye of the pump. This pipe is called the suction pipe since the pressure in this pipe is below the atmospheric pressure.

To avoid cavitation the negative pressure at the pump inlet is maintained within limits. Obviously, from this consideration, the height of the suction pipe above the sump water level is kept as small as possible. Again, from this consideration the diameter of the suction pipe is made large. To prevent pressure drops bends should be avoided in the suction pipe. Due to larger diameter provided, the velocity in the suction pipe is lowered and accordingly, the loss of head due to friction in the pipe is minimized.

ii. The Delivery Pipe:

This is a pipe connecting the pump outlet to the delivery end or delivery reservoir. A delivery valve is provided with strainer near the outlet of the pump, in order to regulate the flow into the delivery pipe.

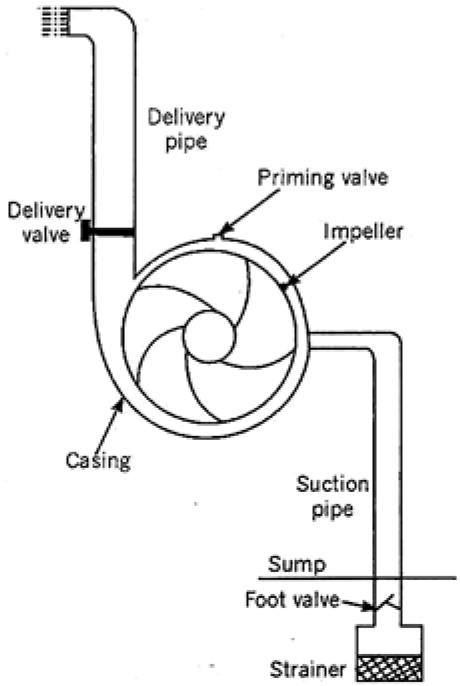


Fig. 24.5. The Centrifugal pump.

Priming of the Pump:

The centrifugal head generated in the pump is proportional to the specific weight of the fluid which fills the passage. If the impeller contains only air, the rotation of the-air mass can produce only a small centrifugal head. Hence, in order to operate the pump it is necessary that the pump should be filled with the liquid to be pumped. After the pump is filled with the liquid, the impeller should be rotated.

This process is called priming of the pump. Generally, priming is done by introducing the liquid into the impeller through a funnel provided. As the liquid fills the impeller, the air present in it will escape through the airvent valve. After all the air in the impeller and the casing is removed, the airvent valve is closed and the pump can be run.

The Analysis of the Pump:

The analysis of the pump is made similar to that of a radial flow turbine. The inlet and outlet diagrams are drawn as usual.

(*i*) *The vector diagrams*: Fig. 24.7 shows the inlet and outlet diagrams. The shape of the vanes is usually such that the flow at inlet is entirely radial, *i.e.*, the whirl component of the velocity at inlet is zero. Note the nomenclature for the inlet angle θ which is taken as the interior angle in the inlet diagram. Since the flow at inlet is entirely radial it follows $V_w = 0$ and $V = V_f$.

In all the cases, the outlet diagram is such that whirl component of the velocity at outlet is in the direction of motion of the vanes.

The velocity of whirl at outlet

$$= V_{w1} = v_1 - V_{f1} \cot \phi$$

where v_1 = peripheral velocity at outlet.

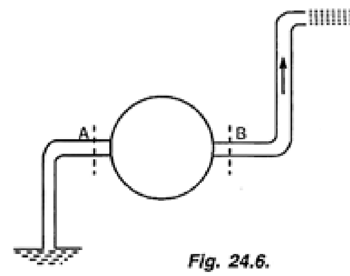


Fig. 24.6.

(*ii*) *Work done per second by the impeller*: In the case of the pump work is done by the impeller on the water. Since there is no whirl component at inlet, the work done per second by the impeller per *N* of water $\frac{V_{w1} v_1}{g}$. This is also the energy head generated by the impeller.

(*iii*) *The Manometric Head* H_m. This is the head against which the pump has to work.

The Manometric head = Static lift + Delivery head + Kinetic heads in the pipes + Losses of head in the pipes

$$H_m = H_s + H_d + \frac{v_s^2}{2g} + \frac{v_d^2}{2g} + h_{fs} + h_{fd}$$

The kinetic heads $\frac{v_s^2}{2g}$ and $\frac{v_d^2}{2g}$ in the suction and delivery pipes are very small and can be ignored in the above relation.

Hence, practically $\qquad H_m = H_S + H_d + h_{fS} + h_{fd}$

The manometric head is ultimately the head developed by the pump. The manometric head is slightly less than the head generated by the impeller due to some losses in the pump.

$$\therefore \qquad H_m = \frac{V_{w1} v_1}{g} - \text{Impeller losses.}$$

The manometric head may also be visualized as the increase of energy head at outlet of the pump over the energy head at inlet to the pump.

If *A* is a section of the suction pipe close to the pump and *B* is a section of the delivery pipe close to the pump then manometric head

$$= H_m = [\text{Energy head at } B] - [\text{Energy head at } A].$$

$$\therefore \qquad H_m = \left[Z_b + \frac{p_b}{w} + \frac{v_d^2}{2g}\right] - \left[Z_a + \frac{p_a}{w} + \frac{v_s^2}{2g}\right]$$

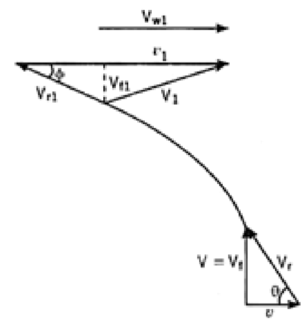


Fig. 24.7.

(*iv*) *The manometric efficiency* η_{man}

This is the ratio of the manometric head to the head actually generated by the impeller.

$$\eta_{man} = \frac{H_m}{\left[\frac{V_{w1} v_1}{g}\right]}$$

(*v*) *Impeller power*: This is power of the impeller determined in terms of the work done by it on the water.

$$\text{Impeller power} = \frac{W\left(\frac{V_{w1} v_1}{g}\right)}{1000}$$

where, $\qquad W$ = weight of water discharged per second $= w\pi d b V_f = w\pi d_1 b_1 V_{f1}$.

(*vi*) *Mechanical efficiency* η_m. This is the ratio of the impeller power to the power of the Prime Mover, (*i.e.*, motor).

$$\therefore \qquad \eta_m = \frac{\text{Impeller Power}}{\text{Power of prime mover}}$$

(*vii*) *The overall efficiency* η_0. This is the ratio of the work done by the pump in lifting the water against gravity and friction in the pipes to the energy supplied by the Prime mover.

$$\eta_0 = \frac{\frac{W H_m}{1000}}{\text{Power of Prime Mover}}$$

There are two ways of arranging the impellers in a multistage pump as explained below:

(i) Impellers in Series:

In this case, a number of impellers are mounted over a common shaft. The discharge from the first impeller is guided into the inlet of the second impeller. The discharge from the second impeller is guided into the inlet of the third impeller and so on and finally, the discharge from the last impeller is directed to the delivery pipe.

As the liquid flows through each impeller, the head H_m is impressed on it. Suppose there are n impellers. The total head developed = H_t = n H_m. The same discharge Q passes through all the impellers and is finally delivered to the delivery pipe.

(ii) Impellers in Parallel:

This arrangement is meant for discharging a high rate of flow at a given small head H_m. The impellers in this case are mounted on separate shafts. The discharges from the various delivery pipes are collected in a collecting pipe which communicates to the final delivery pipe.

If	Q = discharge from one impeller,
Total discharge	$= Q_t = nQ$
where	n = number of impellers.
But the total head developed	= Head developed by each impeller = H_m.

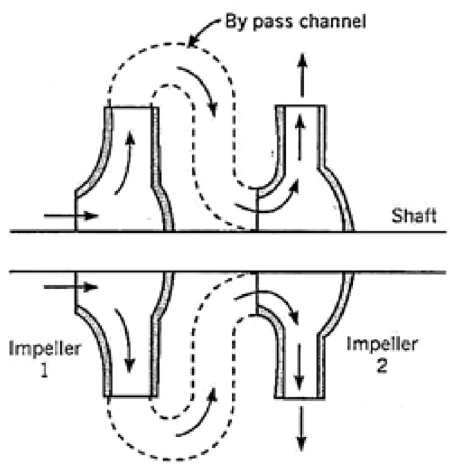


Fig. 24.15. Impellers in series.

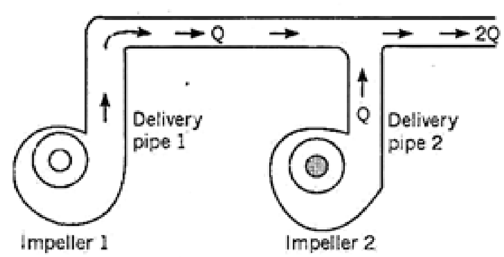


Fig. 24.16. Impellers in parallel.

We can determine the pressure of water at any section of the stream in the pump by using Bernoulli's equation. Fig. 2 shows a centrifugal pump with its suction and delivery pipes. Let A and B be points at inlet and outlet edges of the impeller at the level of the centre of the pump.

Let C be a point on the water surface of the sump. Let D a point just at the outlet of the delivery pipe.

Let H_s = Suction lift
H_d = Delivery head
p_a = Absolute pressure in Pa at A
p_b = Absolute pressure in Pa at B.

Total energy head at A = Total energy head at C

$$H_s + \frac{V^2}{2g} + \frac{p_a}{w} + h_{f_s} = H_{at} = 10.3\ m$$

We can determine p_a from the above equation.

Total energy head at A = Total energy head at B – work done by the impeller

$$\therefore \frac{V^2}{2g} + \frac{p_a}{w} = \frac{V_1^2}{2g} + \frac{p_b}{w} - \left(\frac{V_{w_1} v_1}{g} \times efficiency\right)$$

We can determine p_b from the above equation.

Again, total energy head at B = Total energy head at D + losses

$$\therefore \frac{V_1^2}{2g} + \frac{p_b}{w} = H_{at} + h_d + \frac{v_d^2}{2g} + \text{loss in diffuser} + h_{f_d}$$

We can determine the loss of head in the diffuser from the above equation.

EFFICIENCY OF A CENTRIFUGAL PUMP

Efficiency of a centrifugal pump is three types.

1) **Manometric efficiency (η_{man})**

2)**Mechanical efficiency (η_m)**

3)**Overall efficiency (η_o)**

In a centrifugal pump, Power is transmitted from the shaft of the electric motor to the shaft of the pump and then to the Impeller and from the Impeller the power is given to the water. So power is decreasing from the shaft of the pump to the ImpELler and then to the water. Read work done by a centrifugal pump on water. In this page, we will discuss the three types of **efficiency of a centrifugal pump**.

1) Manometric efficiency (η_{man}):

The power at the Impeller of the pump is more then the power given to the water at outlet of the pump. The ratio of the power given to water at outlet of the pump to the power available at the impeller is known as manometric efficiency. Mathematically, manometric efficiency formula is written as:

$$\eta_{man} = \frac{Manometric\,head}{Head\,imparted\,by\,impeller\,to\,water}$$

$$= \frac{H_m}{\frac{V_{w_2}\,u_2}{g}}$$

$$= \frac{g\,H_m}{V_{w_2}\,u_2}$$

The power at the Impeller of the pump is more then the power given to the water at outlet of the pump. The ratio of the power given to water at outlet of the pump to the power available at the impeller is known as manometric efficiency.

The power given to water at outlet of the pump

$$= \frac{Work\,done\,by\,impeller\,per\,second}{1000}\,kW$$

$$= \frac{W}{g} \times \frac{V_{w_2} \times u_2}{1000}\,kW$$

$$\eta_{man} = \frac{\frac{W \times H_m}{1000}}{\frac{W}{g} \times \frac{V_{w_2} \times u_2}{1000}} = \frac{g \times H_m}{V_{w_2} \times u_2}$$

2) Mechanical efficiency (η_m):

Mechanical efficiency of a centrifugal pump is the ratio of the power available at the impeller to the power at the shaft of the centrifugal pump. The power at the shaft of the centrifugal pump is more than the power available at the impeller of the pump. Mathematically, mechanical efficiency formula is written as:

$$\eta_m = \frac{Power\, at\, the\, impeller}{Power\, at\, the\, shaft}$$

The power at the impeller in kW

$$\eta_m = \frac{Power\, done\, by\, impeller\, per\, second}{1000}$$

$$= \frac{w}{g} \times \frac{V_{w_2}\, u_2}{1000}$$

$$\eta_m = \frac{\frac{W}{g} \times \frac{V_{w_2}\, u_2}{1000}}{S.P.}$$

$$Where\, S.P. = Shaft\, power$$

3) Overall efficiency (η_o):

Overall efficiency of a centrifugal pump is the ratio of the power output of the pump to the power input to the pump. The power output of the pump in kW

$$= \frac{Weight\, of\, water\, lifted \times H_m}{1000}$$

$$= \frac{W\, H_m}{1000}$$

Power input to the pump = Power supplied to the electric motor = S.P. of the pump

$$\eta_o = \frac{\frac{W\, H_m}{1000}}{S.P.}$$

$$\eta_o = \eta_{man} \times \eta_m$$

Reciprocating Pump:

Reciprocating Pump is a Positive Displacement type pump that works on the principle of movement of the piston in forwarding and backward directions whereas the Centrifugal pump uses the kinetic energy of the impeller to supply the liquid from one place to another place.

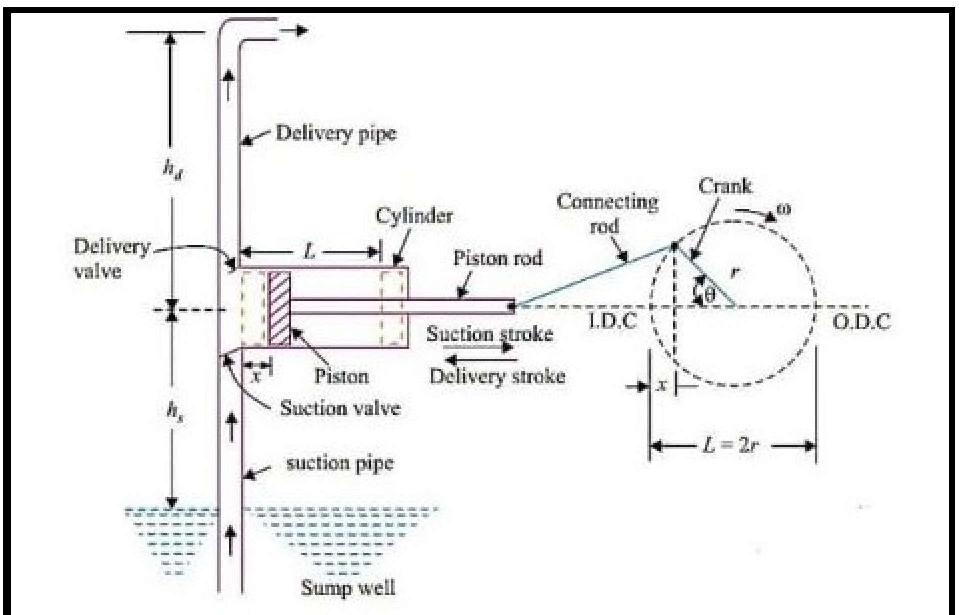
Reciprocating Pump Diagram:

The diagram of Reciprocating Pump was displayed below.

Parts of Reciprocating Pump:

The Parts of Reciprocating Pump are as follows.

- Water Sump
- Strainer
- Suction Pipe
- Suction Valve
- Cylinder
- Piston and Piston rod
- Crank and Connecting rod
- Delivery valve



Parts of Reciprocating Pump

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- Water Sump
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- Suction Pipe
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- Cylinder
- Piston and Piston rod
- Crank and Connecting rod
- Delivery valve
- Delivery pipe

An Explanation for the parts of Reciprocating Pump:

The explanation for the parts of Reciprocating pump are as follows.

Water Sump:

It is the source of water. From the sump, water is to be transported to the delivery pipes by the usage of the piston.

Strainer:

It acts as a mesh that can screen all the dirt, dust particles, etc. from the sump. If there is no strainer, then the dirt or dust also enters into the cylinder which can jam the region

and affects the working of the pump.

Suction Pipe:

The main function of the suction pipe is to collect the water from the sump and send it to the cylinder via a suction valve. The suction pipe connects the water sump and the cylinder.

Suction Valve:

It is a non-return valve which means it can take the fluid from the suction pipe and send it to the cylinder but cannot reverse the water back to it. In the sense, the flow is unidirectional.

This valve opens only during the suction of fluid and closes when there is a discharge of fluid to outside.

Cylinder:

It is a hollow cylinder made of cast iron or steel alloy and it consists of the arrangement of piston and piston rod.

Piston and Piston rod:

For suction, the piston moves back inside the cylinder and for discharging of fluid, the piston moves in the forward direction.

The Piston rod helps the piston to move in a linear direction i.e. either the forward or the backward directions.

Crank and Connecting rod:

For rotation, the crank is connected to the power source like engine, motor, etc. whereas the connecting rod acts as an intermediate between the crank and piston for the conversion of rotary motion into linear motion.

Delivery Pipe:

The function of the delivery pipe is to deliver the water to the desired location from the cylinder.

Delivery valve:

Similar to the suction valve, a delivery valve is also a Non-return valve. During suction, the delivery valve closes because the suction valve is in opening condition and during Discharge, the suction valve is closed and the delivery valve Is opened to transfer the fluid.

These are the various components of Reciprocating pump. Let's understand the working principle of it.

By Ben Franske,Reciprocating Pump

Working Principle of Reciprocating Pump:

When the power supply is given to the reciprocating pump, the crank rotates through an electric motor.

The angle made by the crank is responsible for the movement of the piston inside the cylinder. By referring to the above diagram, the piston moves towards the extreme left of the cylinder when the crank meets position **A** i.e. **θ=0**.

Similarly, the piston moves towards the extreme right of the cylinder when the crank meets the position **C** i.e. **θ=180**.

A partial vacuum in the cylinder takes place when the piston movement is towards the right extreme position i.e. (**θ=0 to θ=180**.) and that makes the liquid enter into the suction pipe.

This is due to the presence of atmospheric pressure on the sump liquid which is quite less than the pressure inside the cylinder. Therefore, due to the difference in pressure, the water enters into the cylinder through a non-return valve.

The water which stays in the volume of the cylinder has to be sent to the discharge pipe via discharge valve and this can be done when the crank is rotating from **C** to **A** i.e. (**θ=180 to θ=360**) which moves the piston in the forward direction.

Due to the movement of the piston in a forward direction, the pressure increases inside the cylinder which is greater than the atmospheric pressure.

This results in the opening of the delivery valve and closing of the suction valve.

Once the water comes into the delivery valve, it cannot move back to the cylinder because it is a unidirectional valve or non-return valve.

From there, it enters into the delivery pipe so that it can be sent to the required position.

Therefore, in this way, the water is sucked and discharged from the sump to the desired location through the piston inside the cylinder.

Reciprocating Pump Advantages:

The advantages of Reciprocating Pump are as follows.

- No priming is needed in the Reciprocating pump compared to the Centrifugal pump.
- It can deliver liquid at high pressure from the sump to the desired height.
- It exhibits a continuous rate of discharge.
- It can work due to the linear movement of piston whereas the centrifugal pump works on the rotary velocity of the impeller.

Reciprocating Pump Disadvantages:

The disadvantages of Reciprocating Pump are as follows.

- The maintenance cost is very high due to the presence of a large number of parts.
- The initial cost of this pump is high.
- Flow rate is less
- Viscous fluids are difficult to pump.

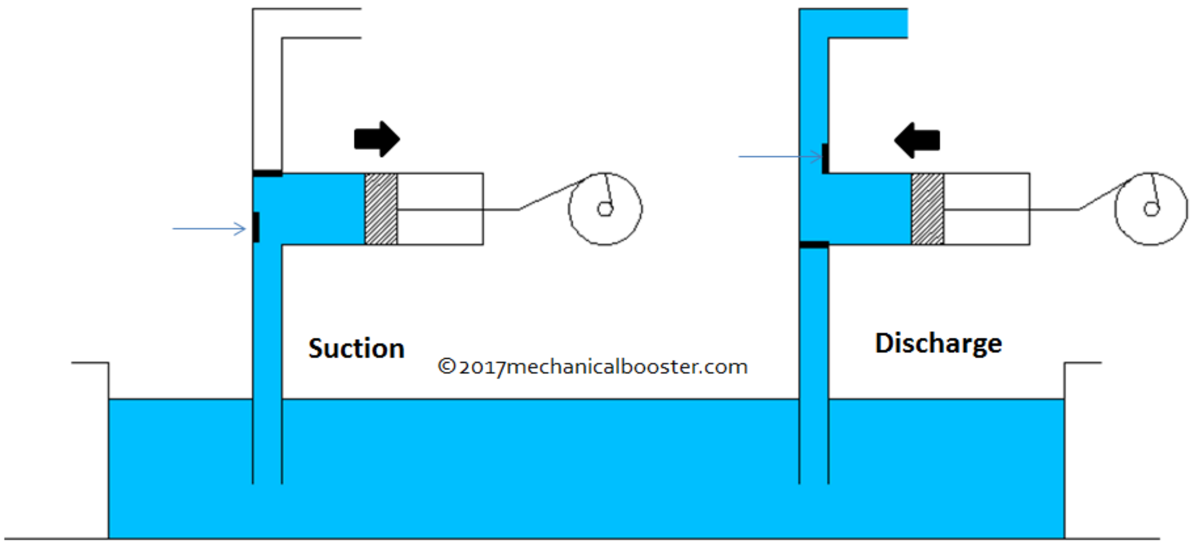
Applications of Reciprocating Pump:

The applications of Reciprocating Pump are as follows.

- Gas industries
- Petrochemical industries
- Oil refineries
- Vehicle water servicing centers etc.

Working

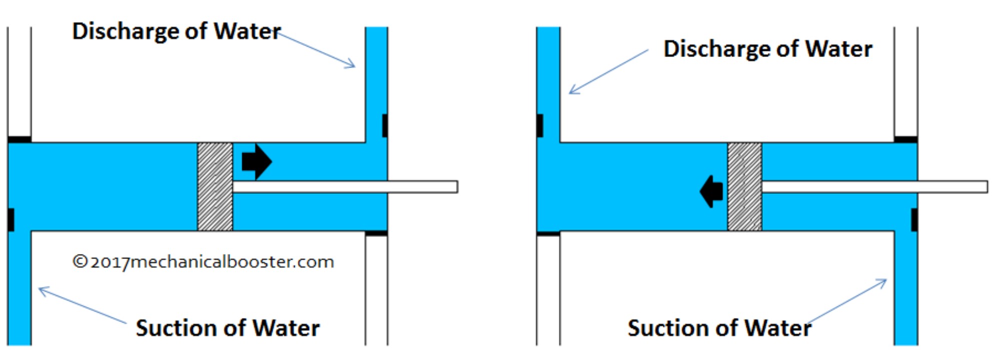
Single Acting Reciprocating pump



Single Acting Reciprocating Pump

During suction stroke, the piston moves backward and this opens the suction valve making the water enter into the cylinder. During suction the delivery valve remains closed and no water is discharged through it.
After suction stroke, the piston moves forward, delivery valve gets open and suction valve come into close position. As the piston moves forward it exerts thrust force on the liquid and it starts escaping out of the cylinder through delivery pipe. The water from the delivery pipes reaches to its required destination.

Double Acting Reciprocating Pump



Double Acting Reciprocating Pump

As the piston moves to the right hand side as shown in the fig above. The following process takes place at left and right side.

At left side:
The suction valve opens and delivery valve gets closed. The water from the water reservoir is sucked into the cylinder.

At right side:
The suction valve is gets closed and delivery valve gets open. the water sucked in the previous stroke is discharges out of the cylinder.

In the same way as the piston moves to left hand side, the discharge of the liquid takes place at left side and suction takes at the right side. And in each stroke of the piston, both suction and discharge of liquid takes place at the same time. If suction is taking place at right side than discharge takes place at left and vice-versa

Slip of pump

Slip in reciprocating pump is the measure of *difference between theoretical discharge and actual discharge*.

Slip = Qth - Qact

When actual discharge delivered by reciprocating pump is ***less*** then theoretical discharge then that difference is called as ***Positive Slip.***

Actual discharge becomes less than theoretical discharge due to leakages while operation.

And when actual discharge delivered by reciprocating pump is ***more*** then theoretical discharge then that difference is called as ***Negative Slip.***

7.3.2 Filters

A filter may be defined as a device for the removal of solids from a fluid wherein the resistance to motion of such solids is in a tortuous path.

Filter elements are rated in micron (238, 149, 74, 40, 20, 10) as absolute and nominal filtration. The 'absolute' rating indicates the size of the filter element pores through which the fluid must flow and gives the maximum size of the solid that can pass through the element.

As the filter element removes contaminating particles from the fluid, they build up on the surface. This reduces the size of the pores through which the fluid must flow. So the term 'nominal filtration' indicates the ability of the filter to remove about 98% of the solid particles from the fluid which are equal to or lesser than the absolute rating of the filter. Thus, a filter rated 60 microns absolute may have a nominal rating of 35 microns.

Filter provides a finer filtration than strainers and can be applied at several different places in the circuit.

The performance of the filter to obtain a required level of filtration is given by the parameter Beta ratio. This ratio is given by the following equation

$$\text{Beta ratio } \beta x = \frac{\text{Number of upstream particles (before filter) greater than } x\ \mu\text{m}}{\text{Number of downstream particles (after filter) greater than } x\ \mu\text{m}}$$

x is the selected particle size for the given filter. For example, a fluid has 7000 particles of size $10\mu m$ or greater passes through a filter. After the filter, if the fluid is found to have 140 particles, then the β_{10} ratio is 50 $\left(\text{i.e., } \frac{7000}{140}\right)$

The efficiency of contaminant removal from the fluid through the filter element is known as removal efficiency and is related to β -ratio

$$\text{Removal efficiency } \eta_x = \left(1 - \frac{1}{\beta_x}\right) \times 100$$

Hence, a filter having a β_{10} ratio equals to 2 will only stop 50% of particles of $10\mu m$ and greater; filter having a β_{10} ratio equals to 10 will stop 90% of particles of $10\mu m$ and greater. The higher the β -ratio, the more efficient is the filter element. The micron size at which $\beta_x = 75$ is generally considered to be an equivalent to the absolute rating of the filter.

7.3.3 Filter Media

There are several basic types of filter media. But the major classification is

1. Mechanical
2. Absorbent
3. Adsorbent

Woven wire cloth It consists of a finely woven wire cloth, made of stainless steel. It is a mechanical type filter media and is commonly used to remove the coarse insoluble particles.

Paper filter It is made of special cellulosic materials which are impregnated with a resin to provide greater strength. The popular type of constructions are as follows.

1. Folding sheets of paper into accordion like pleats.
2. Stacking cellulose discs with alternate spacers.

The paper media may be used as an extended area filter, where the particles removed depend on the amount of surface exposed and the porosity of the filter cake that is formed.

Woven media It is a cloth of yarn (natural or synthetic). 'Warp' is the yarn that runs through the length of a cloth; 'shoot' runs perpendicular to the warp and these two form a weave. Many types of weaves are available such as square, dutch, twill, dutch twill.

Sintered metal powders The metal powders are in granular form and they are joined to form a rigid porous structure. The grains can be joined by an adhesive or by sintering at temperature below the melting point. The degree of filtration depends on the compression and compactness of the grain chosen.

Ceramic and plastic media Plastic and ceramic materials can also be used, but a higher pressure drop is expected. The resistance to mechanical shock is low for ceramic, and the resistance to thermal shock is low for plastic.

12.9 LUBRICATOR

The function of the lubricator is to insert drops of oil into the air stream. A small amount of air from the mainstream is diverted through the bowl pressure control valve into the bowl or reservoir. This air pushes the oil through the siphon tube past the adjustment screw to the drip tube. The drops of oil are then transferred through the center of the variable orifice and enters the mist generator, mixing with the oil delivered by the drip tube. The air-oil mixture then rejoins the remaining air and continues toward its final destination.

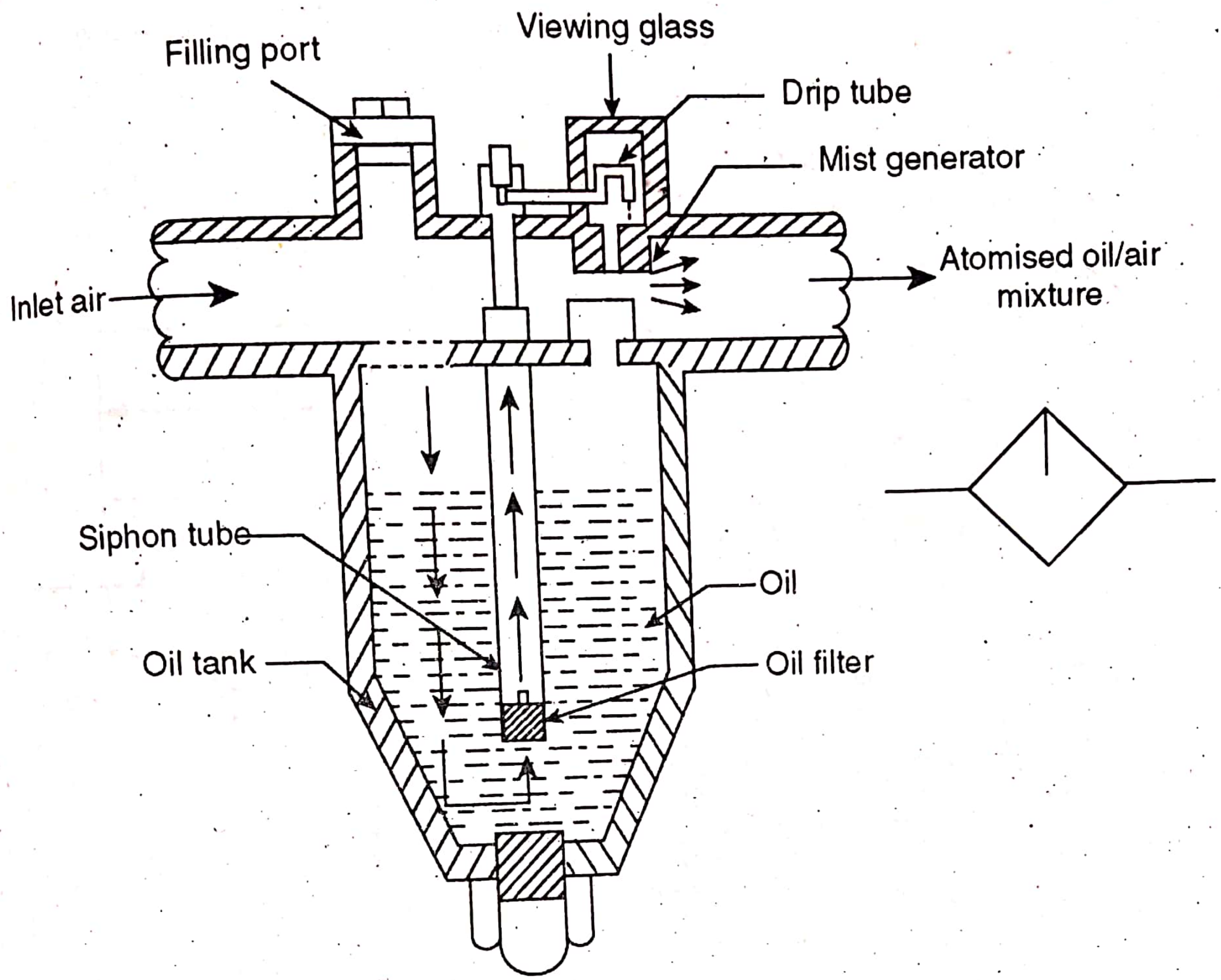


Figure 12.5 Lubricator

* ① Direction control valves (DCV).

DCV are one of the most fundamental parts of hydraulic and pneumatic systems. DCVs allow fluid flow (hydraulic oil, water or air) into different paths from one or more sources. DCVs will usually consist of a spool inside a cylinder which is mechanically or electrically actuated. The position of the spool restricts or permits flow thus it controls the fluid flow.

The purpose of DCV, is to stop fluid flow, allow fluid flow & change the direction of fluid flow. There are four method of actuation they are manual, mechanical, solenoid-operated and pilot-operated.

12.10 PNEUMATIC VALVES

To control pneumatic actuators, the air energy has to be regulated, controlled and reversed with a pre-determined sequence. These are done by pneumatic valves.

12.10.1 Direction Control Valves

Direction control valves are used to direct the flow of the pressurised fluid in the desired direction. The main functions of these valves are to start, stop and regulate the direction of air flow and to help in the distribution of air in the desired line. The different types of direction control valves are spool type, poppet type, seat type etc.

1. ***Two-way valve*** This is an on-off type of device. This valve is usually provided with two external flow ports, a supply port and an exhaust port. A normally open two-way valve permits flow in its normal or in its rest position and blocks flow when actuated. The normally closed valve blocks flow in its normal position and permits flow when actuated.

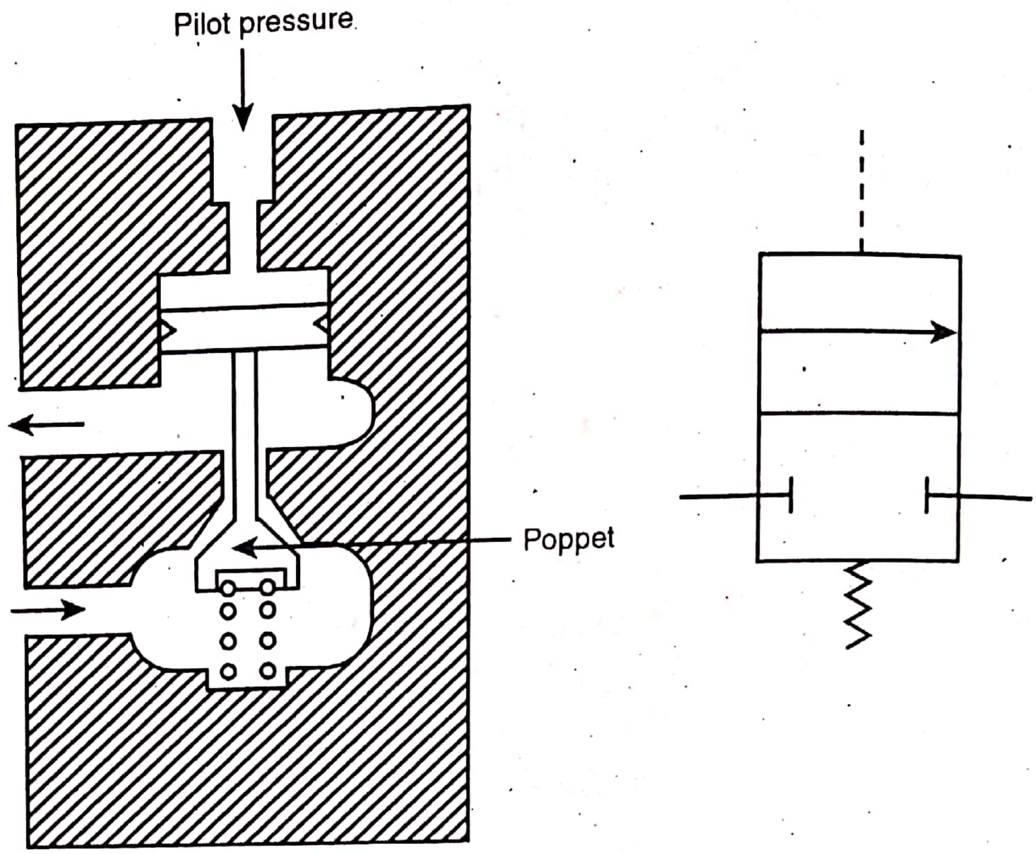


Figure 12.6 Two-way Direction Control Valve–Poppet Type

2. ***Three-way valve*** In this, one flow port is connected to either of the other two ports. It may be used alternatively to pressurise one port and exhaust the other port. These valves can be used as a pilot relay to operate the other valves. These valves may be used to control single acting cylinders or in pairs to control double acting cylinders.

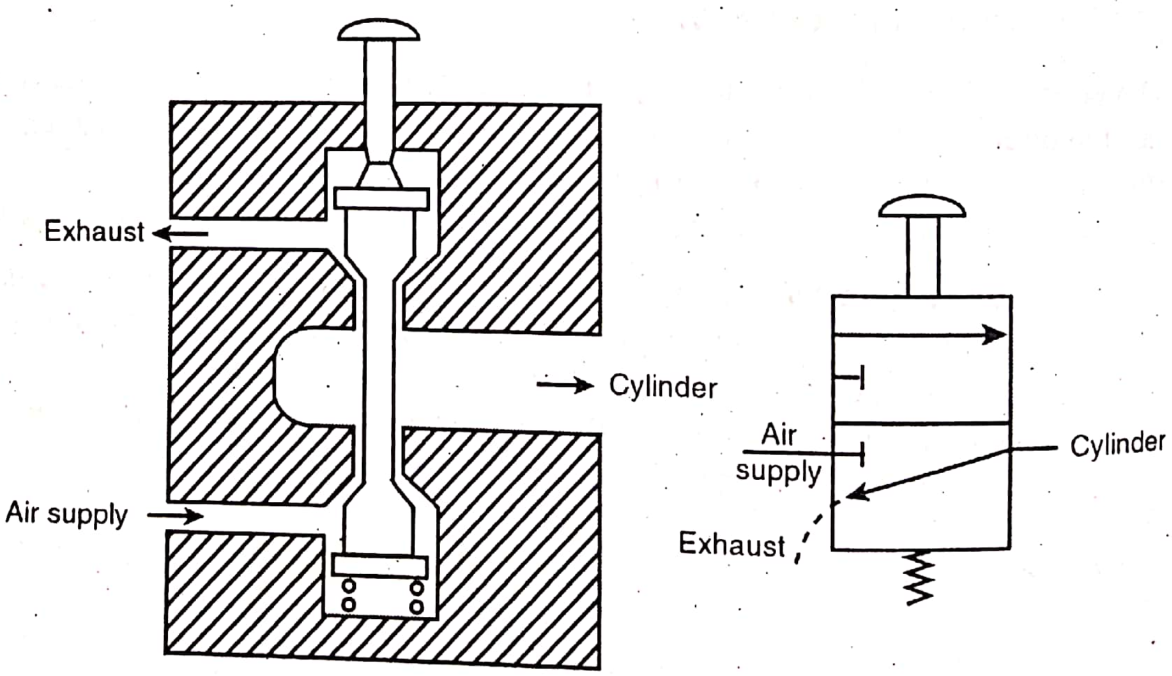
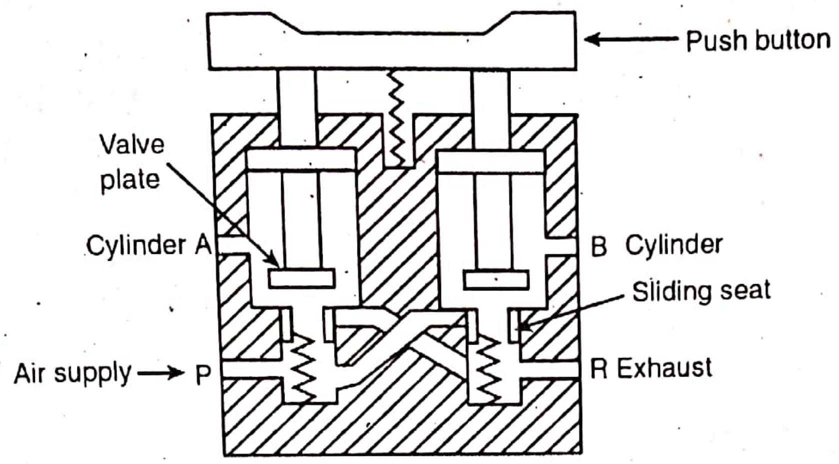


Figure 12.7 Three-way Direction Control Valve–Poppet Type

3. ***Four-way valve*** Four-way valves have two working ports, a supply port and an exhaust port. In one position the valve allows air to flow from the supply source to one of the working ports. Simultaneously air is allowed to flow from the other working port to the exhaust. When the valve is shifted, the flow paths are reversed.



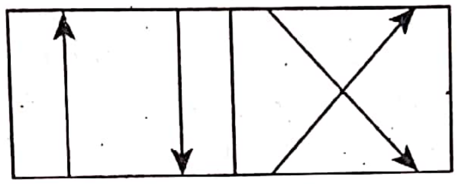


Figure 12.8 Four-way Direction Control Valve–seat Type

4. ***Five-way valve*** In certain designs of direction control valves, five ports are preferred instead of four ports. This permits the use of either dual supply or dual exhaust. A five port version provides the same basic control of flow paths as a four port version. In addition, dual supply ports permit the use of different pressures for the cylinder movement. Dual exhaust enables easy exhaustion of the valve.

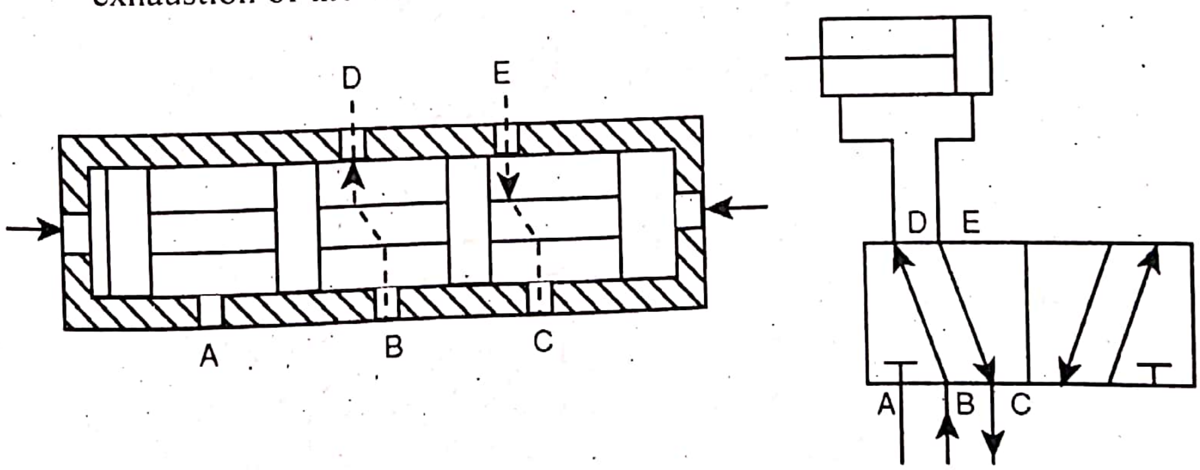


Figure 12.9 Five-way Direction Control Valve—Spool Type

12.10.2 Pneumatic Check Valve

A check valve shuts off against reverse flow and opens at a low cracking pressure in the forward direction. Metal body or light weight plastic body designs with suitable fittings are available.

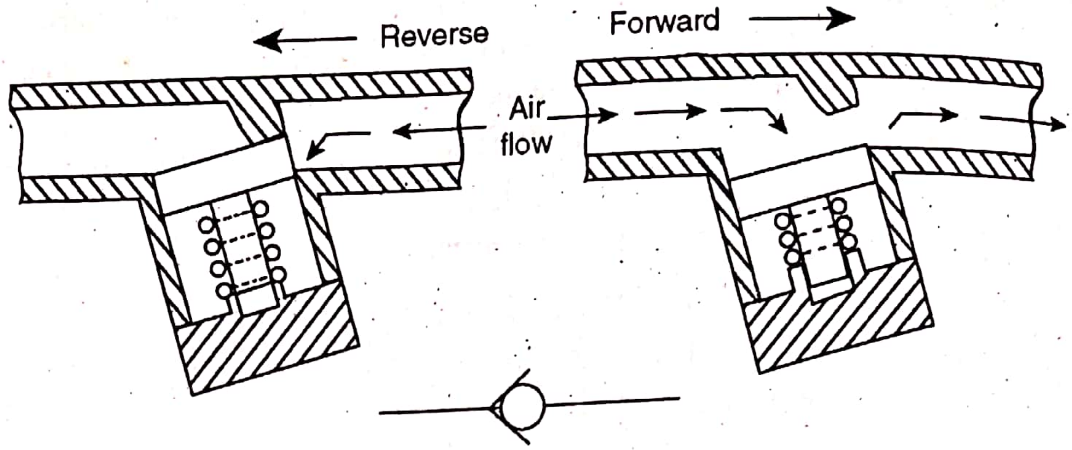


Figure 12.10 Pneumatic Check Valve

12.10.3 Flow Control Valve

A flow control valve is a metering valve and a check valve built into one housing. In one direction, the air flow is restricted as it flows through the metering valve; in the other direction, it flows freely through the check valve. The metering valve and check valve may be of several designs. One such design is shown in figure. The air flow through the metering orifice is controlled by a pointed needle. A ball and spring check valve is used, for free flow.

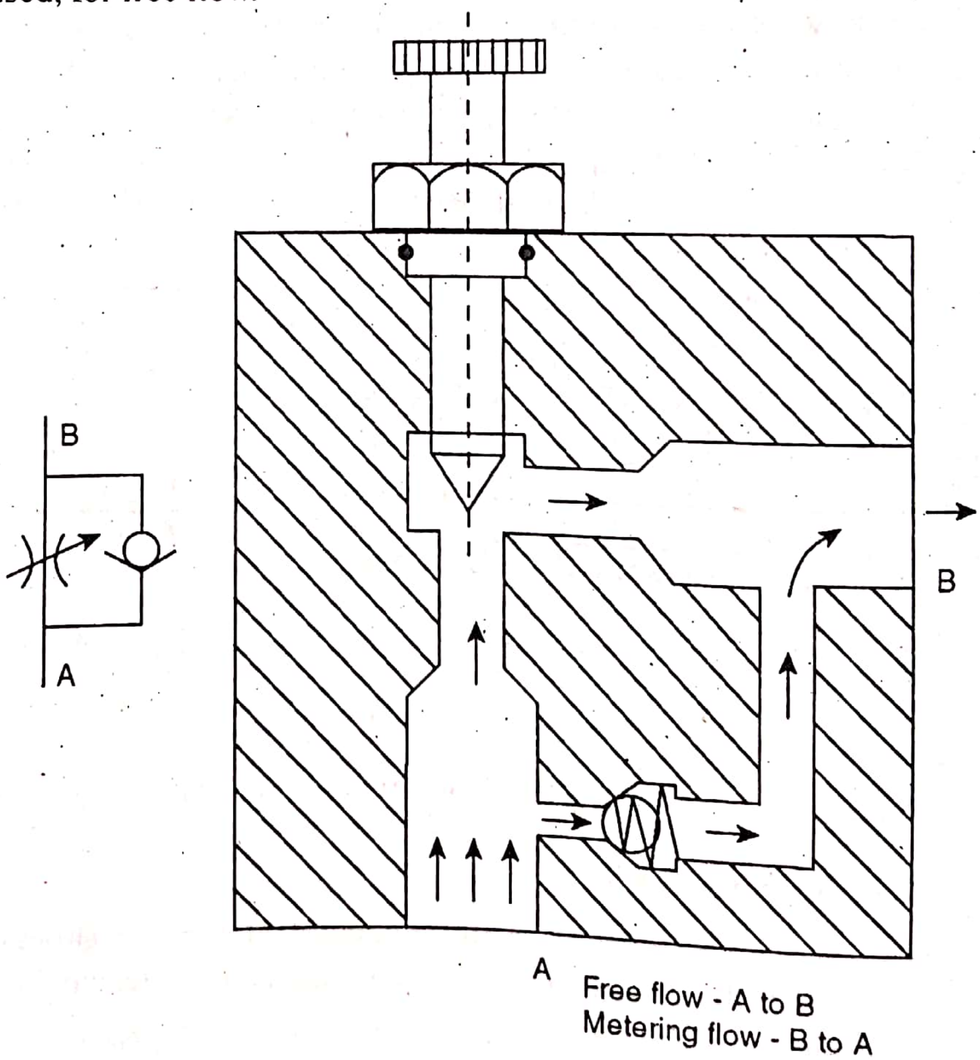


Figure 12.11 Flow Control Valve

15.1 Throttling Valve

The simplest form of a flow control valve is a throttling valve, shown in Fig. 15.2. A needle's tapered nose is used to throttle the flow by reducing the cross-sectional area of the flow path. Simple tapers tend to produce a parabolic flow curve, whereas complex tapers tend to give 35–45 % increased flow per turn of the adjusting screw (Pinches and Callear 1999:92). Throttling valves can be used as shut-off valves, but over-torquing may score the nose and seat.

In our lab we use this kind of valve when measuring the flow characteristics of pneumatic components with two ports according to ISO 6358, see Fig. 5.2. To achieve a smooth opening or closing of the valve for the measurements, we connect a small DC motor with gear box to the turning knob and select the motor's supply voltage such that it takes several minutes to open or close the valve.

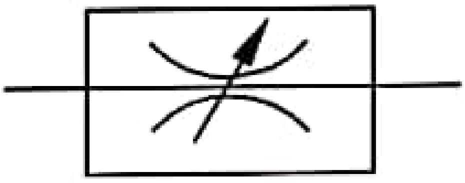


Fig. 15.1. Symbol of a throttling valve

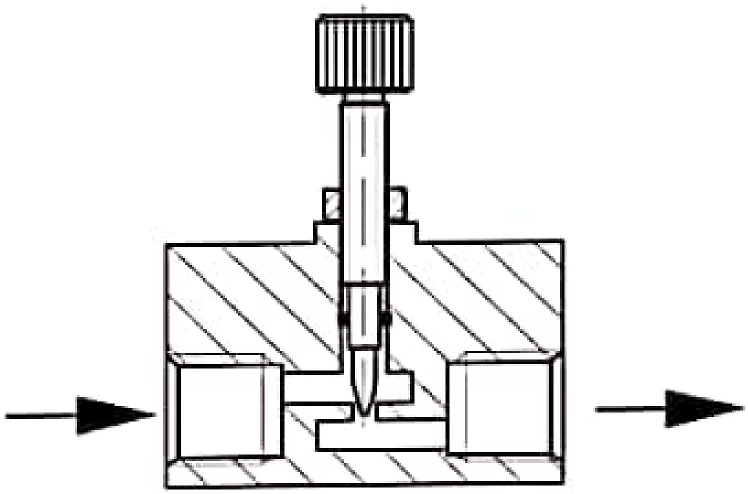


Fig. 15.2. Schematic view

5.3.1 Single Acting Cylinders

A single acting hydraulic cylinder is designed to apply force in only one direction.

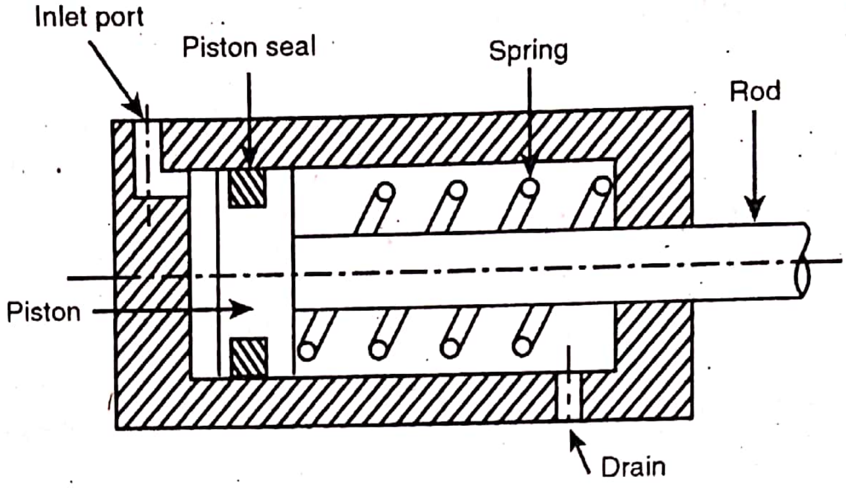


Figure 5.10 Single Acting Cylinder

It consists of a piston inside a cylindrical housing called a barrel. Attached to one end of the piston is a rod which extends outside. At the other end (blank end) is a port for the entrance and the exit of oil. A single acting cylinder can exert a force only in the extending direction, as fluid from the pump enters through the blank end of the cylinder. Single acting cylinders do not hydraulically retract. Retraction is accomplished by using gravity or by the inclusion of a compression spring at the rod end.

5.3.2 Double Acting Cylinders

A double acting cylinder is capable of delivering forces in both directions. The barrel is made of seamless steel tubing, honed to a fine finish on the inside surface. The piston which is made of ductile iron contains U cup packings to seal the leakage between the piston and the barrel. The ports are located in the end caps which are secured to the barrel by tie rods. The load of the piston rod at the neck is taken by a rod bearing, which is generally made of brass or bronze. A rod wiper is provided at the end of the neck to prevent foreign particles and dust from entering into the cylinder along with the piston rod.

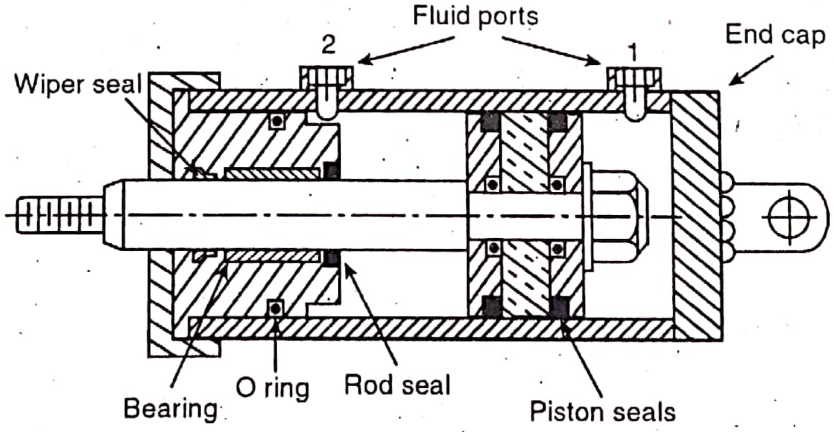


Figure 5.11 Double Acting Cylinder

When the fluid from the pump enters the cylinder through port 1, the piston moves forward and the fluid returns to the reservoir from the cylinder through port 2. During the return stroke the fluid is allowed to enter the cylinder through port 2 and fluid from the other side of the piston goes back to the reservoir through port 1.

cushioning As long as the piston is moving in the middle range of the

12.11 PNEUMATIC ACTUATORS

Pneumatic systems make use of actuators (linear and rotary) in a fashion similar to that of hydraulic systems. But these differ very little from the hydraulic applications because air is used rather than hydraulic oil; pressures are either low or medium and a lighter construction is encountered. Pneumatic cylinder construction makes extensive use of aluminum and other non-ferrous alloy materials to reduce the weight and the corrosive effects of air and to improve heat transfer capabilities.

12.11.1 Pneumatic Cylinders

The pneumatic power is converted into straight-line reciprocating motions by pneumatic cylinders. The various industrial applications for which air cylinders are used can be divided duty-wise into three groups: light duty, medium duty and heavy duty.

According to the operating principle, air cylinders can be classified as follows.

Single acting cylinder It has a single air inlet line. When this line is pressurised, the piston extends. The return movement of the piston is affected by a built-in spring mounted on the rod side of the piston or by application of an external force like gravity. Single acting cylinders with a return spring are limited in stroke, because the spring force that must be overcome while extending increases with the stroke.

The advantage of a single acting cylinder lies in its reduced air consumption, since air is not wasted while retracting the piston.

Double acting cylinder The force exerted by the compressed air moves the piston in two directions in a double acting cylinder. The double acting cylinder.produces less force during retraction, because the piston rod's cross-sectional area is subtracted from the piston area under pressure.

They are used particularly when the piston is required to perform work not only on the advance movement but also on the return movement. In principle, the stroke length is unlimited, although buckling and bending must be considered before we select a particular size of piston diameter, rod length and stroke length.

Advantages of a double acting cylinder over a single acting cylinder.

1. In a single acting cylinder, the compressed air is fed only on one side. Hence, this cylinder can produce work only in one direction. But the compressed air moves the piston in two directions in a double acting cylinder, so they work in both directions.

2. In a single acting cylinder, the stroke is limited by the compressed length of the spring. But in principle, the stroke length is unlimited in a double acting cylinder.
3. While the piston moves forward in a single acting cylinder, the air has to overcome the pressure of the spring and hence some power is lost before the actual stroke of the piston starts. But this problem is not present in a double acting cylinder.

1.7 Basic Components of a Hydraulic System

Hydraulic systems are power-transmitting assemblies employing pressurized liquid as a fluid for transmitting energy from an energy-generating source to an energy-using point to accomplish useful work. Figure 1.1 shows a simple circuit of a hydraulic system with basic components.

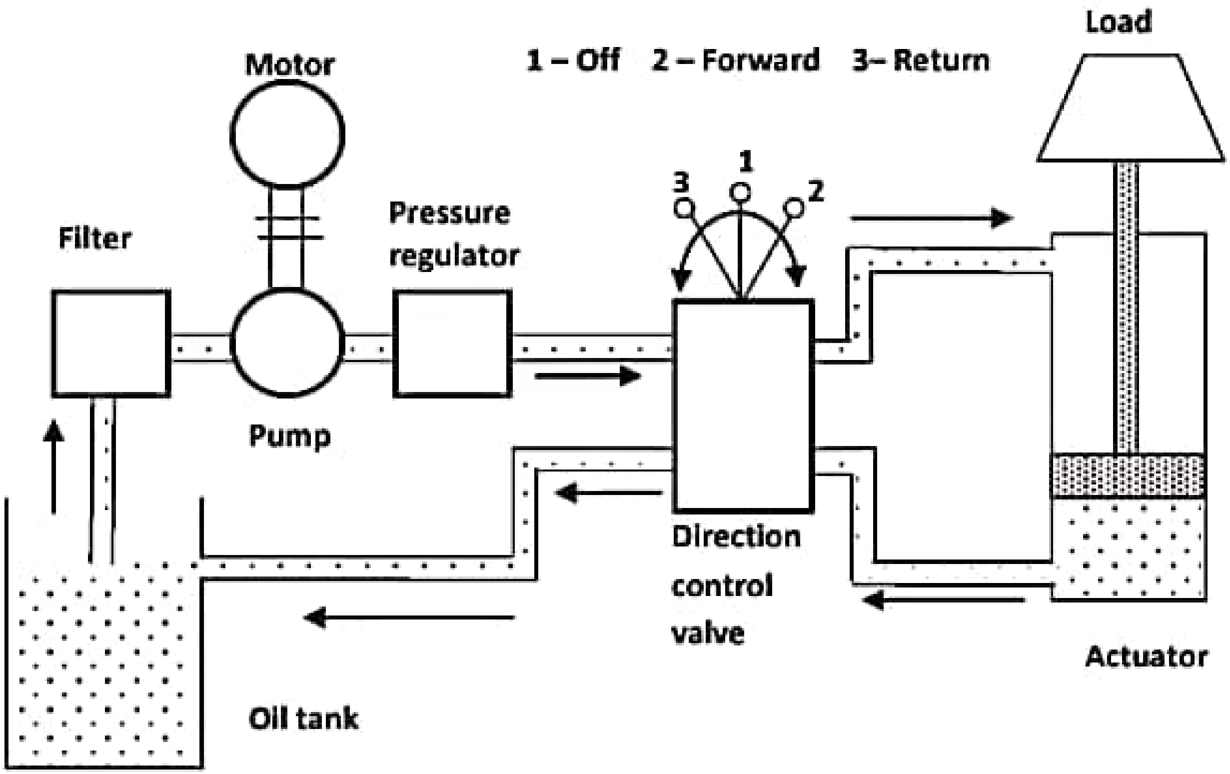


Figure 1.1 Components of a hydraulic system

Functions of the components shown in Fig. 1.1 are as follows:

1. The hydraulic actuator is a device used to convert the fluid power into mechanical power to do useful work. The actuator may be of the linear type (e.g., hydraulic cylinder) or rotary type(e.g., hydraulic motor) to provide linear or rotary motion, respectively.
2. The hydraulic pump is used to force the fluid from the reservoir to rest of the hydraulic circuit by converting mechanical energy into hydraulic energy.
3. Valves are used to control the direction, pressure and flow rate of a fluid flowing through the circuit.

4. External power supply (motor) is required to drive the pump.
5. Reservoir is used to hold the hydraulic liquid, usually hydraulic oil.
6. Piping system carries the hydraulic oil from one place to another.
7. Filters are used to remove any foreign particles so as keep the fluid system clean and efficient, as well as avoid damage to the actuator and valves.
8. Pressure regulator regulates (i.e., maintains) the required level of pressure in the hydraulic fluid.

The piping shown in Fig. 1.1 is of closed-loop type with fluid transferred from the storage tank to one side of the piston and returned back from the other side of the piston to the tank. Fluid is drawn from the tank by a pump that produces fluid flow at the required level of pressure. If the fluid pressure exceeds the required level, then the excess fluid returns back to the reservoir and remains there until the pressure acquires the required level.

Cylinder movement is controlled by a three-position change over a control valve.

1. When the piston of the valve is changed to upper position, the pipe pressure line is connected to port A and thus the load is raised.

2. When the position of the valve is changed to lower position, the pipe pressure line is connected to port B and thus the load is lowered.

3. When the valve is at center position, it locks the fluid into the cylinder(thereby holding it in position) and dead-ends the fluid line (causing all the pump output fluid to return to tank via the pressure relief).

In industry, a machine designer conveys the design of hydraulic systems using a circuit diagram. Figure 1.2 shows the components of the hydraulic system using symbols. The working fluid, which is the hydraulic oil, is stored in a reservoir. When the electric motor is switched ON, it runs a positive displacement pump that draws hydraulic oil through a filter and delivers at high pressure. The pressurized oil passes through the regulating valve and does work on actuator. Oil from the other end of the actuator goes back to the tank via return line. To and fro motion of the cylinder is controlled using directional control valve.

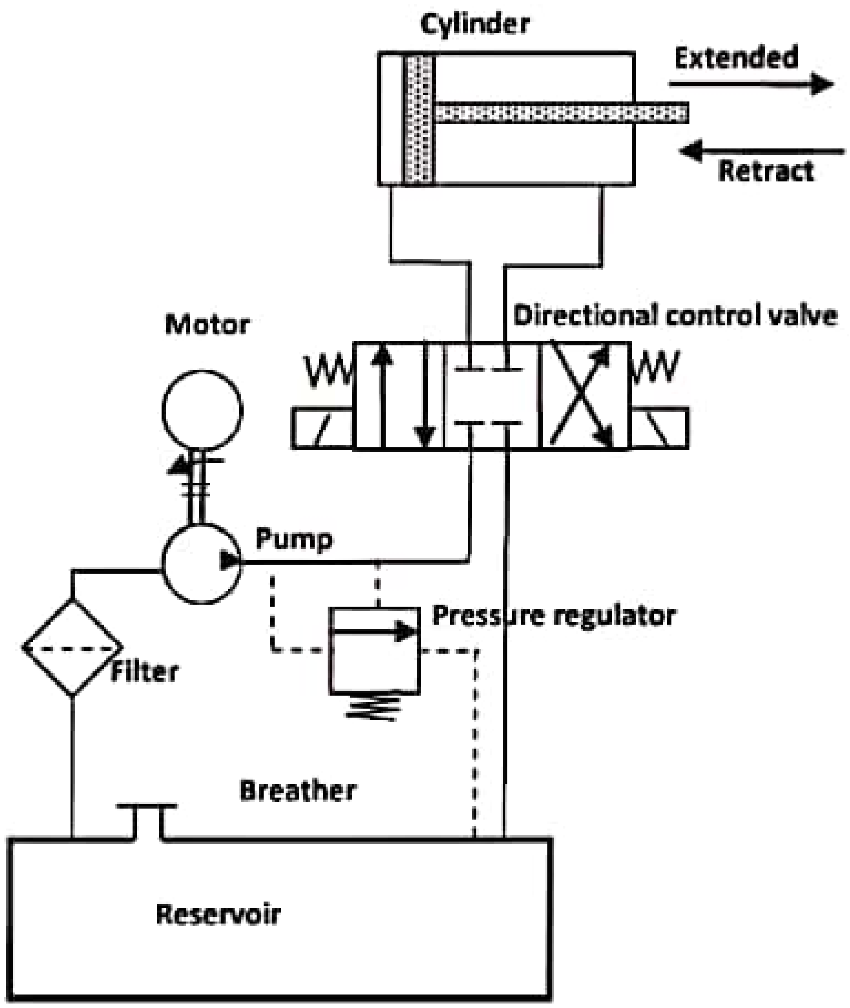


Figure 1.2 Components of a hydraulic system (shown using symbols).

The hydraulic system discussed above can be broken down into four main divisions that are analogous to the four main divisions in an electrical system.

1. The power device parallels the electrical generating station.

2. The control valves parallel the switches, resistors, timers, pressure switches, relays, etc.

3. The lines in which the fluid power flows parallel the electrical lines.

4. The fluid power motor (whether it is a rotating or a non rotating cylinder or a fluid power motor) parallels the solenoids and electrical motors.

* Hydraulic system Advantages/Merit :-

1. Easy to control.

2. Simpler to Maintain.

3. It can deliver constant torque

4. Large amount of power can transmitted.

5. Easy to repair

* Hydraulic system Disadvantages/Demerit :-

1. Leakage of hydraulic fluid will create environmental problem.

2. Contaminants present in the hydraulic fluid will damage system. So it require continuous filtration.

3. Wrong selection of hydraulic fluid for a system will damage the components.

4.5 GEAR PUMPS

4.5.1 External Gear Pumps

These pumps have two mating gears in a closely fitted housing. One of the gear is connected to a drive shaft connected to the prime mover. The second one, the follower gear is driven as it meshes with the driver gear.

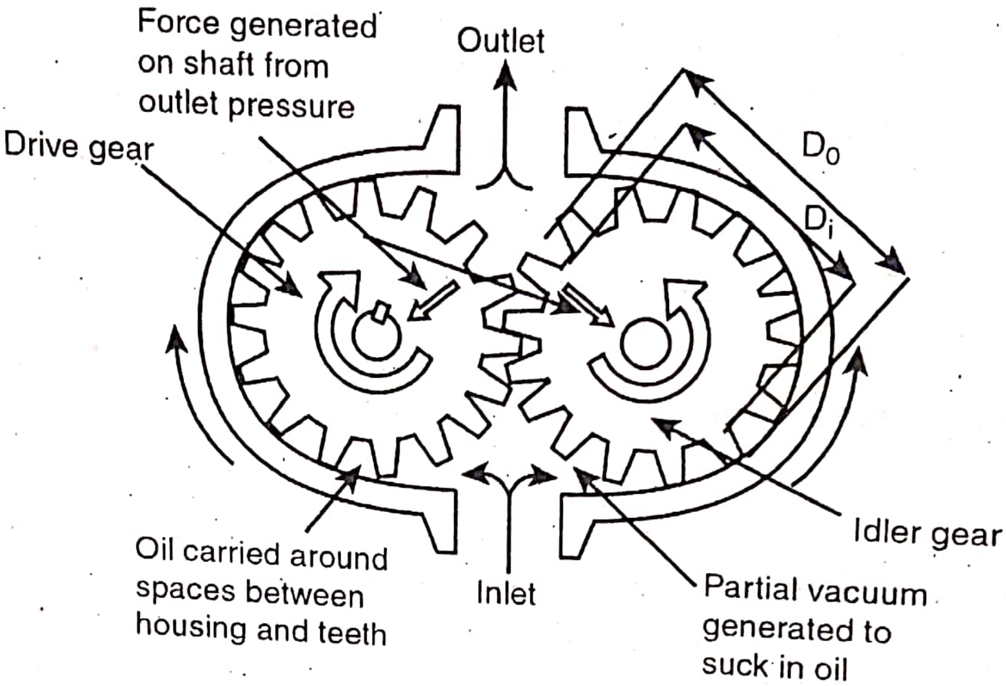


Figure 4.3 External Gear Pump

When the pump is first started, rotation of the gear forces air out of the casing into the discharge pipe. In the suction side where teeth come out of mesh, volume expands bringing out a reduction in pressure below atmospheric i.e., a partial vacuum. So the fluid from the reservoir is forced by atmospheric pressure into the pump inlet. In the discharge side, teeth go into mesh and the volume decreases between the mating teeth. Since the pump has a positive internal seal against leakage, the oil is positively ejected into the outlet port.

The theoretical discharge is given by the following formulae:

i) Theoretical discharge

$$Q_T = 2\pi b m^2 N\left[z + \left(1 + \frac{\pi^2 \cos\alpha}{12}\right)\right] \text{ m}^3/\text{min} \tag{4.1}$$

where

b - width of gear in m

m - module of gear

z - number of teeth in driver or driven gear

α - pressure angle of the gear

N - rpm of pump

ii) Theoretical discharge $Q_T = \frac{\pi}{4}(D_o^2 - D_i^2)\,bN$ m³ / min (4.2)

where

D_o - outside diameter of gear teeth in m

D_i - inside diameter of gear teeth in m

b - width of the gear in m

N - rpm of pump

$D_i = D_o - 2$ (addendum + dedendum)

4.5.2 Internal Gear Pumps

This design consists of two gears; one is an external gear, the other an internal gear. A crescent placed inbetween acts to ensure a seal between suction and discharge.

As the pump operates, the external gear drives the internal gear and both gears rotate in the same direction.

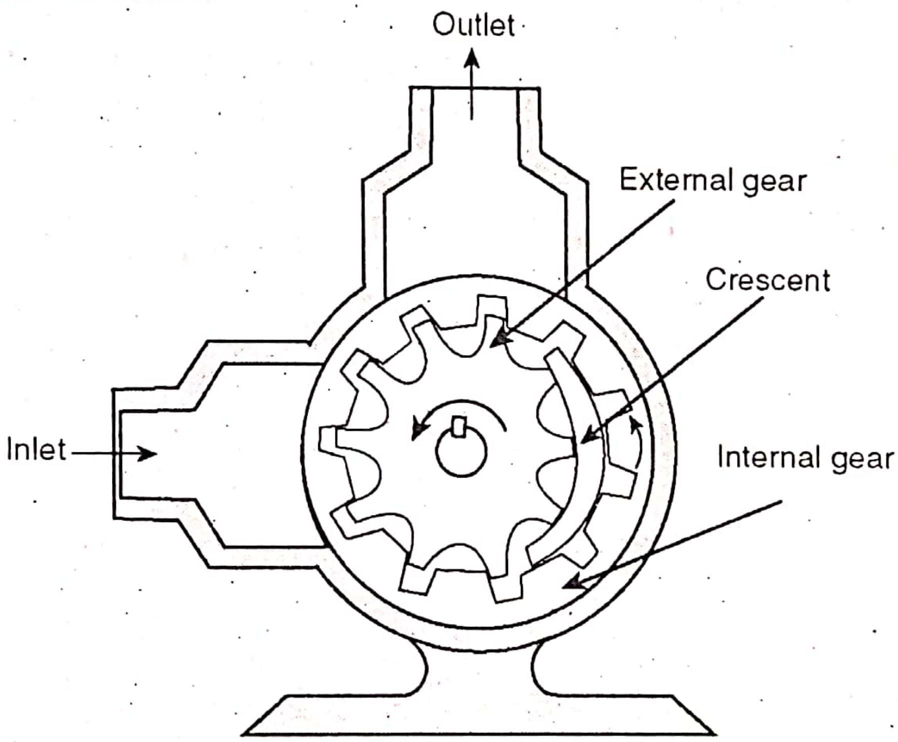


Figure 4.4 Internal Gear Pump

As the external gear turning in a counterclockwise direction moves past the intake. the teeth of the external gear are withdrawn from the internal gear teeth. This action produces a vaccum in the inlet and fluid flows into it to fill the spaces between the teeth. As the rotor continues to turn, fluid is trapped between the teeth, crescent and casing. From here the oil is carried around and forced out into the outlet by the external gear teeth meshing with the internal gear.

4.6 VANE PUMPS

4.6.1 Unbalanced Vane Pump

The pump consists of a rotor which contains radial slots splined to the drive shaft. The rotor rotates inside a 'Cam ring'. Each slot contains a vane which is free to slide in or out of the slots in the pump rotor. The vane is designed to mate with the surface of the cam ring as the rotor turns. The cam ring axis is offset to the drive shaft axis.

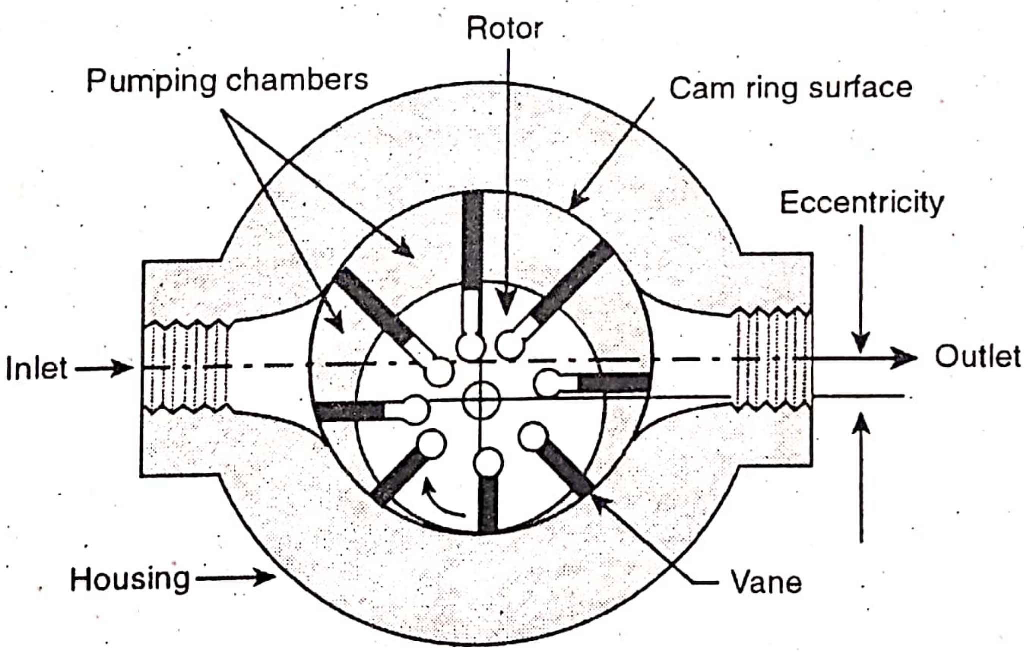


Figure 4.8 Unbalanced Vane Pump

As the rotor rotates, the centrifugal force pushes the vanes out against the surface of the cam ring. The vanes divide the space between the rotor and the cam ring into a series of small chambers. During the first half of rotor rotation, the volume of these chambers increase, thereby causing a reduction of pressure. This is the suction process which causes the fluid to flow through the inlet port and fill the void. As the rotor rotates through the second half, the cam ring pushes the vanes back into their slots and the trapped volume is reduced. This positively ejects the trapped fluid through the outlet port.

In this pump, all the pumping action takes place in the chambers located on one side of the rotor and shaft. So the pump is of an unbalanced design.

Maximum possible eccentricity $= (D_C - D_R) / 2 = e_{max}$

Maximum volumetric displacement $= (\pi/4)\ (D_C^2 - D_R^2)\ L$

$= (\pi/4)\ (D_C + D_R)\ (D_C - D_R)\ L$

$= (\pi/4) \cdot (D_C + D_R)\ 2\ e_{max}\ L$

Theoretical Discharge Q_T $= (\pi/4)\ (D_C + D_R)\ 2\ e_{max} \cdot L\ N\ \text{m}^3/\text{min}$ (4.3)

where

D_C - diameter of the cam ring in m

D_R - diameter of the rotor in m

L - width of the rotor in m

N - rotor speed in rpm

e - eccentricity in m

The delivery rate of the pump depends upon the degree of offset of the rotor with respect to the cam ring.

Some vane pumps have provisions for mechanically varying the eccentricity. By varying the eccentricity, the pump delivery is varied. This is called 'Variable delivery pump'.

4.6.3 Balanced Vane Pump

In balanced vane pump, the rotor rotates inside a cam ring of elliptical shape. It has two inlet and outlet ports which are diametrically opposite each other. Movement of the vanes in and out causes the chamber between them to increase and decrease. When these chambers are increasing in size, the fluid is being sucked into the pump through the inlet ports. The two inlet ports are connected to a common inlet passage. When the chambers are decreasing in size, the fluid starts being delivered into the system through the outlet ports which are connected to a common outlet passage.

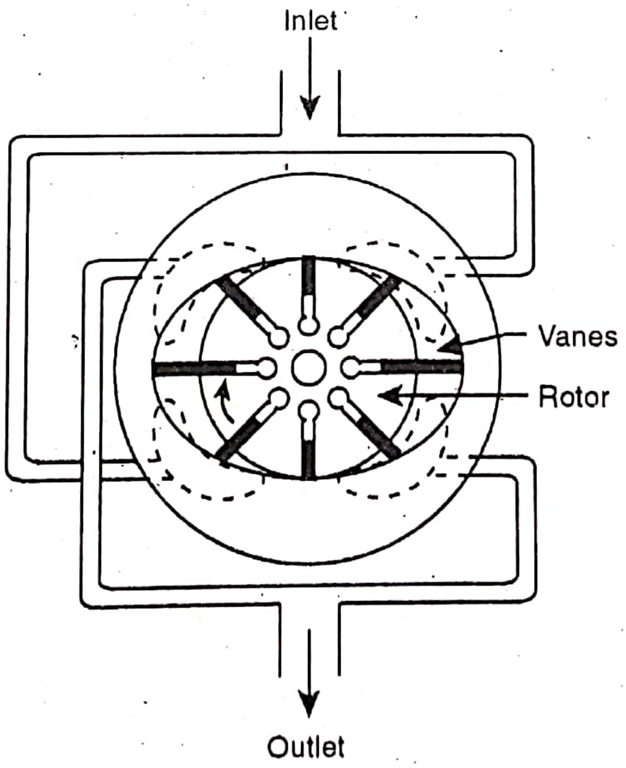


Figure 4.10 Balanced Vane Pump

Because the pressure ports are opposite to each other, a complete hydraulic balance can be achieved. One disadvantage of a balanced vane pump is that it cannot be designed as a variable displacement pump.

4.7.3 Radial Piston Pump

The radial piston pump has a number of radial pistons in a cylinder block which revolves around a stationary pintle or valve. The pistons remain in contact with the reaction ring due to centrifugal force and back pressure on the pistons. A drive shaft is attached to the end of cylinder block and provides the power needed to the pump. The reaction ring is moved eccentrically with respect to the pintle axis.

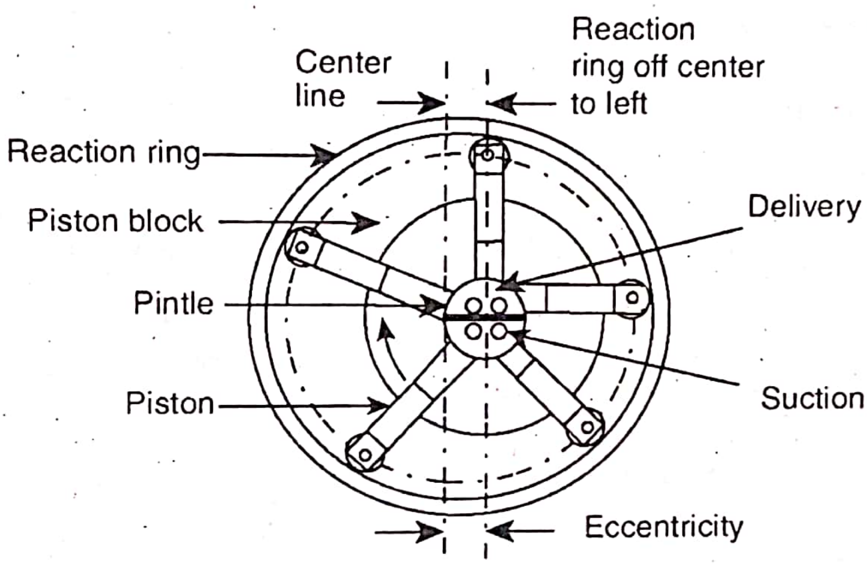


Figure 4.13 Radial Piston Pump

If the cylinder block is rotated in a clockwise direction, the pistons on one side travel outward and sucks the fluid when it passes the suction port of the pintle. When the piston passes the maximum point eccentricity, it is forced inward by the reaction ring. This forces the fluid to enter into the discharge port. The displacement can be varied by moving the reaction ring to change the piston stroke.

Theoretical discharge $Q_T = 0.5\, e\, Y \pi\, D^2 N$ m^3/min (4.6)

e - Eccentricity in m

Y - Number of pistons

D - diameter of piston in m

N - rpm

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* Hydraulic Actuators.

The hydraulic Actuators converts the pressure energy of the fluid into mechanical energy. There are three basic types of Hydraulic Actuators.

1. Rotary Motion - Hydraulic Motor.
   (continous rotation).

2. Rotary Motion - semirotary actuator.
   (limited angle of Movement)

3. Linear Motion - Hydraulic cylinder.

1. Rotary Motion (continous Rotation)
   Hydraulic Motor :—

In hydraulic Motor fluid forces the motor to create a rotary Motion. This rotary motion of the motor develop torque & produce continuous rotary motio. Therefore, Hydraulic motor converts hydraulic energy into mechanical energy.

The types of hydraulic motors are:

(i) Gear type motor.
(ii) Vane type motor.
(iii) piston type motor.

2. Rotary Motion (Semirotary Actuator) (limited Angle of Movement):-

These are used to convert fluid pressure energy into torque which turns through an angle limited by the design of the actuator.

These are two types are as follow:-

(i) Vane type actuators.

(ii) piston type actuators.

3. Linear Motion (Hydraulic Cylinder):

A hydraulic cylinder is a device which converts fluid power into linear Mechanical force & motion. It usually consists of a movable element, a piston & a piston rod operating within a cylindrical bore.

The types of hydraulic cylinders are

(i) Single Acting cylinder.

(ii) Double Acting cylinder.

(iii) Telescoping cylinder.

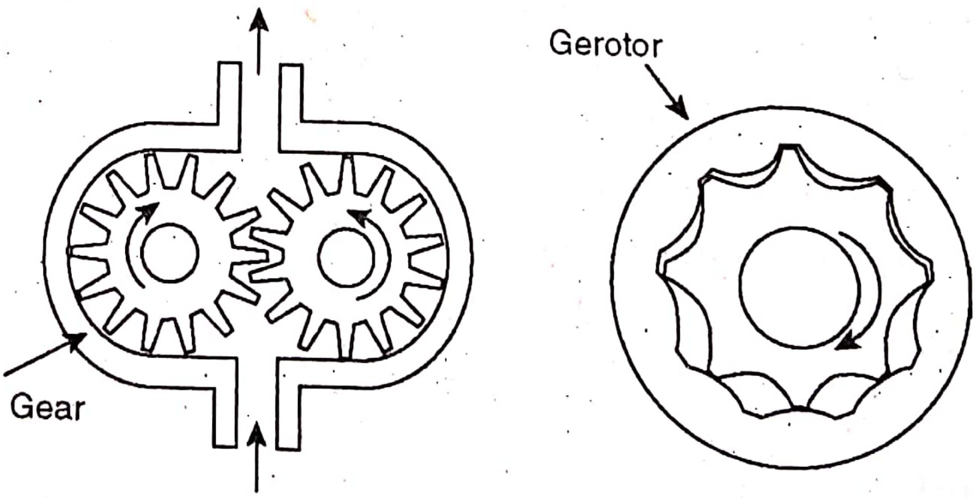
5.1.1 Gear Type Motors

A gear motor consists basically of a housing with inlet and outlet ports, and a pair of meshing external gears. One gear is attached to a shaft that is connected to the load. The other gear is the driver gear. The gear motor develops an output torque at its shaft by allowing hydraulic pressure to act on gear teeth. So the torque produced depends on the size of the teeth and pressure. The larger the gear tooth or higher the pressure, more torque is produced.

Gear motors are used when relatively high speed and low torque are needed, such as fan drives, compressor drives etc.

Gerotor motor is a popular type of internal gear motor. It consists of an inner drive gear and an outer gear. The inner gear is attached to a shaft which is connected to a load. Fluid entering the motor is separated from the fluid exiting the motor by means of a plate with a kidney-shaped inlet and outlet ports. Fluid pressure acting on the unequally exposed teeth results in a torque at the motor speed. The larger the gear or higher the pressure, more torque will be developed at the shaft.

The performance of gerotor motors are much better than gear motors at lower speed range and thus they are more suitable for low speed applications. Due to compactness, these motors are very popular in mobile equipments, especially agricultural machines like harvesters, movers etc.



(a) External Gear Type

(b) Gerotor Type

Figure 5.1 Gear Type Motors

5.1.2 Vane Type Motors

The vane motors are similar in construction to the balanced vane pumps except that the vanes must be held tightly against the contour of the cam ring.

This is generally done with springs applied underneath the vanes to hold them against the surface of the cam ring. The vane motor develops an output torque at its shaft by allowing hydraulic pressure to act on vanes which are extended. The larger the exposed area of the vanes or higher the pressure, more torque will be developed at the shaft. They are generally considered to be low-to-medium torque motors.

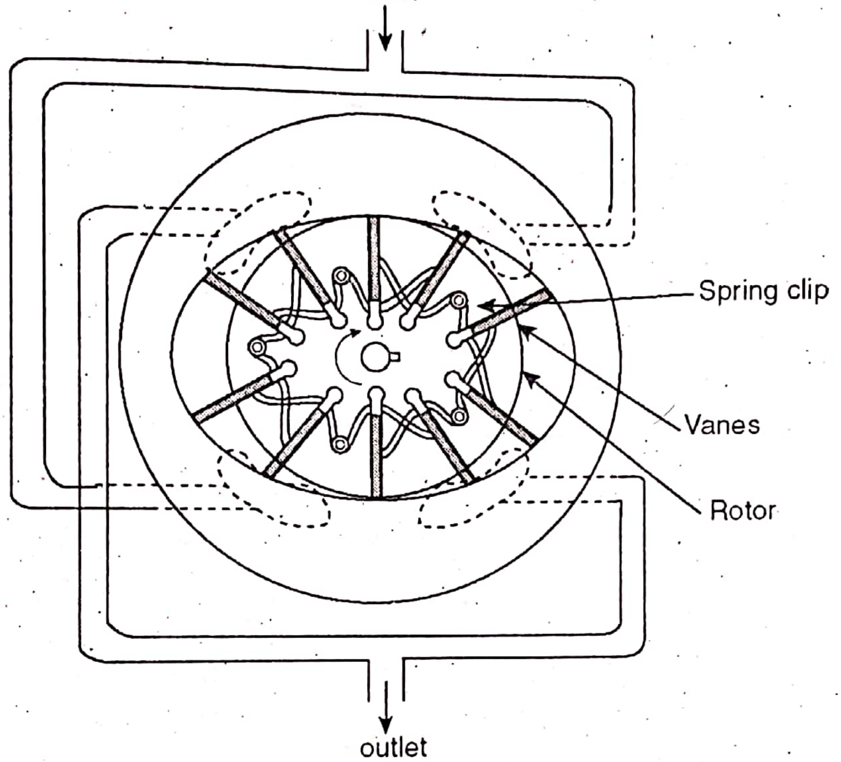


Figure 5.2 Balanced Vane Type Motor

5.1.3 Piston Type Motors

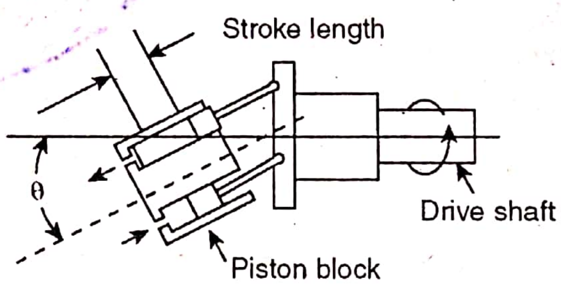
Piston motor develops an output torque at its shaft by allowing hydraulic pressure to act on pistons. Piston designs may be either axial piston type or radial piston type.

Axial piston motors

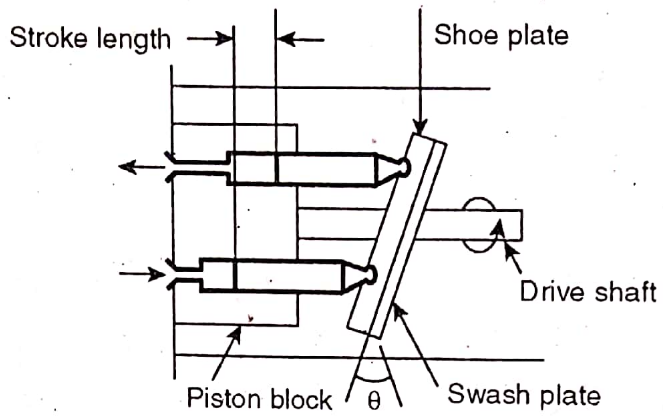
Axial piston motors are of two categories:

1. Swash plate or Bent-axis type
2. Cam lobe opposed ball type

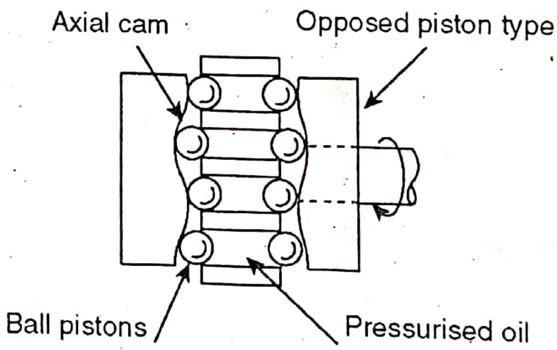
I. The swash plate type motor consists of a port plate, cylinder barrel, pistons, shoe plate, swash plate and a shaft. The arrangement is similar to a swash plate type pump. When fluid pressure acts on a piston, a force is developed which pushes the piston out and causes the piston shoe to slide across the swash plate surface. As the piston shoe slides, it develops a torque attached to the barrel.



(a) Bent-axis type



(b) Swash Plate Type



(c) Cam Lobe Ball Type

Figure 5.3 Axial Piston Motors

The amount of torque depends on the angle of slide caused by the swash plate and the pressure in the system. Since the swash plate angle controls the stroke in pistons of an axial piston motor, changing the angle will alter the stroke and motor displacement.

The operating principle of a bent-axis motor is similar to swash plate type. The angle of the cylinder block assembly with respect to drive shaft determines the stroke or motor displacement. Both these motors are used in high speed application only.

2. The cam lobe opposed ball type consists of a double cam arrangement and a piston block containing a number of cylinders, each with a pair of opposing ball pistons. The pistons are borne on cam plates. Distributor plates feed pressure fluid to the cylinders forcing out the pistons against the cam tracks. The tangential component of the reaction force causes the cylinder block to rotate. The used fluid is returned through another set of distributor plates as the pistons are pushed back by the cam plates.

These motors are extensively used for direct drive in mobile applications and can be directly mounted on wheel rims or sprockets for crawler chains.

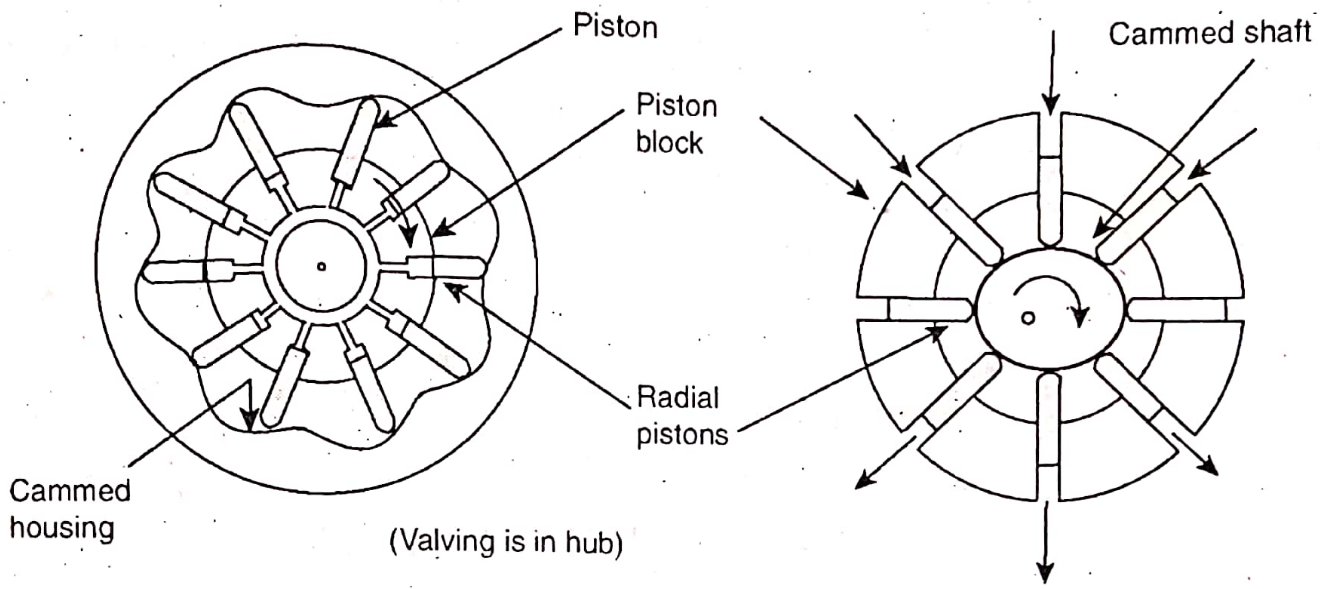
Radial piston motors

Radial piston motors can be broadly classified as:

(i) Eccentric cam shaft type

(ii) Multi lobe cam type

In eccentric cam shaft type, a number of large bore pistons are arranged radially round a shaft which has an equally large eccentric cam. The pressure on the piston produces thrust on the eccentric causing the rotation of the shaft.



(a) Multi Lobe Cam Type

(b) Eccentric Cam Shaft Type

Figure 5.4 Radial Piston Motors

The multi lobe cam motor comprises of a centre-rotating piston assembly and a fixed outer cam ring with eight lobes. A central valve distributes pressurised fluid to the cylinder which are forced outwards on to the cam. As they follow the cam profile, the piston block rotates driving the output shaft.

The radial piston motors are generally used as low speed high torque motors. They are used in heavy-duty applications such as crane hoisting, rolling mills, road rollers etc.

5.2 SEMI-ROTARY ACTUATORS

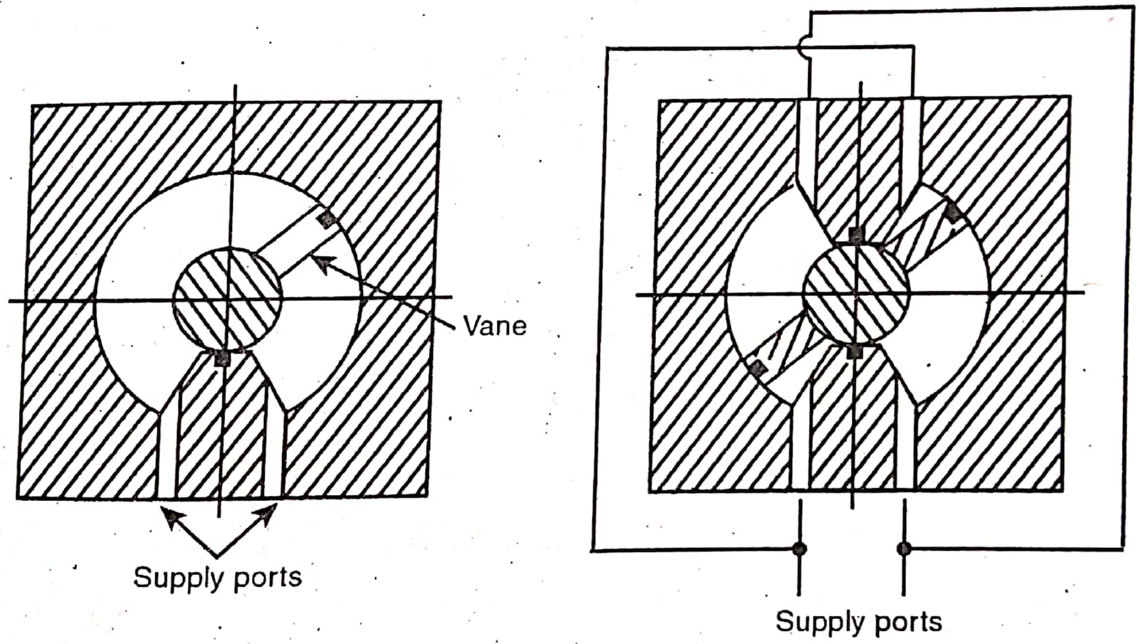
These are used to convert fluid pressure energy into torque which turns through an angle limited by the design of the actuator. With the majority of designs, the angle of rotation is within 360° although it is possible to considerably exceed this when using piston operated actuators.

5.2.1 Vane Type Actuators

A vane type semi-rotary actuator consists of one or two vanes connected to an output shaft which rotates when hydraulic pressure is applied to one side of the vanes. A single vane is limited to 280° rotation and a double vane unit to approximately 100°. Power in a two vane design is doubled.

There will always be some internal fluid leakage across the vanes and this increases with the operating pressure as the viscosity of the working fluid decreases. This causes problems where a smooth speed control of the rotary motion is required. So, for the applications of vane type actuators, the manufacturer's recommendations regarding the operating pressure and type of fluid must be followed.

The maximum torque obtainable from the currently available single vane unit is approximately 40×10^3 Nm and for double vane unit is 80×10^3 Nm.



a) Single Vane b) Two Vanes

Figure 5.5 Vane Type Semi-rotary Actuators

5.2.2 Piston Type Semi-rotary Actuator

Rack and pinion semi-rotary actuator In this design, the cylinder drives a pinion gear and the rack is an integral part of the piston rod. The angle of rotation depends upon the stroke of the cylinder, rack and the pitch circle diameter of the pinion. The start and finish of the stroke is adjusted by means of an internal shop. The output torque available from the rack and pinion type is in an excess of 80×10^3 Nm at a pressure of 210 bar.

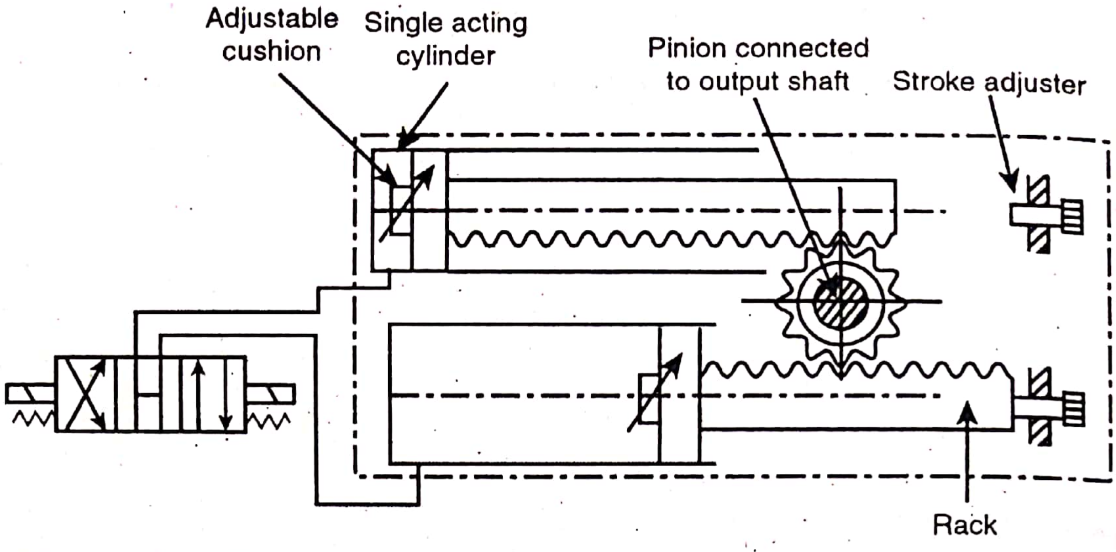


Figure 5.6 Rack and Pinion Semi-rotary Actuator

Lever arm semi-rotary actuator A double acting cylinder can be made to generate rotary motion by using a lever arm. The angle of rotation will be less than 180°. The output is the product of (piston thrust) × (sin ϕ) × (length of lever arm).

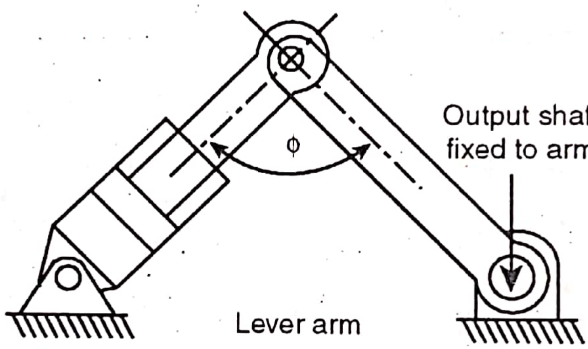


Figure 5.7 Lever Arm Semi-rotary Actuator

Chain and sprocket semi-rotary actuator

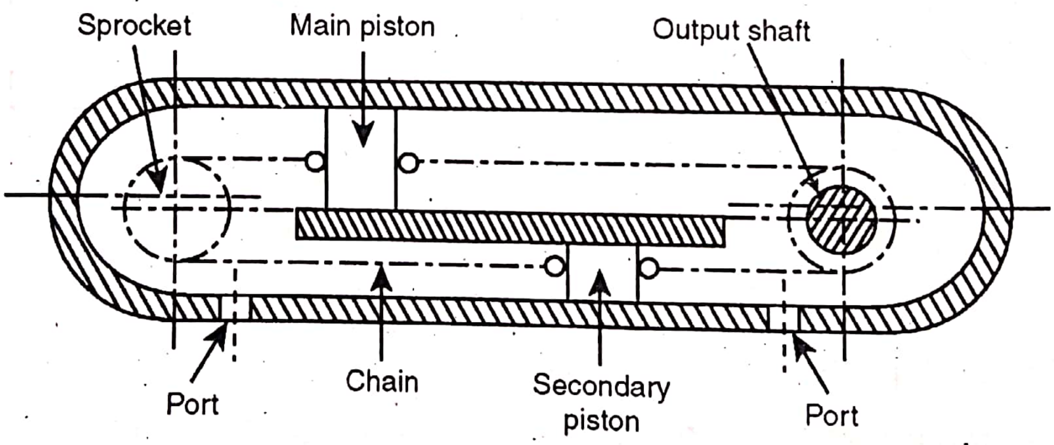


Figure 5.8 Chain and Sprocket Semi-rotary Actuator

In this design, an endless chain and sprocket is used and it is suitable for multi-revolution applications. The chain is anchored to two pistons, one large and the other small, which when in their respective bores, separate the halves of the unit. The larger cylinder is the power cylinder and the small cylinder is the chain return or seal cylinder.

The idler is automatically a tensioned one, so a constant tension is maintained. Pressure is applied to one port of the actuator. The larger piston moves away from the port due to the differential area of the two pistons (large area means large force). Movement of the larger piston pulls the chain, causing the sprocket and output shaft to rotate.

5.2.3 Helical Screw Semi-rotary Actuator

This type consists of a cylinder in which the piston is prevented from rotating by guide rods. The piston rod and the piston contain a helical groove and they mate together analogous to a screw and a nut. As the piston is driven along the barrel, it causes the rod to rotate.

Because of the difficulty in providing a hydraulic seal between the piston and rod, this design is limited to low pressure applications. The self-locking helix angle of the piston and rod eliminate the possibility of external torque causing any rotary movement of the piston rod.

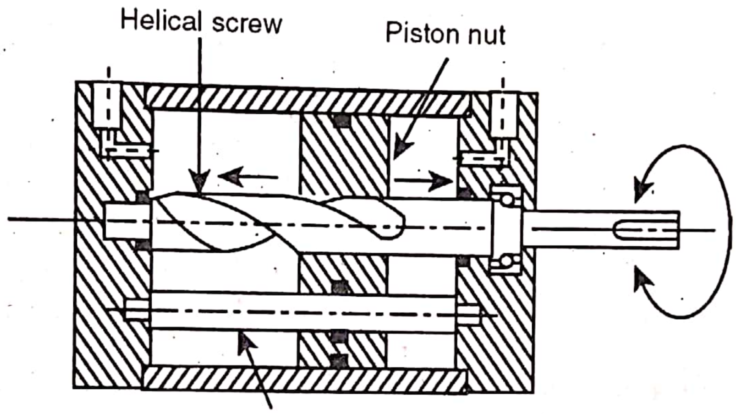


Figure 5.9 Helical Screw Actuator

Uses

1. Semi-rotary actuators are used to move objects through a controlled angle such as opening large butterfly valves in pipelines and to bend and form tubes and bars.
2. They can be used for lifting, tilting, opening, closing, indexing, swinging, bending and many other applications.
3. Conveyors, valve operators, printing presses, rock drills, die clamps etc.

5.3 HYDRAULIC CYLINDERS

A hydraulic cylinder is a device, which converts fluid power into linear mechanical force and motion. It usually consists of a movable element, a piston and a piston rod operating within a cylindrical bore.

Types of hydraulic cylinders

1. Single acting cylinders
2. Double acting cylinders
3. Telescoping cylinders

5.3.1 Single Acting Cylinders

A single acting hydraulic cylinder is designed to apply force in only one direction.

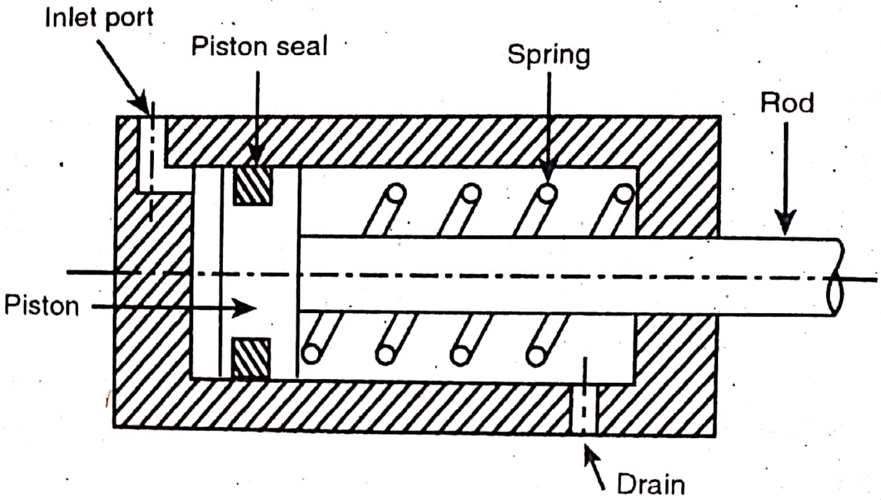


Figure 5.10 Single Acting Cylinder

It consists of a piston inside a cylindrical housing called a barrel. Attached to one end of the piston is a rod which extends outside. At the other end (blank end) is a port for the entrance and the exit of oil. A single acting cylinder can exert a force only in the extending direction, as fluid from the pump enters through the blank end of the cylinder. Single acting cylinders do not hydraulically retract. Retraction is accomplished by using gravity or by the inclusion of a compression spring at the rod end.

5.3.2 Double Acting Cylinders

A double acting cylinder is capable of delivering forces in both directions. The barrel is made of seamless steel tubing, honed to a fine finish on the inside surface. The piston which is made of ductile iron contains U cup packings to seal the leakage between the piston and the barrel. The ports are located in the end caps which are secured to the barrel by tie rods. The load of the piston rod at the neck is taken by a rod bearing, which is generally made of brass or bronze. A rod wiper is provided at the end of the neck to prevent foreign particles and dust from entering into the cylinder along with the piston rod.

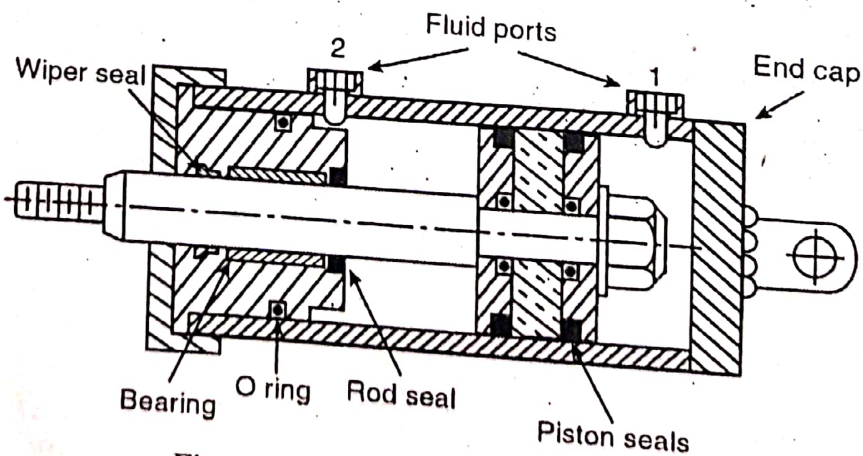


Figure 5.11 Double Acting Cylinder

When the fluid from the pump enters the cylinder through port 1, the piston moves forward and the fluid returns to the reservoir from the cylinder through port 2. During the return stroke the fluid is allowed to enter the cylinder through port 2 and fluid from the other side of the piston goes back to the reservoir through port 1.

Telescoping Cylinders

Telescoping cylinders are used where long work-strokes are needed. A telescoping cylinder provides a relatively long working stroke for an overall reduced length by employing several pistons which telescope into each other.

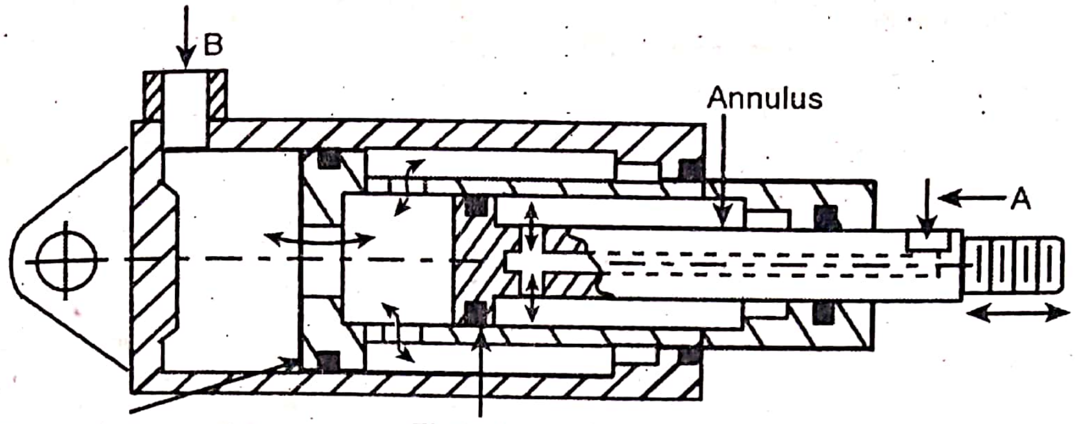


Figure 5.15 Telescoping Cylinder

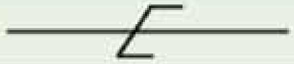
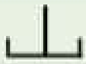
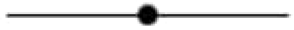
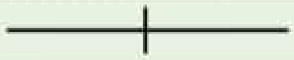
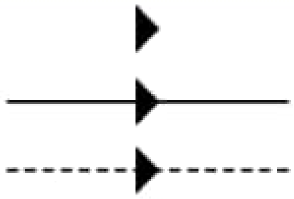
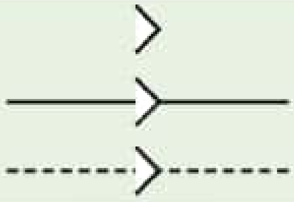
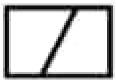
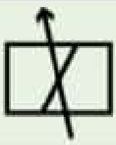
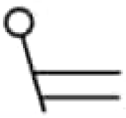
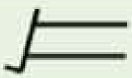
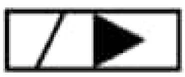
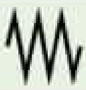
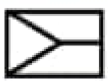
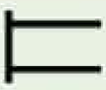
The figure shows a two stage double acting telescopic cylinder. Fluid for the retraction stroke is fed into port 'A' and passes through the hollow piston rod into the annulus behind the first stage piston. So the first stage piston is forced to the left until it uncovers the fluid ports connecting this with the second stage annulus, thereby moving the larger piston to the left until both the pistons are fully retracted into the body of the cylinder.

Fluid for the extension stroke is then fed through port 'B', forcing both pistons to the right until the cylinder is fully extended.

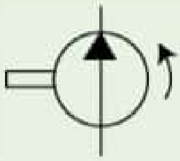
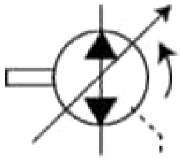
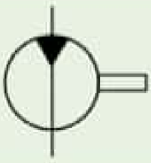
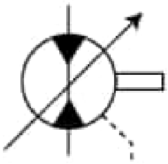
Table 1.2 Comparison between a hydraulic and a pneumatic system</table>

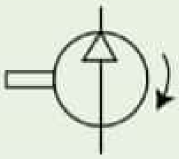
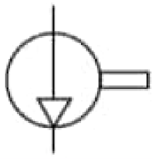
S. No.	Hydraulic System	Pneumatic System
1.	It employs a pressurized liquid as a fluid	It employs a compressed gas, usually air, as a fluid
2.	An oil hydraulic system operates at pressures up to 700 bar	A pneumatic system usually operates at 5–10 bar
3.	Generally designed as closed system	Usually designed as open system
4.	The system slows down when leakage occurs	Leakage does not affect the system much
5.	Valve operations are difficult	Valve operations are easy
6.	Heavier in weight	Lighter in weight
7.	Pumps are used to provide pressurized liquids	Compressors are used to provide compressed gases
8.	The system is unsafe to fire hazards	The system is free from fire hazards
9.	Automatic lubrication is provided	Special arrangements for lubrication are needed

Graphic symbols for fluid power systems

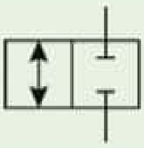
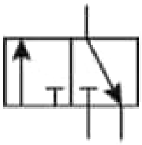
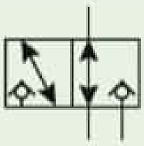
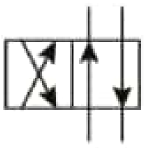
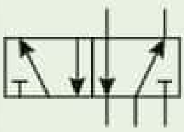
	Supply lines, return lines, component enclosure, symbol enclosure
	Pilot (control) line, drain line, flushing line, bleed line
	Electrical control line
	Frame for several components
	Hose assembly
	Drain to tank
	Return to tank
	Connection of two fluid lines (indicated by the connection point ●)
	Two fluid lines crossing (no connection)
	Hydraulic source of energy
	Pneumatic source of energy
	Valve control - solenoid
	Valve control - Proportional solenoid
	Valve control - Lever
	Valve control - Pedal
	Valve control - Electro-hydraulic (pilot operated DCV)
	Valve control - Spring
	Valve control - Pneumatic spring
	Valve control - Manual override

Graphic symbols for fluid power systems

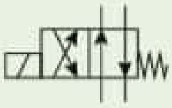
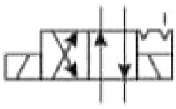
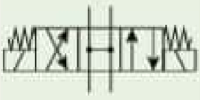
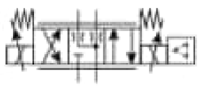
	Hydraulic pump Fixed displacement, one direction of rotation, one direction of flow, internal case drain
	Hydraulic pump Variable displacement, one direction of rotation, two directions of flow, external case drain
	Hydraulic motor Fixed displacement, one direction of rotation, internal case drain
	Hydraulic motor Variable displacement, bi-directional rotation, external case drain

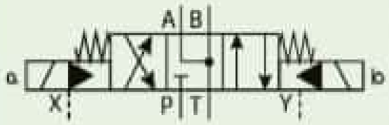
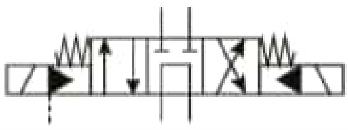
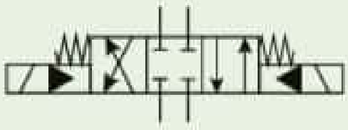
	Compressor: clockwise rotation
	Air motor: one direction of rotation
	1. Diaphragm accumulator 2. Bladder accumulator 3. Piston accumulator 4. Back-up bottle, 5. Air reservoir [pressurised]

Directional control valves (DCV's)

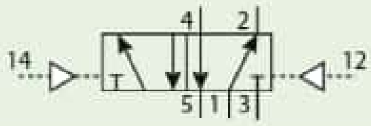
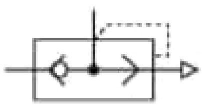
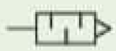
	2/2 Valve (2 ports, 2 positions)
	3/2 Valve (3 ports, 2 positions)
	3/2 Poppet valve (reversible flow, leak-free closure)
	4/2 Valve (4 ports, 2 positions)
	5/2 Valve (5 ports, 2 positions)

Direct operated (by solenoid) DCV's

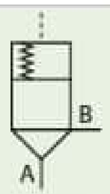
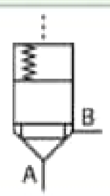
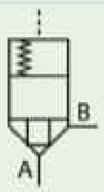
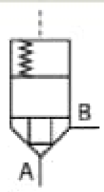
	4/2 "spring return" or "spring offset" DCV
	4/2 "detented" or "impulse" DCV
	4/3 spring centred DCV (open centre spool)
	"force controlled" or "non-feedback" proportional DCV (shown with integral amplifier)

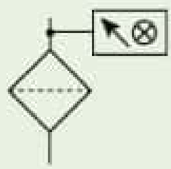
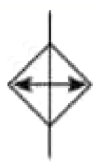
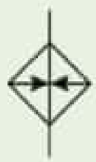
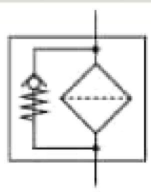
	External pilot supply (X), external pilot drain (Y)
	External pilot supply, internal pilot drain
	Internal pilot supply, internal pilot drain

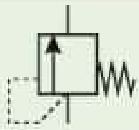
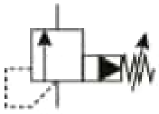
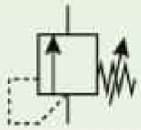
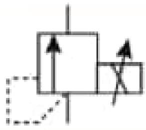
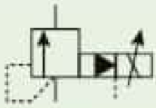
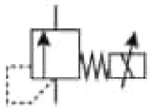
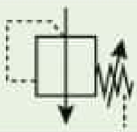
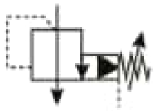
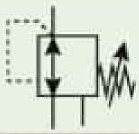
Port identification for pneumatic valves according to ISO 11727

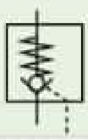
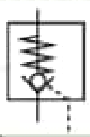
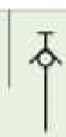
	Direct operated (by pneumatic pilot) 5/2 DCV
	Pneumatic quick-exhaust valve with possibility of connection to the exhaust port
	Pneumatic exhaust silencer with no possibility of connection to the outlet port

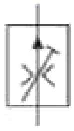
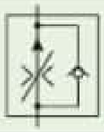
2/2 cartridge valves ("slip in valves" or "logic elements")

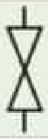
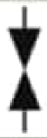
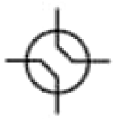
	Pressure control, normally closed, area ratio: 1
	Directional control, area ratio: >0.5
	Directional control, area ratio: <0.5
	Directional control, area ratio: <0.5 (with damping nose or throttle nose)

	Filter with optical clogging indicator
	Filter with bypass (the enclosure indicates that the component has two or more main functions that are connected to each other)
	Cooler (with no indication of the cooling fluid flow path)
	Heater (with no indication of the heat exchange fluid flow path)

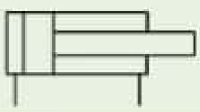
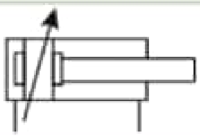
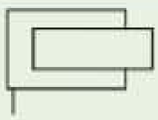
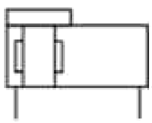
	Direct operated ("single-stage") relief valve with adjustable spring
	Pilot operated ("two-stage") relief valve
	Direct operated sequence valve (external spring chamber drain)
	Direct operated proportional relief valve (solenoid acts directly on valve poppet)
	Pilot operated proportional relief valve (external pilot drain)
	Direct operated proportional relief valve (solenoid acts on valve poppet via spring - this type of valve is often equipped with a stroke transducer)
	Direct operated reducing valve
	Pilot operated reducing valve
	Direct operated 3-way reducing valve ("reducing/relieving" valve)

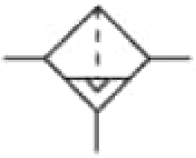
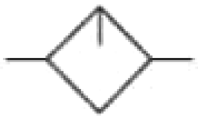
	Check valve without spring (symbol often used for valves with only a light spring)
	Check valve with spring (spring is drawn if its rating is significant)
	Pilot to open check valve ("PO check valve")
	Vented (or "4 port") pilot to open check valve
	Quick connect coupling (this symbol also used for pressure test points)

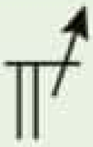
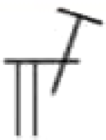
	Throttle valve with adjustable opening
	Pressure compensated and temperature (viscosity) compensated flow control valve with fixed setting
	Pressure compensated and temperature (viscosity) compensated flow control valve with adjustable setting and reverse flow check valve

	Normally open isolation valve (ball valve, gate valve, globe valve etc. or a fully open needle valve)
	Normally closed isolation valve (ball valve, gate valve, globe valve etc. or a fully closed needle valve)
	3 way ball valve ("L" configuration)
	3 way ball valve ("T" configuration)
	3 way ball valve ("inverted T" configuration)
	4 way ball valve ("X" configuration)

Cylinders (linear actuators)

	Double-acting cylinder (single rod)
	Cylinder with adjustable cushions at each end of stroke
	Single-acting ("plunger") cylinder
	"Rodless" cylinder [band type] with non-adjustable cushioning

	Filter with separator with manual drain
	Filter with separator with automatic drain
	Air dryer
	Lubricator

	Permanent magnet
	Stroke transducer (as used on proportional valves with position feedback)
	Stroke limiter (adjustable)
	Stroke limiter (fixed setting)
	Flowmeter (type of output not shown)