

HYDRAULIC MACHINES & INDUSTRIAL FLUID POWER

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COURSE CONTENTS

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1.0 HYDRAULIC TURBINES

- 1.1 Definition and classification of hydraulic turbines
- 1.2 Construction and working principle of impulse turbine
- 1.3 Velocity diagram of moving blades, work done and derivation efficiencies of impulse turbine
- 1.4 velocity diagram of moving blades, work done and derivation of various efficiencies of Francis turbine.
- 1.5 Velocity diagram of moving blades, work done and derivation of various efficiencies of Kaplan turbine.
- 1.6 Numerical on above
- 1.7 Distinguish between impulse turbine and reaction turbine.

2.0 CENTRIFUGAL PUMPS

- 2.1 Construction and working principle of centrifugal pumps.
- 2.2 Work done and derivation of various efficiencies of centrifugal pumps.
- 2.3 Numerical on above

3.0 RECIPROCATING PUMPS

- 3.1 Describe construction and working of single acting reciprocating pump
- 3.2 Describe construction and working of double acting reciprocating pump
- 3.3 Derive the formula for power required to drive the pump (single acting & double acting)

3.4 Define slip

3.5 State positive and negative slip and establish relation between slip and coefficient of discharge.

3.6 Solve numerical on above

4.0 PNEUMATIC CONTROL SYSTEM

4.1 Elements - filters - regulators - lubrication

4.2 Pressure control valves

4.2.1 Pressure relief valves

4.2.2 Pressure regulation valves

4.3 Direction control valves

4.3.1 3/2 DCV, 5/2 DCV, 5/3 DCV

4.3.2 Flow control valves

4.3.3 Throttle valves

4.4 ISO symbols of pneumatic components

4.5 Pneumatic circuits

4.5.1 Direct control of single acting cylinder

4.5.2 Operation of double acting cylinder

4.5.3 Operation of double acting cylinder with metering in and metering out control

5.0 HYDRAULIC CONTROL SYSTEM

5.1 Hydraulic system, its merit and demerits

5.2 Hydraulic accumulators

5.3.1 Pressure control valves

5.3.2 Pressure relief valves

5.3.3 Pressure regulation valves

5.3 Direction Control Valves

5.3.1 3/2 DCV, 5/2 DCV, 5/3 DCV

5.3.2 Flow Control Valves

5.3.3 Throttle Valves

5.4 Fluid Power pumps

5.4.1 External and internal gear pumps

5.4.2 Vane pump

5.4.3 Radial Piston pumps

5.5 ISO Symbols for hydraulic components

5.6 Actuators

5.7 Hydraulic circuits

5.7.1 Direct control of single acting cylinder

5.7.2 Operation of double acting cylinder

5.7.3 Operation of double acting cylinder with metering in and metering out control

5.8 Comparison of hydraulic and pneumatic system.

Page No. _____
Date _____

Page No. _____

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

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

CHAPTER - I

HYDRAULIC TURBINES

The study of hydraulic machines consists of study of turbines and pumps.

Turbines consist of mainly study of Pelton turbine, Francis turbine and Kaplan turbine.

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The study of turbines consists of mainly study of Pelton turbine, Francis turbine and Kaplan turbine.

- Pelton turbine
- Francis turbine
- Kaplan turbine

1.1 Hydraulic Machines

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

The hydraulic turbine machines, which convert the hydraulic energy into mechanical energy are called turbines while the hydraulic machines which convert the mechanical energy into hydraulic energy are called pumps.

Thus the study of hydraulic machines consists of study of turbines and pumps.

Turbines consists of mainly study of

- Pelton turbine
- Francis turbine
- Kaplan turbine

Pumps consists of mainly study of

- Centrifugal pump
- Reciprocating pump

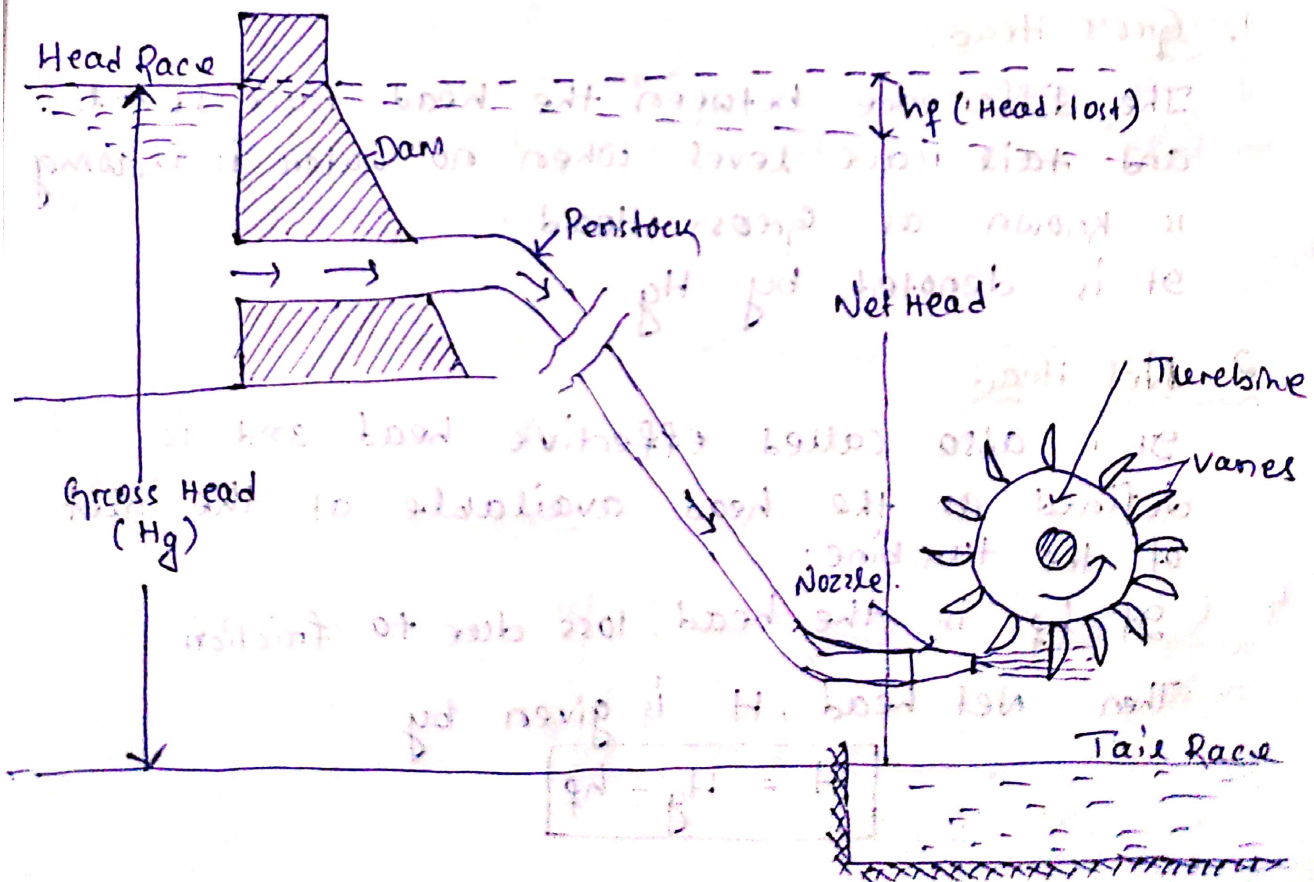
TURBINES

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Defn

- Turbines are defined as the hydraulic machines which convert hydraulic energy into mechanical energy.
- This mechanical energy is used in running an electric generator which is directly coupled to the shaft of the turbine.
 - Thus the mechanical energy is converted into electrical energy.
 - The electric power which is obtained from the hydraulic energy is known as Hydro-electric power.

General Layout of a Hydro-Electric Power Plant



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A general layout of hydro electric power plant consists of :

- ① A dam constructed across a river to store water.
- ② Pipes of large diameters called penstocks which carry water under pressure from the storage reservoir to the turbines. These pipes are made of steel or reinforced concrete.
- ③ Turbines having different types of vanes fitted to the wheels.
- ④ Tail race, A channel which carries water away from the turbine after the water has worked on the turbines.

Definitions of Heads and Efficiencies of a Turbine

1. 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 H_g .

2. Net Head

It is also called effective head and is defined as the head available at the inlet of the turbine.

If h_f is the head loss due to friction

Then Net head, H is given by

$$H = H_g - h_f$$

where

H_g = Gross Head

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$$h_f = \frac{4fLV^2}{D \times 2g}$$

V = Velocity of flow in Penstock

L = Length of Penstock

D = Diameter of Penstock

Efficiencies

The important efficiencies of a turbine are

1. Hydraulic Efficiency (η_h)

2. Mechanical Efficiency (η_m)

3. Volumetric Efficiency (η_v)

4. Overall Efficiency (η_o)

1. Hydraulic Efficiency

It is defined as the ratio of power given by water to the runner of a turbine, to the power supplied by the water at the inlet of the turbine.

Mathematically

$$\eta_h = \frac{\text{Power delivered to runner}}{\text{Power supplied at inlet}}$$

$$\eta_h = \frac{R.P.}{W.P.}$$

where $R.P. = \frac{W}{g} \frac{[V_{w1} \pm V_{w2}] \times u}{1000}$ for Pelton turbine

$$= \frac{\rho A V_1 [V_{w1} \pm V_{w2}] \times u}{1000}$$

$$= \frac{\gamma Q V_1 [V_{w1} u_1 + V_{w2} u_2]}{1000}$$

for a radial turbine

$$W.P. = \frac{W \times H}{1000} \text{ kW}$$

$$= \frac{\gamma Q H}{1000} \text{ kW}$$

2. Mechanical Efficiency

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

Mathematically

$$\eta_m = \frac{\text{Power at the shaft of turbine}}{\text{Power delivered to Runner}}$$

$$= \frac{S.P.}{R.P.}$$

3. Volumetric Efficiency

It is defined as the ratio of the volume of the water actually striking the runner to the volume of water supplied to the turbine.

$$\eta_v = \frac{\text{Volume of water actually striking}}{\text{Volume of water supplied to turbine}}$$

4. Overall Efficiency

It is defined as the ratio of power available at the shaft of the turbine to the power supplied by the water at the inlet of the turbine.

Mathematically

$$\eta_o = \frac{\text{Power available at the shaft}}{\text{Power supplied at inlet}}$$

$$= \frac{\text{Shaft power}}{\text{Water power}}$$

$$= \frac{S.P}{W.P}$$

$$= \frac{S.P}{R.P} \times \frac{R.P}{W.P}$$

$$\boxed{\eta_o = \eta_m \times \eta_h}$$

Classification of Hydraulic Turbines

The hydraulic turbines are classified according to the type of energy available at the inlet of the turbine, direction of flow through the vanes, head at the inlet of the turbine and specific speed of the turbines. Thus the important classification of turbines are

① According to the type of energy at inlet

② Impulse turbine

③ Reaction turbine

② According to the direction of flow through runners

④ Tangential flow turbine

⑤ Radial flow turbine

⑥ Axial flow turbine

⑦ Mixed flow turbine

③ According to the head at the inlet of turbine

① High head turbine

② Medium head turbine

③ Low head turbine

④ According to the specific speed of the turbine

① Low specific speed turbine

② Medium specific speed turbine

③ High specific speed turbine

1.2 Construction and Working principle of Impulse Turbine (PELTON WHEEL)

- The Pelton wheel or Pelton turbine is a tangential flow impulse turbine.

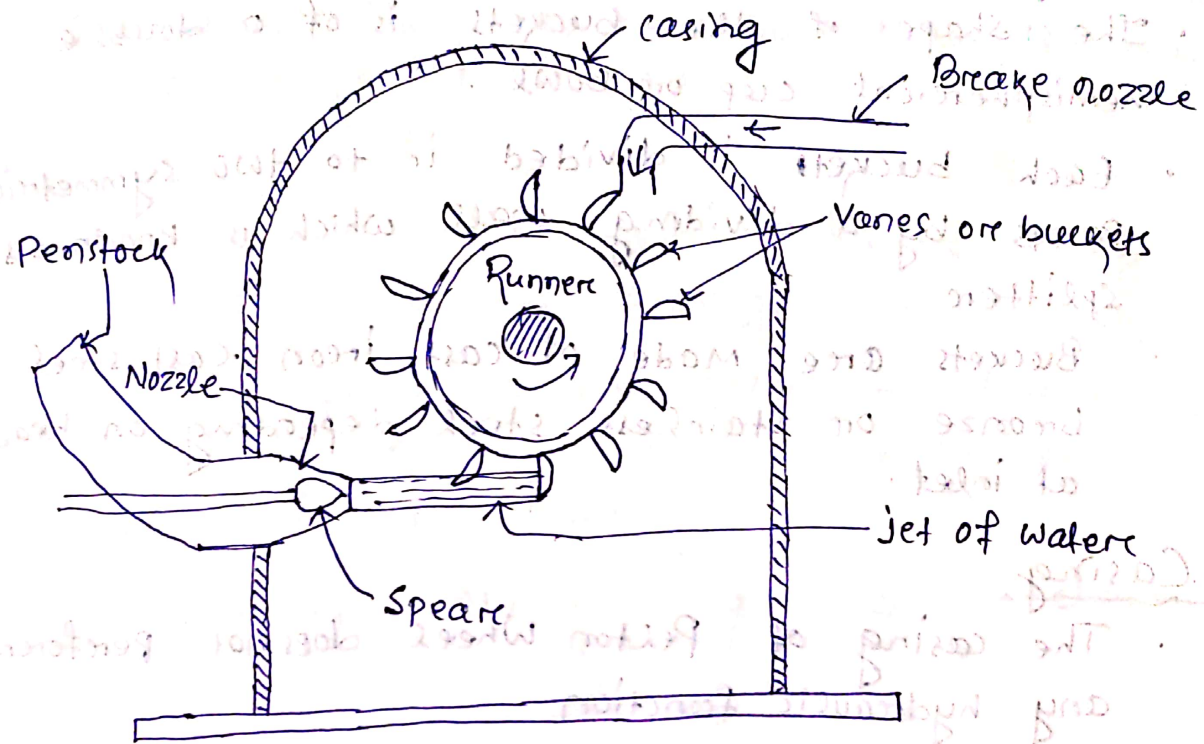
- In an impulse turbine the pressure energy of water is converted into kinetic energy when passed through the nozzle and forms the high velocity jet of water. The water jet thus formed is used for driving the wheel.

- The most utilized impulse turbine is Pelton wheel.

- Pelton wheel is named after the American engineer Lester Allen Pelton.

- In this case the water strikes the vane tangentially (tangent to the circumference)

Construction



The main parts of the Pelton turbine are

1. Nozzle and flow regulating arrangement
2. Runner and buckets
3. Casing
4. Breaking jet

1. Nozzle and flow regulating arrangement (Spear)

- Water transferred from a high head source through penstock which is fitted with a Nozzle through which water flows out at a high speed jet.
- A needle spear moving inside the nozzle controls the water flow through the nozzle.

2. Runner with buckets

- The runner consists of a circular disc on the periphery of which a number of buckets

evenly spaced are fixed.

- The shape of the buckets is of a double hemispherical cup or bowl.
- Each bucket is divided into two symmetrical parts by a dividing wall which is known as splitter.
- Buckets are made of cast iron, cast steel, bronze or stainless steel depending on head at inlet.

3. Casing

- The casing of Pelton Wheel does not perform any hydraulic function.
- Its function is to prevent the splashing of the water and to discharge water to tail race.
- It acts as a safeguard against accidents.
- It is made of cast iron or fabricated steel plates.

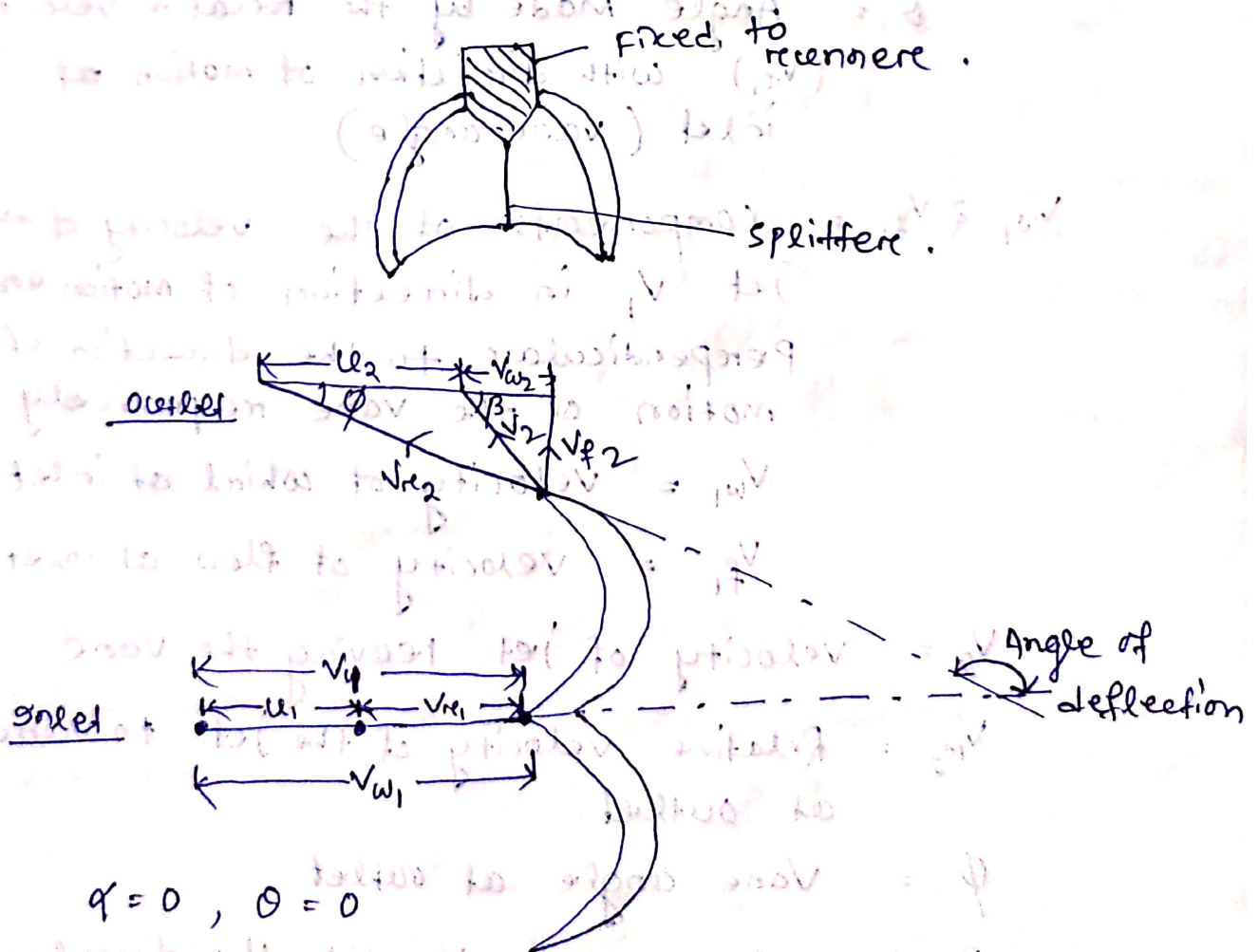
4. Breaking Jet

- When the nozzle is completely closed by moving the spear in the forward direction the amount of water striking the runner is reduced to zero but the runner due to inertia continues revolving for a long time.
- In order to bring the runner to rest in a short time, a nozzle (break) is provided which directs the jet of water on the back of the bucket, this jet of water is called breaking jet.

Working

- The water from the reservoir flows through the penstocks at the outlet of which a nozzle is fitted.
- The nozzle increases the kinetic energy of the water flowing through the penstock.
- At the outlet of the nozzle, the water comes out in the form of a jet and strikes the buckets of the runner.
- The runner starts rotating, developing mechanical power.

Work done and Efficiency of a Pelton wheel.



Let

N = Speed of wheel in rpm

D = Diameter of the wheel

d = Diameter of the jet

U = Peripheral velocity of runner

$$U_1 = U_2 = U$$

$$= \frac{\pi DN}{60}$$

V_1 = Absolute velocity of water at inlet

V_{r1} = Relative velocity of jet and bucket at inlet

α = Angle between direction of the jet and direction of motion of vane at inlet (guide angle)

θ = Angle made by the relative velocity (V_{r1}) with direction of motion at inlet (vane angle)

V_{w1} & V_{f1} = Components of the velocity of the jet V_1 in direction of motion and perpendicular to the direction of motion of the vane respectively.

V_{w1} = velocity of whirl at inlet

V_{f1} = velocity of flow at inlet

V_2 = Velocity of jet leaving the vane

V_{r2} = Relative velocity of the jet to vane at outlet.

ϕ = Vane angle at outlet

β = angle made by V_2 with the direction of motion

V_{w2} & V_{f2} = Components of the velocity V_2

Inlet

The velocity triangle at inlet will be a straight line where

$$V_{re1} = V_1 - u_1$$

$$= V_1 - u \quad (u = u_1 = u_2)$$

$$V_{w1} = V_1$$

$$\alpha = 0$$

$$\theta = 0$$

Outlet

From velocity triangle at outlet

$V_{re2} = K V_{re1}$ [where K = blade friction coefficient, slightly less than unity. If the surface of blades are perfectly smooth and energy loss due to impact of splitter are neglected then

$$K = 1, V_{re1} = V_{re2}$$

$$\begin{aligned} V_{w2} &= V_{re2} \cos \phi - u_2 \\ &= V_{re2} \cos \phi - u \quad [u_1 = u_2 = u] \end{aligned}$$

Force exerted by the jet of water in the direction of motion is given as

$$F = \rho a V_1 [V_{w1} + V_{w2}]$$

Work done by the jet on runner per second
 $= F \times u$

$$= \rho a v_1 (v_{w1} + v_{w2}) \times l$$

Work done per second per unit weight of water striking per second

$$= \frac{\rho a v_1 (v_{w1} + v_{w2}) l}{\text{Weight of water striking/second}}$$

$$= \frac{\rho a v_1 (v_{w1} + v_{w2}) l}{\text{Mass/second} \times g}$$

$$= \frac{\rho a v_1 (v_{w1} + v_{w2}) l}{\rho a v_1 \times g}$$

$$= \frac{1}{g} [v_{w1} + v_{w2}] \times l$$

The energy supplied to the jet at inlet is in the form of kinetic energy and is equal to

$$\frac{1}{2} M V^2$$

$$\text{K.E. of jet per second} = \frac{1}{2} (\rho a v_1) \times v_1^2$$

Hydraulic efficiency

$$\eta_h = \frac{\text{Work done per second}}{\text{K.E. of jet per second}} = \frac{R.P}{W.P}$$

$$= \frac{\rho a v_1 [v_{w1} + v_{w2}] \times l}{\frac{1}{2} (\rho a v_1) \times v_1^2}$$

$$= \frac{2 [v_{w1} + v_{w2}] l}{v_1^2}$$

Here

$$v_{w1} = v_1$$

$$v_{r1} = v_1 - u_1 = v_1 - u$$

$$v_{r2} = v_1 - u \quad \left[\text{assuming } v_{r1} = v_{r2} \right]$$

$$V_{w2} = V_{r2} \cos \phi - u_2$$

$$= (V_1 - u) \cos \phi - u$$

Substituting the values of V_{w1} and V_{w2}

$$\eta_h = \frac{2 [V_1 + (V_1 - u) \cos \phi - u] \times u}{V_1^2}$$

$$= \frac{2 [(V_1 - u) + (V_1 - u) \cos \phi] \times u}{V_1^2}$$

$$= \frac{2 (V_1 - u) (1 + \cos \phi) \times u}{V_1^2}$$

The efficiency will be maximum for a given value of V_1 when

$$\frac{d}{du} (\eta_h) = 0$$

$$\Rightarrow \frac{d}{du} \left[\frac{2u(V_1 - u)(1 + \cos \phi)}{V_1^2} \right] = 0$$

$$\Rightarrow \frac{(1 + \cos \phi)}{V_1^2} \times \frac{d}{du} [2uV_1 - 2u^2] = 0$$

$$\Rightarrow \frac{d}{du} (2uV_1 - 2u^2) = 0$$

$$\Rightarrow 2V_1 - 4u = 0$$

$$\Rightarrow u = \frac{V_1}{2} = \frac{V}{b} = M$$

Then maximum efficiency (hydraulic) will be

$$(\eta_h)_{\max} = \frac{2(2u - u)(1 + \cos \phi)u}{4u^2}$$

$$\boxed{(\eta_h)_{\max} = \frac{1 + \cos \phi}{2}}$$

Design Aspects of Pelton Wheel

The following points should be considered while designing a Pelton wheel.

1. velocity of jet at inlet.

$$V_1 = C_v \sqrt{2gH}$$

C_v = Co-efficient of velocity (0.98 or 0.99)

H = Net head on turbine

2. The velocity of wheel (u) is given by

$$u = K_u \sqrt{2gH}$$

K_u = Speed ratio (varies from 0.43 to 0.48)

3. Angle of deflection of the jet is taken as 165° if no angle of deflection is given.

4. Mean diameter of the wheel (D)

we know $u = \frac{\pi D N}{60}$

$$D = \frac{60u}{\pi N}$$

5. Jet ratio = $\frac{\text{Pitch diameter } (D)}{\text{diameter of the jet}}$

$$M = \frac{D}{d} = (12 \text{ for most cases})$$

6. Number of buckets on a runner is given by

$$Z = 15 + \frac{D}{2d} = 15 + 0.5M$$

7. Number of jet is obtained by dividing the total rate of flow through the turbine by the rate of flow of water through a single jet.

Q.1 A Pelton wheel is receiving water from a penstock with a gross head of 510 m. One third of gross head is lost in friction in the penstock. The rate of flow through the nozzle fitted at the end of the penstock is $2.2 \text{ m}^3/\text{s}$. The angle of deflection of the jet is 165° . Determine.

- The power given by water to the runner
- Hydraulic efficiency of the Pelton wheel.

Take C_v (co-efficient of velocity) $= 1.0$

Speed ratio $= 0.45$

Ans

Given data

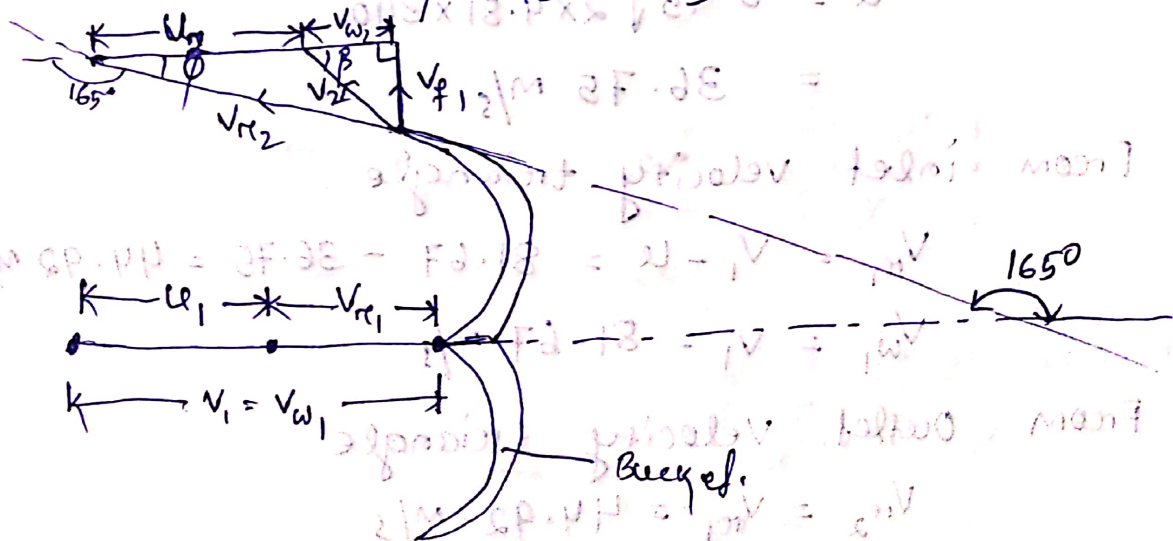
$$H_g = 510 \text{ m}$$

$$\text{Head lost in friction} = h_f = \frac{H_g}{3} = \frac{510}{3} = 170 \text{ m}$$

$$Q = 2.2 \text{ m}^3/\text{s}$$

$$\text{Angle of deflection} = 165^\circ$$

$$\phi = 180^\circ - 165^\circ = 15^\circ$$



Coefficient of velocity $C_v = 1$

Speed ratio $K_u = 0.45$

To find

(i) The power given by water to the runner (P)

$$R.P = \rho Q (V_{w1} + V_{w2}) u$$

(ii) Hydraulic efficiency

$$\eta_h = \frac{2(V_{w1} + V_{w2}) \times u}{V_1^2}$$

Solution

We know

$$\text{velocity of jet } V_1 = C_v \sqrt{2gH}$$

$H = \text{net head}$

$$= H_g - h_f$$

$$= H_g - H_g/3 = 510 - 170 = 340 \text{ m}$$

$$V_1 = 1.0 \sqrt{2 \times 9.81 \times 340}$$

$$= 81.67 \text{ m/s}$$

$$\text{velocity of wheel } u = K_u \sqrt{2gH}$$

$$u = 0.45 \sqrt{2 \times 9.81 \times 340}$$

$$= 36.75 \text{ m/s}$$

From inlet velocity triangle.

$$V_{r1} = V_1 - u = 81.67 - 36.75 = 44.92 \text{ m/s}$$

$$V_{w1} = V_1 = 81.67 \text{ m/s}$$

From outlet velocity triangle

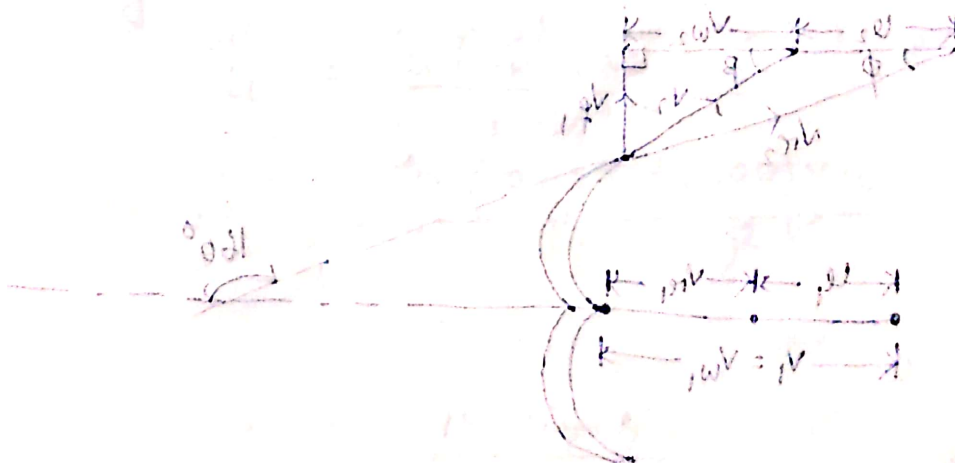
$$V_{r2} = V_{r1} = 44.92 \text{ m/s}$$

$$V_{r2} \cos \phi = u_2 + V_{w2}$$

$$\begin{aligned}
 V_{w2} &= V_{w2} \cos \phi - u \\
 &= 44.92 \cos 15^\circ - 36.75 \\
 &= 6.64 \text{ m/s}
 \end{aligned}$$

$$\begin{aligned}
 \text{(i) R.P} &= \rho Q (V_{w1} + V_{w2}) \times u \\
 &= 1000 \times 2.2 \times (81.67 + 6.64) \times 36.75 \\
 &= 7139863 \text{ Nm/s} \\
 &= \underline{7139.863 \text{ kW}}
 \end{aligned}$$

$$\begin{aligned}
 \text{(ii) } \eta_h &= \frac{2(V_{w1} + V_{w2})u}{V_1^2} \\
 &= \frac{2(81.67 + 6.64) \times 36.75}{(81.67)^2} \\
 &= 0.973 \\
 &= \underline{97.3\%}
 \end{aligned}$$



$$\begin{aligned}
 \text{HP of jet} &= \rho Q V^2 / 2 \\
 &= 0.8 \times 18.8 \times 67.3^2 / 2 \\
 &= 21.7 \text{ MW}
 \end{aligned}$$

Q.2 A Pelton wheel has a mean bucket speed of 10 metres per second with a jet of water flowing at the rate of 700 lts/s under a head of 30 metres. The buckets deflect the jet through an angle of 160° . Calculate the power given by water to the runner and the hydraulic efficiency of the turbine. Assume co-efficient of velocity as 0.98.

Solution

Given data

$$u_1 = u_2 = u = 10 \text{ m/s}$$

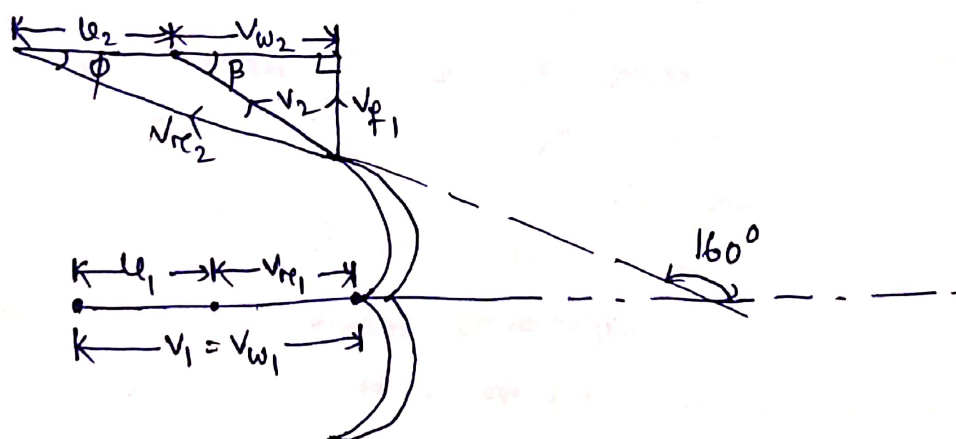
$$Q = 700 \text{ lts/s} \\ = 0.7 \text{ m}^3/\text{s}$$

$$H = 30 \text{ m}$$

$$\text{Angle of deflection} = 160^\circ$$

$$\phi = 180^\circ - 160^\circ = 20^\circ$$

$$C_v = 0.98$$



At the inlet

$$V_1 = C_v \sqrt{2gH} \\ = 0.98 \sqrt{2 \times 9.81 \times 30} \\ = 23.77 \text{ m/s}$$

$$V_{r1} = V_1 - u$$

$$= 23.77 - 10 = 13.77 \text{ m/s}$$

$$V_{w1} = V_1 = 23.77 \text{ m/s}$$

From outlet velocity triangle

$$V_{r2} = V_{r1} = 13.77 \text{ m/s}$$

$$V_{w2} = V_{r2} \cos \phi - u$$

$$= 13.77 \cos 20^\circ - 10$$

$$= 2.94 \text{ m/s}$$

Work done by the jet per second on the runner is given by

$$= \rho a V_1 [V_{w1} + V_{w2}] \times u$$

$$= 1000 \times 0.7 [23.77 + 2.94] \times 10 \quad [aV_1 = Q]$$

$$= 186970 \text{ Nm/s}$$

$$\text{Power in kW} = \frac{186970}{1000} = 186.97 \text{ kW}$$

The hydraulic efficiency

$$\eta_h = \frac{2(V_{w1} + V_{w2}) \times u}{V_1^2}$$

$$= \frac{2(23.77 + 2.94) \times 10}{(23.77)^2}$$

$$= 0.9454$$

$$= \underline{94.54 \%}$$

Ans

1.4 Velocity diagram of moving blades, work done and derivation of various efficiencies of Francis Turbine

Francis Turbine is a radial flow reaction turbines

Radial flow turbines are those turbines in which the water flows in the radial direction. The water may flow from outward to inward or from inward to outward radially.

Water flows from outward to inward through the runner - Inward radial flow turbine

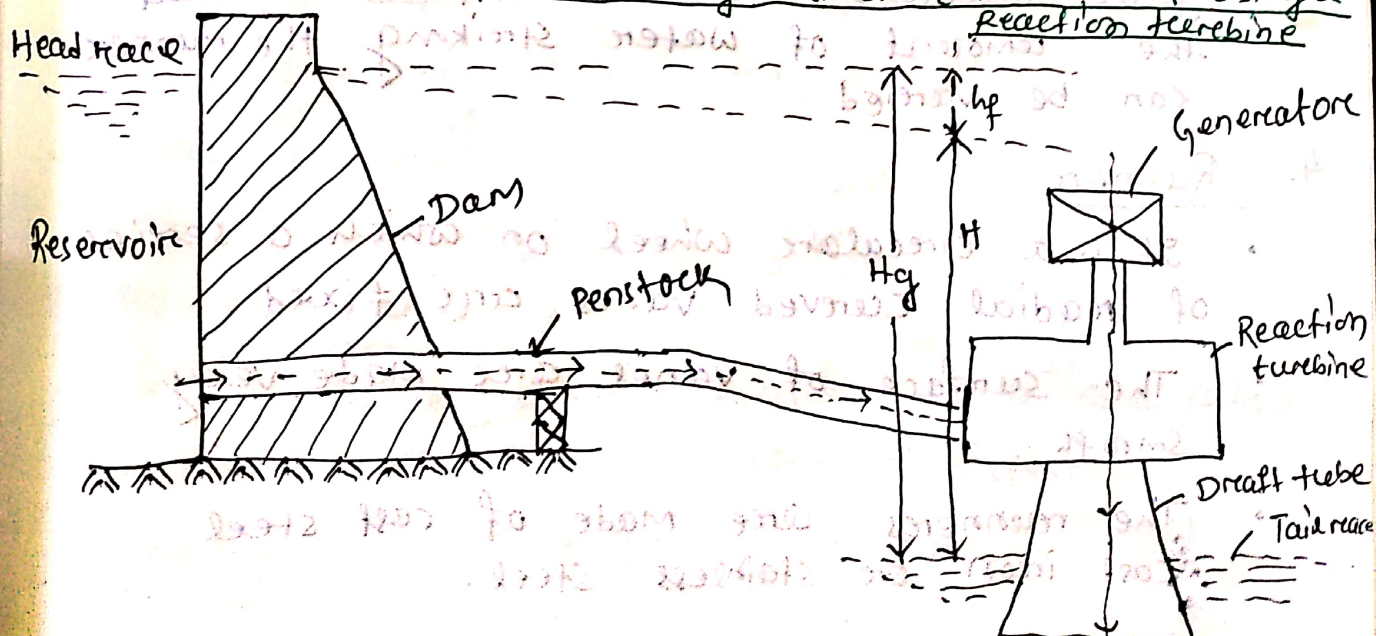
Water flows from inward to outward through the runner - Outward radial flow turbine

Reaction turbine means that the water at the inlet of the turbine possesses kinetic energy as well as pressure energy.

- As the water flows through the runner, a part of pressure energy goes on changing into kinetic energy.

- The runner is completely enclosed in an air-tight casing and casing and the runner is always full of water.

General Layout of a hydroelectric power plant using a Reaction turbine



11.50-12.45	12.45-1.40	1.40-2.15	2.15-3.10	3.10-4.05
I(AKB)	PT(PM)	SCA(PM)	R	
W/S-II(SS.BSP)				

(SP)

PKP)

Francis Turbine is an Inward Radial Flow Reaction turbine.

The main parts of a Francis Turbine are.

1. Penstock

It is a large size conduit which conveys water from the 'upstream' of the dam/reservoir to the turbine runner.

2. Casing

- It constitutes a closed passage whose cross-sectional area gradually decreases along the flow direction.
- The casing is made of concrete, cast steel or plate steel.
- It is spiral in shape.

3. Guide Mechanism

- It consists of a stationary circular wheel all round the runner of the turbine.
- These vanes allow the water to strike the moving vanes without shock at inlet.
- The width between two adjacent vanes of a guide mechanism can be altered so that the amount of water striking the runner can be varied.

4. Runner

- It is a circular wheel on which a series of radial curved vanes are fixed.
- The surface of vanes are made very smooth.
- The runners are made of cast steel, cast iron or stainless steel.

They are keyed to shaft

5. Draft Tube

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

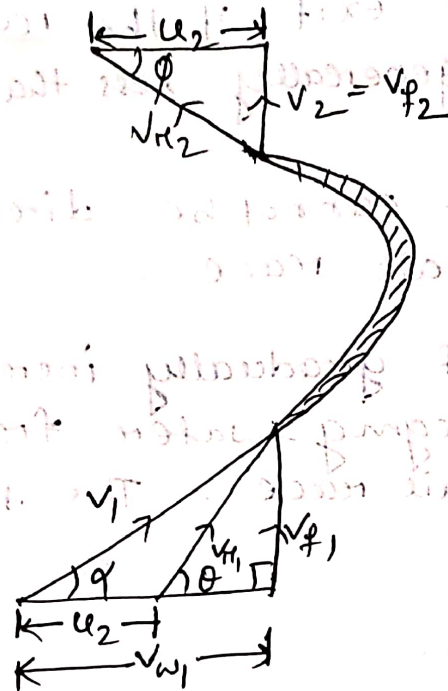
6. Governing Mechanism

It changes the position of the guide vanes to affect a variation in water flow rate, when the load conditions on the turbine change.

Modern Francis turbine is an inward mixed flow reaction turbine (unlike earlier Francis turbine) i.e. water enters the runner of the turbine in radial direction at outlet and leaves in axial direction at the inlet of the runner.

- The inward flow reaction turbine having radial discharge at outlet is known as Francis Turbine.
- It operates under medium heads and also requires medium quantity of water.
- Runner is always full of water.

Velocity Triangle of moving blades of Francis Turbine.



$$V_{w2} = 0$$

Work done by the runner

$$= \rho Q (V_{w1} u_1 + V_{w2} u_2)$$

As $V_{w2} = 0$

$$\text{Work done/sec} = \rho Q (V_{w1} u_1)$$

Work done/second / unit weight/seconds

$$= \frac{\rho Q (V_{w1} u_1)}{\rho g Q} = \frac{1}{g} [V_{w1} u_1]$$

Hydraulic Efficiency.

$$\eta_h = \frac{R.P}{W.P} = \frac{\rho Q [V_{w1} u_1]}{\rho Q g H}$$

$$= \frac{V_{w1} u_1}{g H}$$

The hydraulic efficiency of the Francis turbine varies from 85 to 90 %



Mechanical Efficiency

$$\eta_m = \frac{S.P}{R.P}$$

Overall Efficiency

$$\eta_o = \frac{S.P}{W.P}$$

Important Relations for Francis Turbine

1. The ratio of width of the wheel to its diameter is given as $\eta = \frac{B_1}{D_1}$
The value of η varies from 0.10 to 0.40

2. The flow ratio is given as
Flow ratio = $\frac{V_{f1}}{\sqrt{2gH}}$ and varies from 0.15 to 0.30

3. The speed ratio = $\frac{U_1}{\sqrt{2gH}}$ and varies from 0.6 to 0.9

4. Discharge of the turbine
 $Q = \pi D_1 B_1 V_{f1} = \pi D_2 B_2 V_{f2}$

If the thickness of vanes considered
Area = $(\pi D_1 - nt) B_1$ $\frac{n}{\pi}$ no. of vanes t thickness.
 $Q = (\pi D_1 - nt) B_1 V_{f1}$

5. The head on the turbine is given by

$$H = \frac{P_1}{\rho g} + \frac{V_1^2}{2g}$$

Q.1 A Francis turbine with an overall efficiency of 75% is required to produce 148.25 kW power. It is working under a head of 7.62 m. The peripheral velocity = $0.26\sqrt{2gH}$ and the radial velocity of flow at inlet is $0.96\sqrt{2gH}$. The wheel runs at 150 rpm and the hydraulic losses in the turbine are 22% of the available energy. Assuming radial discharge, determine.

- The guide blade angle.
- The wheel vane angle at inlet
- Diameter of the wheel at inlet
- Width of the wheel at inlet.

Solution

Given data

$$\eta_o = 75\%$$

$$S.p = 148.25 \text{ kW}$$

$$H = 7.62 \text{ m}$$

$$u_1 = 0.26\sqrt{2gH}$$

$$= 0.26\sqrt{2 \times 9.81 \times 7.62}$$

$$= 3.179 \text{ m/s}$$

$$V_{f1} = 0.96\sqrt{2gH}$$

$$= 0.96\sqrt{2 \times 9.81 \times 7.62}$$

$$= 11.738 \text{ m/s}$$

$$N = 150 \text{ rpm}$$

$$\eta_h = 100 - 22 = 78\%$$

$$\text{radial discharge i.e. } V_{w2} = 0$$

To Find

$$\alpha = ?$$

$$\theta = ?$$

$$D_1 = ?$$

$$B_1 = ?$$

We know

$$\eta_h = \frac{V_{w1} u_1}{gH} = 0.78$$

$$\Rightarrow \frac{V_{w1} \times 3.179}{9.81 \times 7.62} = 0.78$$

$$\Rightarrow V_{w1} = 18.34 \text{ m/s}$$

from inlet velocity triangle.

$$\tan \phi = \frac{V_{f1}}{V_{w1}}$$

$$\phi = \tan^{-1} \left(\frac{V_{f1}}{V_{w1}} \right) = \tan^{-1} \left(\frac{11.738}{18.34} \right)$$

$$= 32.619^\circ$$

$$\tan \theta = \frac{V_{f1}}{V_{w1} - u_1}$$

$$\theta = \tan^{-1} \left(\frac{V_{f1}}{V_{w1} - u_1} \right) = \tan^{-1} \left(\frac{11.738}{18.34 - 3.179} \right)$$

$$= 37.74^\circ \text{ Ans}$$

We know

$$u_1 = \frac{\pi D_1 N}{60}$$

$$\Rightarrow D_1 = \frac{60 u_1}{\pi N} \Rightarrow D_1 = \frac{60 \times 18.34}{\pi \times 150}$$

$$= 0.4047 \text{ m}$$

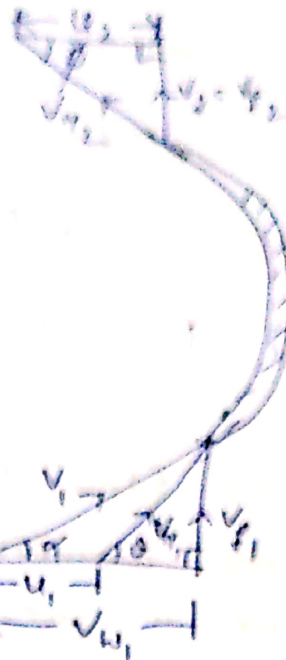
Again

$$\eta_o = \frac{\text{S.P}}{\text{W.P}}$$

$$\Rightarrow \text{W.P} = \frac{\text{S.P}}{\eta_o} = \frac{148.25}{0.75}$$

$$\Rightarrow \frac{\rho g Q H}{1000} = \frac{148.25}{0.75}$$

$$\Rightarrow Q = \frac{148.25 \times 1000}{0.75 \times 1000 \times 9.81 \times 7.26}$$



$$Q = 2.644 \text{ m}^3/\text{s}$$

$$\pi D_1 B_1 V_{f1} = 2.644$$

$$\Rightarrow \pi \times 0.4047 \times B_1 \times 11738 = 2.644$$

$$\Rightarrow B_1 = 0.177 \text{ m}$$

Q2 An inward flow reaction turbine has external and internal diameters of 1.08 m and 0.54 m. The turbine is running at 200 r.p.m. The width of the turbine at inlet is 240 mm and velocity of flow through the runner is constant and is equal to 2.16 m/s. The guide blades make an angle of 10° to the tangent of the wheel and discharge at the outlet of the turbine is radial. Draw the inlet and outlet velocity triangle and determine

- (i) Absolute velocity of water at inlet of runner
- (ii) The velocity of wheel at inlet
- (iii) The relative velocity at inlet
- (iv) The runner blade angles
- (v) Width of runner at outlet
- (vi) Weight of water flowing through the runner per second.
- (vii) Head at inlet of the turbine
- (viii) Power developed.
- (ix) Hydraulic efficiency of the turbine

Solution

Given data

$$D_1 = 1.08 \text{ m}$$

$$D_2 = 0.54 \text{ m}$$

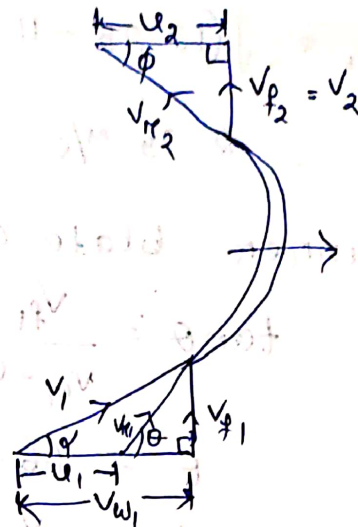
$$N = 200 \text{ rpm}$$

$$B_1 = 240 \text{ mm} = 0.24 \text{ m}$$

$$V_{f1} = V_{f2} = 2.16 \text{ m/s}$$

$$\alpha = 10^\circ$$

$$\beta = 90^\circ \quad V_{w2} = 0$$



To find

$$V_1 =$$

$$V_{w1} =$$

$$V_{r1} =$$

$$\theta, \phi =$$

$$B_2 =$$

$$\text{weight / sec} =$$

$$H =$$

$$R.P =$$

$$\eta_h =$$

- (i) Absolute velocity of water at inlet.

$$V_1 = \frac{V_{f1}}{\sin \alpha} = \frac{2.16}{\sin 10^\circ} = 12.44 \text{ m/s}$$

- (ii) velocity of wheel at inlet V_{w1}

$$V_{w1} = V_1 \cos \alpha = 12.44 \cos 10^\circ = 12.25 \text{ m/s}$$

- (iii) Relative velocity at inlet V_{r1}

$$V_{r1} = \sqrt{(V_{w1} - U_1)^2 + V_{f1}^2}$$

$$U_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 1.08 \times 200}{60} = 11.31 \text{ m/s}$$

$$V_{r1} = \sqrt{(12.25 - 11.31)^2 + (2.16)^2}$$

$$= 2.35 \text{ m/s}$$

(iv) Runner blade angles θ, ϕ

$$\tan \theta = \frac{V_{f1}}{V_{w1} - u_1}$$

$$\theta = 66.48^\circ$$

$$\tan \phi = \frac{V_{f2}}{u_2} = \frac{2.16}{5.65}$$

$$\phi = 20.9^\circ$$

(v) Width of runner at outlet B_2

$$\pi D_1 B_1 V_{f1} = \pi D_2 B_2 V_{f2}$$

$$D_1 B_1 = D_2 B_2$$

$$\Rightarrow B_2 = \frac{D_1 B_1}{D_2}$$

$$= 0.48 \text{ m}$$

(vi) weight / sec

$$= Q \cdot \text{m/s} \times g$$

$$= 9.8 \times g = 1000 \times \pi \times 1.08 \times 0.24 \times 2.16$$

$$\times 9.81$$

$$= 17.25 \text{ kN/sec}$$

(vii)

$$H = \frac{V_{w1} u_1}{g} + \frac{V_2^2}{2g}$$

$$= \frac{1}{9.81} (12.25 \times 11.31) + \frac{(2.16)^2}{2 \times 9.81}$$

$$= 14.136 \text{ m}$$

(viii) Power developed (P.P)

$$P.P = \rho Q (V_w u_1)$$

$$= 1000 \times \pi D_1 B V_{f1} \times u_1 \times V_{w1}$$

$$= 1000 \times \pi \times 1.08 \times 0.24 \times 2.16 \times 11.31 \times 12.25$$
$$= 243.6 \text{ kW}$$

(ix) Hydraulic efficiency

$$\eta_h = \frac{V_{w1} u_1}{g H}$$

$$= \frac{12.25 \times 11.31}{9.81 \times 14.36} = 0.9835$$

$$= 98.35\%$$

Ans

Q.3 The following data is given for a Francis's Turbine. Net head $H = 60 \text{ m}$, Speed = 700 r.p.m
Shaft power = 294.3 kW, $\eta_o = 84\%$, $\eta_h = 93\%$,
flow ratio = 0.20, breadth ratio $n = 0.1$, outer diameter of the runner = 2 x inner diameter of runner. The thickness of vanes occupy 5% of circumferential area of the runner, velocity of flow is constant at inlet and outlet and discharge is radial at outlet. Determine

- (i) Guide blade angle
- (ii) Runner vane angles at inlet and outlet
- (iii) Diameters of runner at inlet and outlet
- (iv) Width of wheel at inlet.

Solutions:

Given data

$$H = 60 \text{ m}$$

$$N = 700 \text{ rpm}$$

$$S.P. = 294.3 \text{ kW}$$

$$\eta_o = 84 \%$$

$$\eta_h = 93 \%$$

$$\frac{V_{f1}}{\sqrt{2gH}} = 0.20$$

$$V_{f1} = 0.20 \sqrt{2 \times 9.81 \times 60}$$
$$= 6.862 \text{ m/s}$$

$$\frac{B_1}{D_1} = 0.1$$

$$D_1 = 2 D_2$$

$$V_{f1} - V_{f2} = 6.862 \text{ m/s}$$

Thickness of vanes = 5% of circumferential area of runner.

$$\text{So Area of flow} = (100 - 5)\pi D_1 B_1$$

$$= 0.95 \pi D_1 B_1$$

$$\beta = 90^\circ$$

$$V_{w2} = 0$$

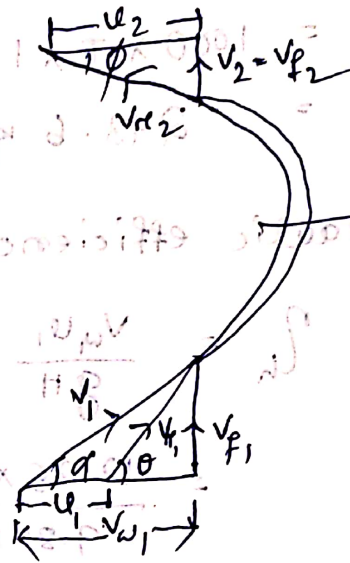
$$V_{f2} = V_2$$

To Find

$$\theta, \phi =$$

$$D_1, D_2 =$$

$$B_1 =$$



We know

$$\eta_0 = \frac{S.P}{W.P}$$

$$W.P = \frac{S.P}{\eta_0} = \frac{294.3}{0.84} = 350.357 \text{ kW}$$

$$\frac{9QH}{1000} = 350.357$$

$$\Rightarrow Q = \frac{350.357 \times 1000}{1000 \times 9.81 \times 60} = 0.5952 \text{ m}^3/\text{s}$$

$$\Rightarrow 0.95\pi D_1 B_1 V_{f1} = 0.5952$$

$$\Rightarrow 0.95 \times \pi \times D_1 \times 0.1 D_1 \times 6.862 = 0.5952$$

$$D_1 = 0.54 \text{ m}$$

$$\frac{B_1}{D_1} = 0.1$$

$$\Rightarrow B_1 = 0.1 D_1 = 0.054 \text{ m} = 54 \text{ mm}$$

Then

$$\begin{aligned} \omega_1 &= \frac{\pi D_1 N}{60} \\ &= \frac{\pi \times 0.54 \times 700}{60} = 19.79 \text{ m/s} \end{aligned}$$

We know

$$\eta_h = \frac{V_{w1} \omega_1}{gH}$$

$$\Rightarrow 0.93 = \frac{V_{w1} \times 19.79}{9.81 \times 60}$$

$$\Rightarrow V_{w1} = 27.66 \text{ m/s}$$

$$D_2 = \frac{D_1}{2} = \frac{0.54}{2} = 0.27 \text{ m}$$

$$\omega_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.27 \times 700}{60} = 9.895 \text{ m/s}$$



Guide blade angle (α)

$$\tan \alpha = \frac{V_{f1}}{V_{w1}} = \frac{6.862}{27.66}$$

$$\alpha = 13.928^\circ$$

(ii)

Runner vane angles θ & ϕ

$$\tan \theta = \frac{V_{f1}}{V_{w1} - u_1}$$

$$\theta = \tan^{-1} \left[\frac{6.862}{(27.66 - 19.79)} \right]$$
$$= 41.09^\circ$$

from outlet velocity triangle

$$\tan \phi = \frac{V_{f2}}{u_2}$$
$$= \frac{6.862}{9.895}$$

$$\phi = 34.74^\circ$$

(ii) Diameter of runner at inlet & outlet (D_1 & D_2)

$$D_1 = 0.54 \text{ m}$$

$$D_2 = 0.27 \text{ m}$$

(iv)

Width of wheel at inlet

$$B_1 = 54 \text{ mm}$$

1.5 KAPLAN TURBINE

- Kaplan Turbine is Axial flow reaction turbine
- If the water flows parallel to the axis of the rotation of the shaft, the turbine is known as axial flow turbine.
- If the energy available at inlet is both KE & PE and during the flow a part of pressure energy is converted into kinetic energy, the turbine is known as reaction turbine.
- In Axial flow reaction turbine, the shaft of the turbine is vertical. The lower end of the shaft is made larger which is known as hub or boss.
- The vanes are fixed on the hub and hence hub act as a runner. It is axial flow reaction turbine.

There are 2 types of Axial flow reaction turbine

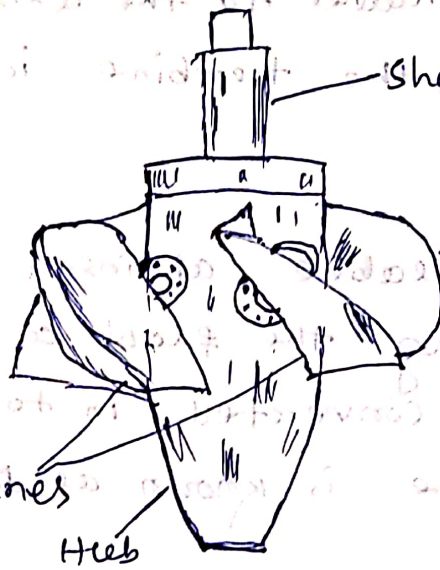
- Propeller Turbine

When the vanes are fixed to the hub and they are not adjustable, the turbine is known as propeller turbine.

- Kaplan Turbine

When the vanes on the hub are adjustable the turbine is known as Kaplan turbine (V. Kaplan, Austrian Engineer)

It is suitable where large quantity of water at low heads is available.



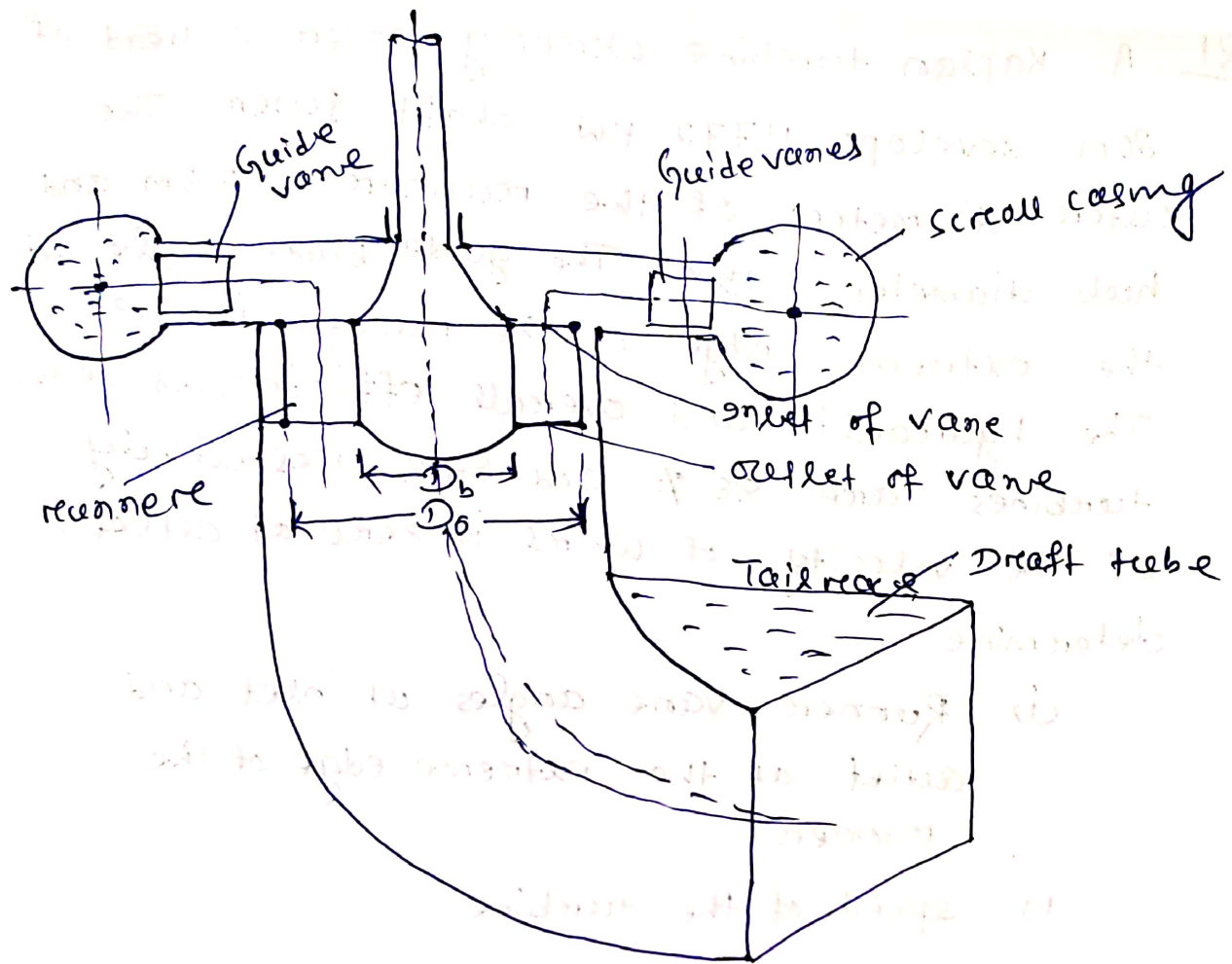
Kaplan turbine runner

Main parts of Kaplan turbine

- Scroll casing
- Guide vanes mechanism
- Hub with vanes or runner of the turbine
- Draft tube

Working

- The water from penstock enters the scroll casing and then moves to the guide vanes.
- From the guide vanes, the water turns through 90° and flows axially through the runner.



Some important points for Propeller/Kaplan turbine.

① Discharge through the runner of Kaplan turbine

$$Q = \frac{\pi}{4} (D_o^2 - D_b^2) V_{f1}$$

Where Area of flow = $\frac{\pi}{4} (D_o^2 - D_b^2)$

D_o = Outer dia of runner

D_b = Dia of hub

V_{f1} = velocity of flow at inlet

② $u_1 = u_2 = \frac{\pi D_o N}{60}$

③ $V_{f1} = V_{f2}$ (velocity of flow at inlet & outlet are constant.)

11.50-12

Q1 A Kaplan turbine working under a head of 20m develops 11772 kW shaft power. The outer diameter of the runner is 3.5m and hub diameter 1.75m. The guide blade angle at the extreme edge of the runner is 35° . The hydraulic and overall efficiencies of the turbine are 88% and 84% respectively. If the velocity of whirl is zero at outlet. determine

- Runner vane angles at inlet and outlet at the extreme edge of the runner.
- speed of the turbine

Solution

Given data

$$H = 20 \text{ m}$$

$$S.P = 11772 \text{ kW}$$

$$D_o = 3.5 \text{ m}$$

$$D_b = 1.75 \text{ m}$$

$$\alpha = 35^\circ$$

$$\eta_h = 88\%$$

$$\eta_o = 84\%$$

$$V_{w2} = 0 \text{ i.e } \beta = 90^\circ$$



$$u_1 = u_2 = \frac{\pi D_o N}{60}$$

we know

$$\eta_o = \frac{S.P}{W.P}$$

$$W.P = \frac{S.P}{\eta_o} = \frac{11772}{0.84}$$

$$\frac{9994}{1000} = \frac{11772}{0.84}$$

$$Q = \frac{11772 \times 1000}{0.84 \times 1000 \times 9.81 \times 20}$$

$$= 71.428 \text{ m}^3/\text{s}$$

$$\Rightarrow \frac{\pi}{4} (D_o^2 - D_i^2) V_{f1} = 71.428$$

$$V_{f1} = \frac{71.428}{\frac{\pi}{4} [(3.5)^2 - (1.75)^2]}$$

$$= 9.9 \text{ m/s}$$

we know

$$V_1 \sin \alpha = V_{f1}$$

$$V_1 = \frac{V_{f1}}{\sin 35^\circ} =$$

$$V_{w1} = V_1 \cos \alpha = \frac{V_{f1}}{\sin 35^\circ} \cos 35^\circ$$

$$= 14.14 \text{ m/s}$$

given

$$\eta_h = 88\%$$

$$\Rightarrow \frac{V_{w1} u_1}{g H} = 0.88$$

$$\Rightarrow u_1 = \frac{0.88 \times 9.81 \times 20}{14.14}$$

$$= 12.21 \text{ m/s}$$

(i) Runner vane angles i.e. θ, ϕ

$$\tan \theta = \frac{V_{f1}}{V_{w1} - u_1} = \frac{9.9}{14.14 - 12.21} = 5.13$$

$$\theta = \tan^{-1} 5.13 = 78.97^\circ$$

We know $u_1 = u_2 = 12.21 \text{ m/s}$ & $V_{f1} = V_{f2} = 9.9 \text{ m/s}$

$$\tan \phi = \frac{V_{f2}}{u_2} = \frac{9.9}{12.21}$$

$$\phi = 39.035^\circ$$

(ii) Speed of the turbine

$$u_1 = u_2 = \frac{\pi D_o N}{60}$$

$$\Rightarrow 12.21 = \frac{\pi \times 3.5 \times N}{60}$$

$$\Rightarrow N = \underline{66.63 \text{ rpm}} \quad \text{Ans}$$

Q.2 A Kaplan turbine develops 22000 kW at an average head of ~~30~~³⁵ m. Assuming a speed ratio 2 flow ratio of 0.6, diameter of the boss equal to 0.35 times the diameter of the runner and an overall efficiency of 88 percent. Calculate the diameter, speed and specific speed of the turbine.

Solution Given data

$$S.P = 22000 \text{ kW}$$

$$H = 35 \text{ m}$$

$$K_u = 2$$

$$K_f = 0.6$$

$$D_b = 0.35 D_o$$

$$\eta_o = 88 \%$$

$$V_{f1} = K_f \sqrt{2gH} = 0.6 \sqrt{2 \times 9.81 \times 35} \\ = 15.7 \text{ m/s}$$

$$u_1 = u_2 = K_u \sqrt{2gH} = 2 \sqrt{2 \times 9.81 \times 35} \\ = 52.4 \text{ m/s}$$

Diameter of the runner (D_o)

$$\text{we know } \eta_o = \frac{S.P}{W.P}$$
$$W.P = \frac{S.P}{\eta_o}$$

$$\Rightarrow \frac{9gQH}{1000} = \frac{22000}{0.88} \Rightarrow Q = 72.8 \text{ m}^3/\text{s}$$

$$\Rightarrow \frac{\pi}{4} [D_o^2 - (0.35 D_o)^2] V_{f1} = 72.8$$

$$\Rightarrow D_o = \underline{2.6 \text{ m}}$$

Speed

$$u_1 = u_2 = \frac{\pi D_o N}{60} \Rightarrow N = \frac{60 u_1}{\pi D_o} \Rightarrow N = \frac{60 \times 52.4}{\pi \times 2.6} \\ = 384.9 \text{ rpm}$$

Specific speed of the turbine

$$N_s = \frac{N \sqrt{P}}{H^{5/4}} = \frac{384.9 \times \sqrt{22000}}{(35)^{5/4}} \\ = 670.6 \text{ rpm}$$

Impulse Turbine

1. The energy available at the inlet of the turbine is only kinetic energy.
2. The pressure remains same (atmospheric) throughout the action of water on the runner.
3. Nozzle is used to form water jet to strike the runner of the turbine.
4. Runner is not full of water.
5. No draft tube is used.

Ex - Pelton wheel

Reaction Turbine

1. The energy available at the inlet of the turbine is both kinetic energy and pressure energy.
2. The pressure and velocity gradually changes while passing through the runner.
3. Guide wheel with guide vanes ~~are~~ is used to direct the water to runner.
4. Runner is always full of water.
5. Draft tube is used.

Ex - Francis and Kaplan turbine.

CHAPTER - 2

CENTRIFUGAL PUMPS

2.1 Construction and Working Principle of Centrifugal pump

Introduction

The hydraulic machines which convert the mechanical energy into hydraulic energy (pressure energy) are called pumps.

If the mechanical energy is converted into pressure energy by means of centrifugal force acting on the fluid, the hydraulic machine is called centrifugal pump.

Centrifugal Pump

- The centrifugal pump acts as a reversed of an inward radial flow reaction turbine. i.e. flow in centrifugal pumps is in the radial outward directions.
- It works on the principle of force vortex flow which means that when a certain mass of liquid is rotated by an external torque the rise in pressure head of the rotating liquid takes place.

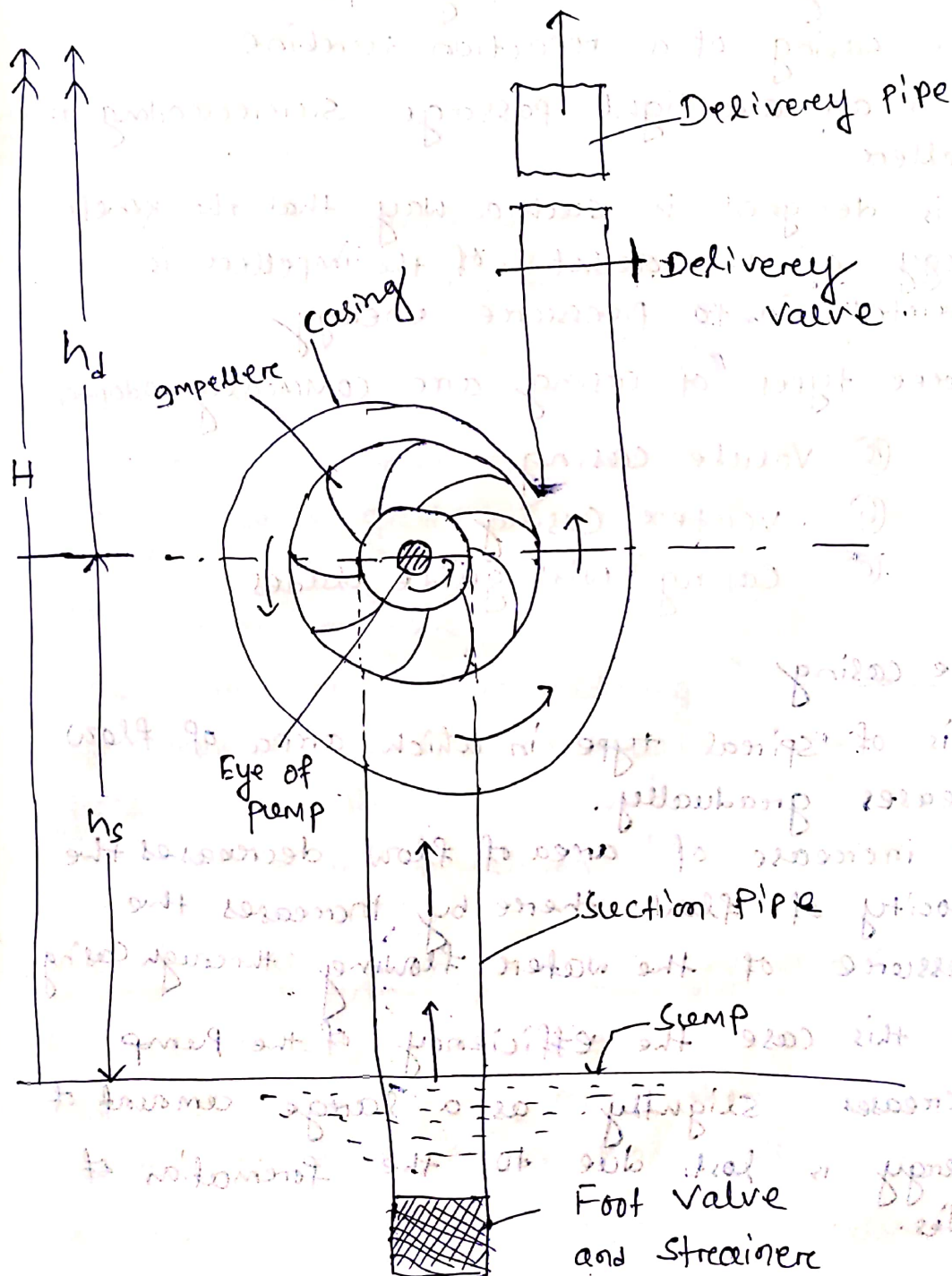
- rise in pressure head = $\frac{v^2}{2g}$ or $\frac{\omega^2 r^2}{2g}$

So at the outlet as the radius is more, the rise of pressure head will be more.

Main parts of a centrifugal pump

The main parts are

1. Impeller
2. Casing
3. Suction pipe with a foot valve and a strainer
4. Delivery pipe



Centrifugal pump

1. Impellere

The rotating part of a centrifugal pump is called 'impellere'. It consists of a series of backward curved vanes. The impellere is mounted on a shaft which is connected to the shaft of an electric motor.

2. Casing

- The casing of a centrifugal pump is similar to the casing of a reaction turbine.
- It is an air tight passage surrounding the impellere
- It is designed in such a way that the kinetic energy at the outlet of the impellere is converted into pressure energy

Three types of casings are commonly adopted.

(a) Volute casing

(b) Vortex casing

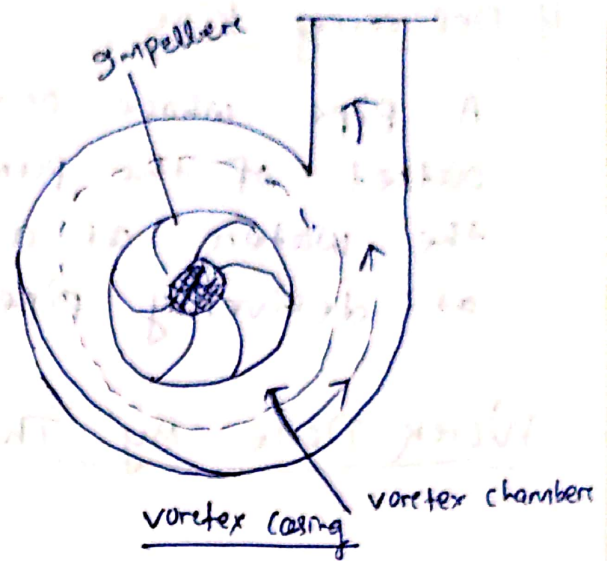
(c) casing with guide blades

Volute casing

- It is of spiral type in which area of flow increases gradually.
- The increase of area of flow decreases the velocity of flow, thereby increases the pressure of the water flowing through casing.
- In this case the efficiency of the pump increases slightly as a large amount of energy is lost due to the formation of eddies.

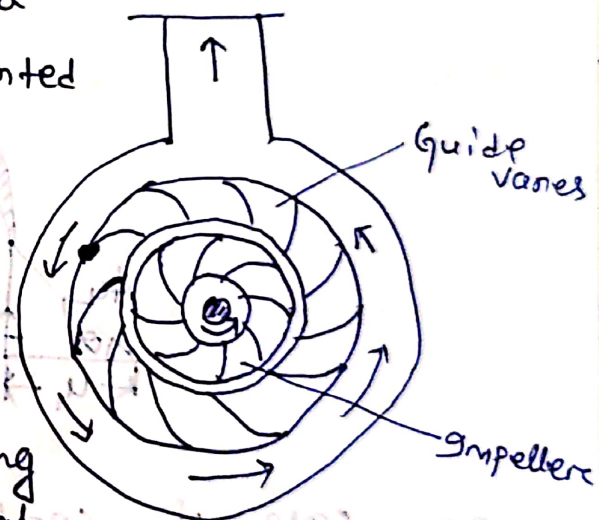
Vortex casing

- If a circular chamber is introduced between the casing and impeller is known as vortex casing.
- Due to this the loss of energy due to the formation of eddies is reduced to a considerable extent.



Casing with Guide Blades

- The casing in which the impeller is surrounded by a series of guide blades mounted on a ring which is called diffuser is known as casing with guide blades.
- The area of the guide vanes increases thus reducing the velocity of flow through guide vane thus increasing the pressure of water.



③ Suction Valve with a foot valve and strainer

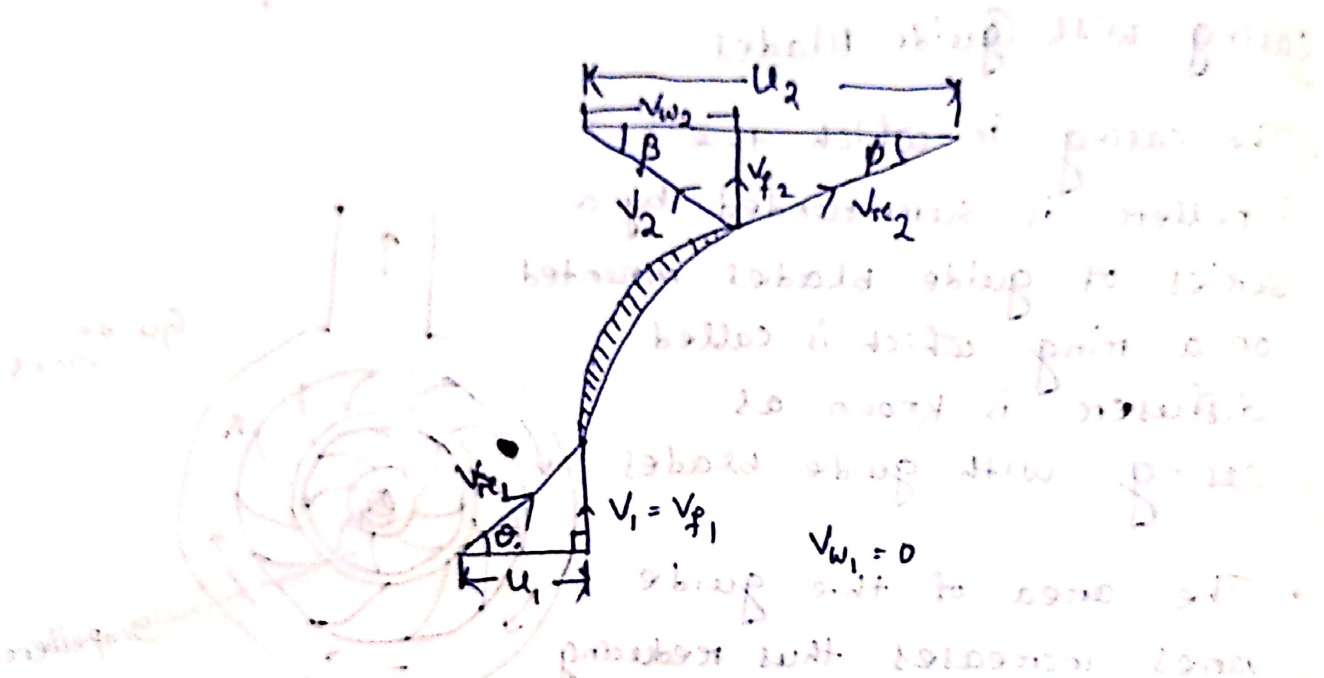
- A pipe whose one end is connected to the inlet of the pump and other end dips into water in a sump is known as suction pipe.
- A foot valve is a non return valve which is fitted at the lower end of the suction pipe.

- A strainer is also fitted at the lower end of the suction pipe.

4 Delivery Pipe

A pipe whose one end is connected to the outlet of the pump and other end delivers the water at a required height is known as delivery pipe.

Work Done By The Centrifugal Pump



In case of centrifugal pump, work is done on the system.

The water enters the impeller radially at inlet for best efficiency.

The absolute velocity at inlet makes an angle of 90° with the direction of motion.

$$\theta = 90^\circ, \quad V_{w1} = 0$$

Let N = Speed of the impeller in r.p.m

D_1 = Diameter of impeller at inlet

D_2 = Diameter of impeller at outlet

$$u_1 = \frac{\pi D_1 N}{60} = \text{Tangential velocity at inlet}$$

$$u_2 = \frac{\pi D_2 N}{60} = \text{Tangential velocity at outlet}$$

A centrifugal pump is the reverse of a radially inward flow reaction turbine.

For a radially inward flow reaction turbine

$$\text{Workdone/sec} = \rho Q [V_{w1} u_1 - V_{w2} u_2]$$

Then workdone/sec by the impeller of the centrifugal pump on the water

$$= - \left(\text{Workdone/sec in case of inward radial flow reaction turbine} \right)$$

$$= - \rho Q [V_{w1} u_1 - V_{w2} u_2]$$

$$\Rightarrow \rho Q [V_{w2} u_2 - V_{w1} u_1]$$

We know $V_{w1} = 0$ then workdone/sec = $\rho Q [V_{w2} u_2]$

workdone/sec / unit weight of water/sec

$$= \frac{\text{Workdone/sec}}{\text{weight/sec}}$$

$$= \frac{\rho Q [V_{w2} u_2]}{\rho Q g}$$

$$= \frac{1}{g} [V_{w2} u_2]$$

Q = Volume of water / sec

$$\pi D_1 B_1 V_{f1} = \pi D_2 B_2 V_{f2}$$

B_1, B_2 are width of impeller at inlet and outlet

V_{f1}, V_{f2} are velocity of flow at inlet and outlet

Definitions of heads and efficiencies of a centrifugal pump.

Suction Head (h_s)

It is the vertical height of the centre line of the centrifugal pump above the water

surface in the tank or sump from which water is to be lifted

This height is also called suction lift.

It is denoted by h_s .

2. Delivery Head (h_d)

The vertical distance between the centre line of the pump and the water surface in the tank to which water is delivered is known as delivery head.

It is denoted by h_d .

3. Static Head (H_s)

The sum of suction head and delivery head is known as static head:

$$H_s = h_s + h_d$$

4. Manometric Head (H_m)

The manometric head is defined as the head against which a centrifugal pump has to work. It is denoted by H_m .

$$\textcircled{a} \quad H_m = \text{Head imparted by the impeller to the water} - \text{Loss of head in the pump} \\ = \frac{V_{w2} u_2}{g} - \text{Loss of head in impeller casing}$$

$$\textcircled{b} \quad H_m = \text{Total head at outlet} - \text{Total head at inlet} \\ = \left(\frac{P_o}{\rho g} + \frac{V_o^2}{2g} + z_o \right) - \left(\frac{P_i}{\rho g} + \frac{V_i^2}{2g} + z_i \right)$$

$$\textcircled{c} \quad H_m = h_s + h_d + h_{fs} + h_{fd} + \frac{V_d^2}{2g}$$

Efficiencies of a centrifugal pump

Power transmission in case of centrifugal pump is

$$\boxed{S.P > I.P > W.P}$$

The important efficiencies are

① Manometric efficiency (η_{man})

② Mechanical efficiency (η_m)

③ Overall efficiency (η_o)

(a) Manometric Efficiency (η_{man})

The ratio of manometric head to the head imparted by the impeller to the water is known as manometric efficiency.

$$\eta_{man} = \frac{H_m}{\frac{V_{w2} u_2}{g}}$$
$$= \frac{g H_m}{V_{w2} u_2}$$

Or

$$\eta_{man} = \frac{W.P}{I.P}$$
$$= \frac{\rho g Q H_m}{\rho Q [V_{w2} u_2]}$$
$$= \frac{g H_m}{V_{w2} u_2}$$

(b) Mechanical Efficiency (η_m)

The power at the shaft of the centrifugal pump is more than the power available at the impeller of the pump. The ratio of impeller power to shaft power is known as Mechanical Efficiency.

$$\eta_m = \frac{I.P}{S.P}$$
$$= \frac{\rho Q [V_{w2} u_2]}{S.P}$$

② Overall Efficiency (η_o)

It is defined as the ratio of power output of the pump to the power input to the pump.

$$\eta_o = \frac{W.P}{S.P}$$

$$= \frac{\rho g Q H_m}{S.P}$$

also

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

Q1 The internal and external diameters of the impeller of a centrifugal pump are 200 mm and 400 mm respectively. The pump is running at 1200 rpm. The vane angles of the impeller at inlet and outlet are 20° and 30° respectively. The water enters the impeller radially and velocity of flow is constant. Determine the work done by the impeller per unit weight of water.

Solution

Given data

$$D_1 = 200 \text{ mm} = 0.2 \text{ m}$$

$$D_2 = 400 \text{ mm} = 0.4 \text{ m}$$

$$N = 1200 \text{ rpm}$$

$$\theta = 20^\circ$$

$$\phi = 30^\circ$$

Water enters the impeller radially i.e. $V_{w1} = 0$, $\alpha = 90^\circ$

$$V_{f1} = V_{f2}$$

To find

$$\text{Work done / unit weight of water} = \frac{V_{w2} u_2}{g}$$

We know

$$u_1 = \frac{\pi D_1 N}{60} = 12.56 \text{ m/s}$$

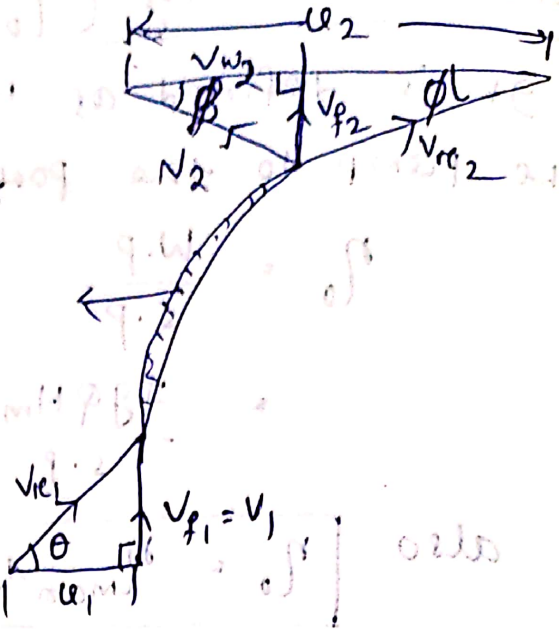
$$u_2 = \frac{\pi D_2 N}{60} = 25.13 \text{ m/s}$$

$$\tan \theta = \frac{v_{f1}}{u_1}$$

$$\Rightarrow v_{f1} = u_1 \tan \theta$$

$$= 12.56 \tan 20$$

$$= 4.57 \text{ m/s}$$



We know $v_{f1} = v_{f2} = 4.57 \text{ m/s}$

$$\tan \phi = \frac{v_{f2}}{u_2 - v_{w2}}$$

$$\Rightarrow v_{w2} = 17.215 \text{ m/s}$$

The work done by impeller per unit weight

$$= \frac{v_{w2} u_2}{g}$$

$$= \frac{17.215 \times 25.13}{9.81} = 44.1 \text{ M}$$

Q.2 A centrifugal pump is to discharge $0.118 \text{ m}^3/\text{s}$ at a speed of 1450 rpm against a head of 25 m . The impeller diameter is 250 mm , its width at outlet is 50 mm and manometric efficiency is 75% . Determine the Vane angle at the outer periphery of the impeller.

Solution Given data

$$Q = 0.118 \text{ m}^3/\text{s}$$

$$N = 1450 \text{ rpm}$$

$$H_m = 25 \text{ m}$$

$$D_2 = 250 \text{ mm} = 0.25 \text{ m}$$

$$B_2 = 50 \text{ mm} = 0.05 \text{ m}$$

$$\eta_{\text{man}} = 75\% = 0.75$$

To find

$$\phi =$$

we know

$$u_2 = \frac{\pi D_2 N}{60} = 18.98 \text{ m/s}$$

$$Q = \pi D_2 B_2 v_{f2}$$

$$\Rightarrow v_{f2} = \frac{Q}{\pi D_2 B_2} = \frac{0.118}{\pi \times 0.25 \times 0.05} = 3.0 \text{ m/s}$$

$$\eta_{\text{man}} = \frac{g H_m}{v_{w2} u_2} = 0.75$$

$$\Rightarrow \frac{g \times 25}{v_{w2} \times 18.98} = 0.75$$

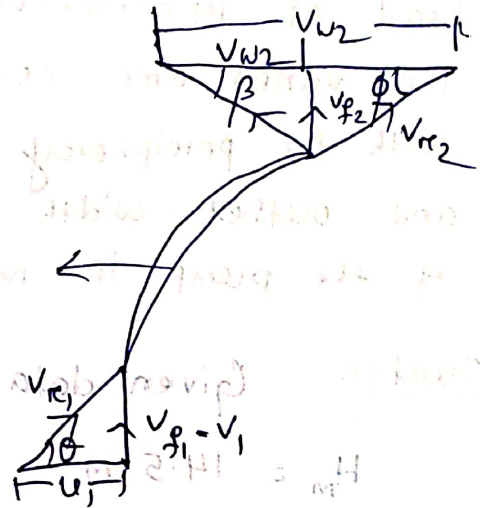
$$\Rightarrow v_{w2} = 17.23 \text{ m/s}$$

on outlet velocity triangle

$$\tan \phi = \frac{v_{f2}}{u_2 - v_{w2}}$$

$$\Rightarrow \phi = \tan^{-1} \frac{3.0}{18.98 - 17.23}$$

$$\phi = 59.74^\circ \quad \underline{\text{Ans}}$$



Q3. A centrifugal pump delivers water against a head of 14.5 metres and a design speed of 1000 rpm. The vanes are curved back to an angle of 30° with the periphery. The impeller diameter is 300 mm and outlet width 50 mm. Determine the discharge of the pump if manometric efficiency is 95%.

Solution Given data

$$H_m = 14.5 \text{ m}$$

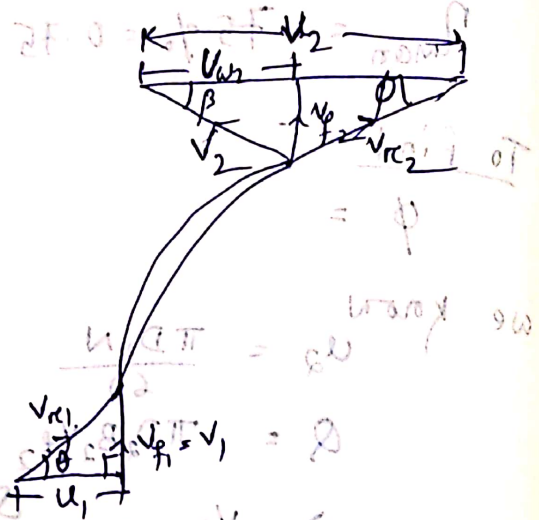
$$N = 1000 \text{ rpm}$$

$$\phi = 30^\circ$$

$$D_2 = 300 \text{ mm} = 0.3 \text{ m}$$

$$B_2 = 50 \text{ mm} = 0.05 \text{ m}$$

$$\eta_{\text{man}} = 95\% = 0.95$$



To find

$$Q = \pi D_2 B_2 V_{f2}$$

We know $u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.3 \times 1000}{60} = 15.70 \text{ m/s}$

$$\eta_{\text{man}} = \frac{g H_m}{V_{w2} u_2}$$

$$\Rightarrow V_{w2} = \frac{g H_m}{u_2 \times \eta_{\text{man}}} = \frac{9.81 \times 14.5}{15.7 \times 0.95} = 9.54 \text{ m/s}$$

In the outlet velocity triangle

$$\tan \phi = \frac{V_{f2}}{u_2 - V_{w2}}$$

$$\Rightarrow V_{f2} = \tan \phi (u_2 - V_{w2}) = 3.556 \text{ m/s}$$

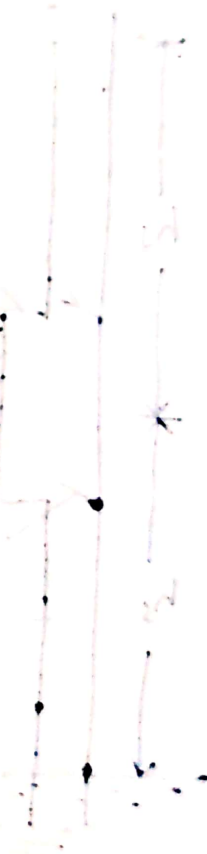
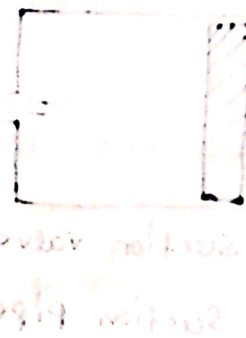
Then $Q = \pi D_2 B_2 V_{f2}$

$$= \pi \times 0.3 \times 0.05 \times 3.556$$

$$= 0.1675 \text{ m}^3/\text{sec} \text{ Ans}$$

CHAPTER-3

RECIPROCATING PUMP



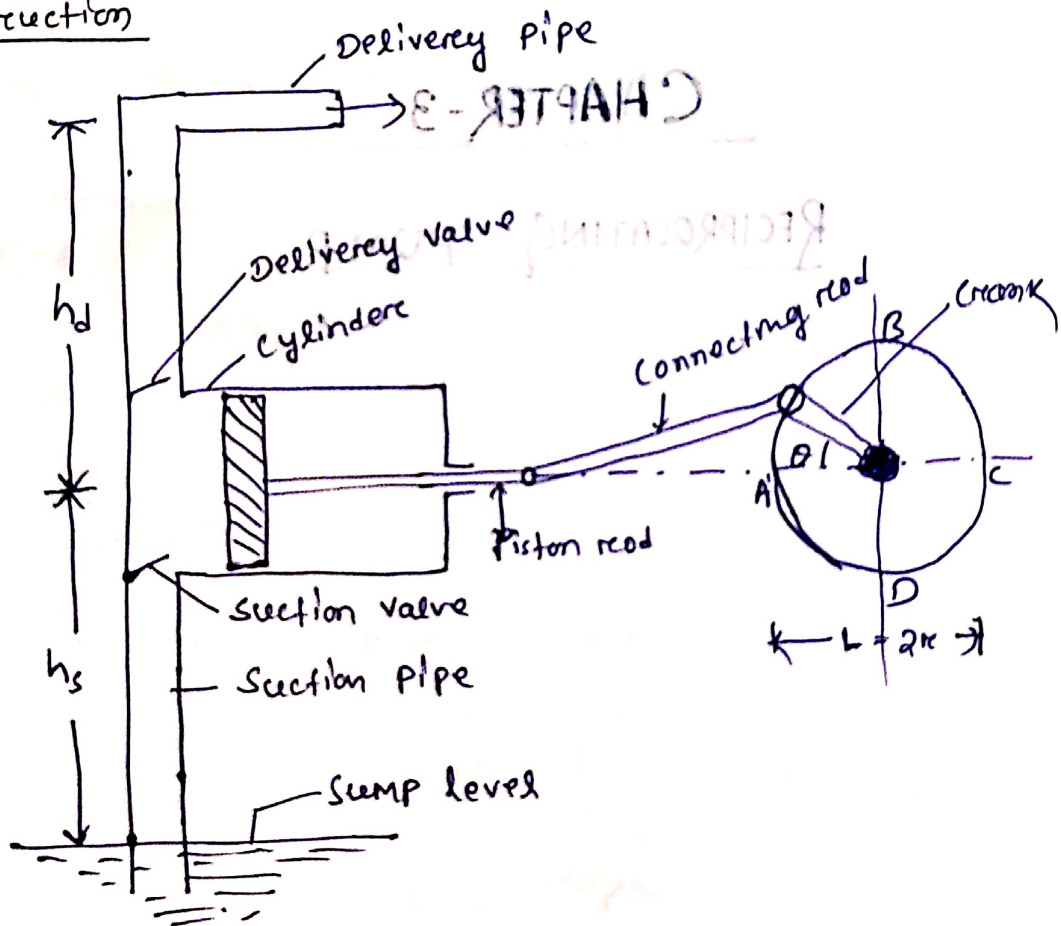
RECIPROCATING PUMPS

3.0

Reciprocating pump is a hydraulic machine which converts mechanical energy into hydraulic energy (or pressure energy) by sucking the liquid into a cylinder in which a piston is reciprocating which exerts the thrust on the liquid and increases its hydraulic energy.

3.1 Construction and working of a single acting Reciprocating pump

Construction



Main parts of a reciprocating pump

1. A cylinder with a piston, piston rod, connecting rod and a crank
2. Suction pipe
3. Delivery pipe

4. Suction Valve

5. Delivery Valve

Working

- A single acting reciprocating pump consists of a piston which moves forwards and backwards (reciprocates) in a close fitting cylinder.
- The movement of piston is obtained by connecting rod which connects the piston to the crank. The crank is rotated by means of an electric motor.
- Suction pipes and delivery pipes with suction valve and delivery valve are connected to the cylinder.
- The suction and delivery valves are non return valves.
- When the crank starts rotating, the piston moves to & fro in the cylinder. When crank is at A, the piston is at extreme left position. As the crank starts rotating from A to C i.e. 0° to 180° , the piston moves right in the cylinder by creating partial vacuum in the cylinder. Due to the pressure difference the liquid is forced in the suction pipe from sump, opens the suction valve and enters in to the cylinder.
- When crank is rotating from C to A i.e. 180° to 360° , the piston from its extreme right position starts moving towards left in the cylinder. The movement of piston increases the pressure of the liquid. Hence suction valve closes and delivery valve

opens. The liquid is forced in to the delivery pipe and raised to a required height.

Discharge through a Reciprocating Pump

Let D = Diameter of the cylinder

A = Cross-sectional area of the piston or cylinder

$$= \frac{\pi}{4} D^2$$

r = Radius of crank

N = r.p.m. of the crank

$L = 2r$ = Length of the stroke

h_s = Height of the axis of cylinder from water surface in sump

h_d = Height of delivery outlet above the cylinder axis or delivery head

Volume of water delivered in one revolution

$$= \text{Area} \times \text{length} = AL$$

$$\text{No. of revolution per second} = \frac{N}{60}$$

Discharge of the pump per second

$$= AL \times \frac{N}{60} = \frac{ALN}{60}$$

Weight of water delivered per second

$$W = \rho g Q = \frac{\rho g ALN}{60}$$

Work done / second = Weight of water lifted per second

$\times$ Total height through which water is lifted

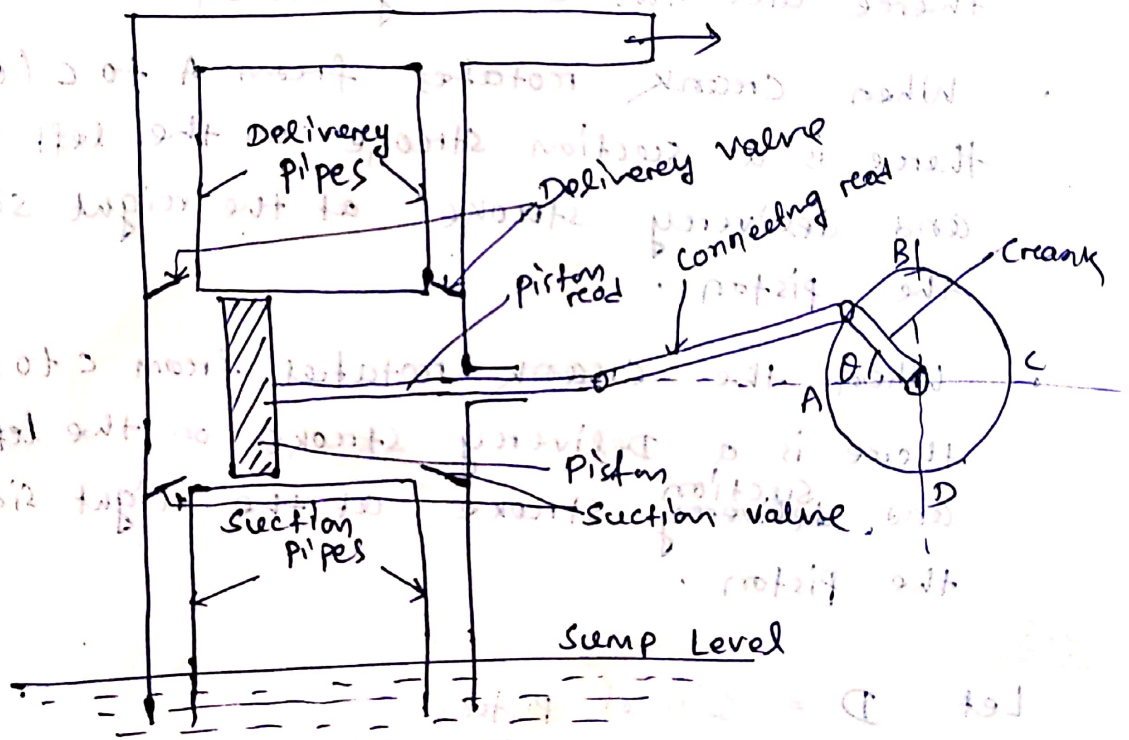
$$= W \times (h_s + h_d)$$

$$= \frac{\rho g A L N}{60} \times (h_s + h_d)$$

Power required to drive the pump in kw

$$= \frac{\rho g \times A L N \times (h_s + h_d)}{60,000}$$

3.2 Construction and Working of double acting Reciprocating Pump



Main components

1. A cylinder with a piston, piston rod, connecting rod and a crank
2. Two suction pipes
3. Two delivery pipes
4. Two suction valves
5. Two delivery valves

Working

- In case of double acting pump, the water is acting on both sides of the piston. Thus two suction pipes and two delivery pipes for double acting pump.
- When there is a suction stroke on one side of the piston, there is at the same time a delivery stroke on the other side of the piston.
- For one complete revolution of the crank there are two delivery strokes.
- When crank rotates from A to C ($\theta = 0^\circ$ to 180°) there is a suction stroke on the left side and delivery stroke at the right side of the piston.
- When the crank rotates from C to A ($\theta = 180^\circ$ to 360°) there is a delivery stroke on the left side and ~~delivery~~ suction stroke at the right side of the piston.

3.3

Let D = Dia of piston

d = Dia of piston rod

Area on one side of piston = $A_1 = \frac{\pi}{4} D^2$

Area on other side of piston = $A_2 = \frac{\pi}{4} D^2 - \frac{\pi}{4} d^2$
 $= \frac{\pi}{4} (D^2 - d^2)$

Total Area of flow

$$= A_1 + A_2$$

$$= \frac{\pi}{4} D^2 + \frac{\pi}{4} (D^2 - d^2)$$

Discharge of the pump

= Volume of water delivered per second

$$= (A_1 + A_2) \frac{LN}{60}$$

$$= \left[\frac{\pi}{4} D^2 + \frac{\pi}{4} (D^2 - d^2) \right] \frac{LN}{60}$$

d is very small as compared to D , then it can be neglected

$$\text{So } Q = 2 \times \frac{\pi}{4} D^2 \times \frac{LN}{60}$$

$$= \frac{2 A L N}{60}$$

Work done / sec = weight of water delivered $\times$ Total height

$$= \rho g Q \times (h_s + h_d)$$

$$= 2 \frac{\rho g A L N}{60} (h_s + h_d)$$

3.4 SLIP of Reciprocating pump.

Slip of a pump is defined as the difference between the theoretical discharge and actual discharge of pump.

The actual discharge of a pump is less than the theoretical discharge due to leakage.

$$\text{Slip} = Q_{th} - Q_{act}$$

$$\begin{aligned} \% \text{ge of slip} &= \frac{Q_{th} - Q_{act}}{Q_{th}} \times 100 = \left(1 - \frac{Q_{act}}{Q_{th}} \right) \times 100 \\ &= (1 - C_d) 100 \quad \because C_d = \text{co-efficient of discharge} \end{aligned}$$



Positive and negative slip and percentage of slip

Positive slip

When theoretical discharge (Q_{th}) is more than the actual discharge, the slip of the pump is called as positive slip.

$$Q_{th} > Q_{act}$$

Slip is +ve

Negative slip

When actual discharge is more than the theoretical discharge, the slip of the pump is called as negative slip.

$$Q_{act} > Q_{th}$$

Slip is -ve

Negative slip occurs when delivery pipe is short, suction pipe is long and pump is running at high speed.

$$\% \text{ slip} = \left(\frac{Q_{th} - Q_{act}}{Q_{th}} \right) \times 100$$

$$\text{Slip} = Q_{th} - Q_{act}$$

$$\% \text{ slip} = \frac{Q_{th} - Q_{act}}{Q_{th}} \times 100$$

3.6 Numericals

Q.1 A single acting reciprocating pump running at 50 r.p.m., delivers $0.01 \text{ m}^3/\text{s}$ of water. The diameter of the piston is 200 mm and stroke length 400 mm. Determine

- The theoretical discharge
- Co-efficient of discharge
- Slip and the percentage of slip of the pump.

Solution

Given data

$$N = 50 \text{ r.p.m.}$$

$$Q = 0.01 \text{ m}^3/\text{s}$$

$$D = 200 \text{ mm} = 0.2 \text{ m}$$

$$A = \pi/4 D^2 = 0.031416 \text{ m}^2$$

$$L = 400 \text{ mm} = 0.4 \text{ m}$$

(i) Theoretical discharge

$$Q_{th} = \frac{A L N}{60} = \frac{0.031416 \times 0.4 \times 50}{60}$$

$$= 0.01047 \text{ m}^3/\text{s}$$

(ii)

Co-efficient of discharge

$$C_d = \frac{Q_{act}}{Q_{th}} = \frac{0.01}{0.01047} = 0.955$$

(iii)

$$\begin{aligned} \text{Slip} &= Q_{th} - Q_{act} \\ &= 0.01047 - 0.01 = 0.00047 \text{ m}^3/\text{s} \end{aligned}$$

$$\begin{aligned} \% \text{ of slip} &= (1 - C_d) \times 100 \\ &= (1 - 0.955) \times 100 = 4.489\% \end{aligned}$$

Q.2 A double acting reciprocating pump, running at 40 r.p.m., is discharging 1.0 m^3 of water per minute. The pump has a stroke of 400 mm. The diameter of the piston is 200 mm. The delivery and suction heads are 20 m and 5 m respectively. Find the slip of the pump and power required to drive the pump.

Solution

Given data

$$N = 40 \text{ r.p.m.}$$

$$Q_{\text{act}} = 1.0 \text{ m}^3/\text{min} = \frac{1.0}{60} \text{ m}^3/\text{sec}$$

$$= 0.01666 \text{ m}^3/\text{s}$$

$$L = 400 \text{ mm} = 0.4 \text{ m}$$

$$D = 200 \text{ mm} = 0.2 \text{ m}$$

$$h_d = 20 \text{ m}$$

$$h_s = 5 \text{ m}$$

(i) Theoretical discharge

$$Q_{\text{th}} = \frac{A L N}{60} = \frac{\frac{\pi}{4} (0.2)^2 \times 0.4 \times 40}{60}$$

$$= 0.01675 \text{ m}^3/\text{s}$$

$$\text{Slip} = Q_{\text{th}} - Q_{\text{act}}$$

$$= 0.01675 - 0.01666$$

$$= 0.00009 \text{ m}^3/\text{s}$$

(ii) Power required to drive the pump

$$P = \frac{2.39 A L N (h_s + h_d)}{60,000}$$

$$= \frac{2 \times 1000 \times 9.81 \times 0.031416 \times 0.4 \times 40 \times (20+5)}{60,000}$$

$$= 4.109 \text{ kW} \quad \underline{\text{Ans}}$$

Q3 The cylinder bore diameter of a single acting reciprocating pump is 150 mm and its stroke is 300 mm. The Pump runs at 50 r.p.m and lifts water through a height of 25 m. ~~The delivery pipe is 22 m long and 100 mm in diameter.~~ Find the theoretical discharge and the theoretical power required to run the pump. If the actual discharge is 4.2 lts/sec find the Percentage slip.

Introduction

Fluid Power : It is the technology that deals with the generation, control and transmission of power, using pressurized fluids.

- It can be said that fluid power is the muscle that moves industry.
- This is because fluid power is used to push, pull, regulate or drive virtually all the machines of modern industry.

Examples - • Fluid power steers and brakes

in automobiles
PNEUMATIC CONTROL SYSTEM

- Launches spacecraft
- drives machine tools
- Controls airplanes
- Processes food
- even drills teeth

Fluid power is called hydraulic fluid power when liquid is used as working fluid. and is called pneumatic fluid power when the fluid used is a gas.

Advantages of Fluid Power

- Ease and accuracy of control
- Multiplication of Force
- Constant force or torque
- Simplicity, safety, economy.

Disadvantages:

- Oil leakage from the hydraulic system.
- Excessive oil pressure will lead to bursting of pipeline.
- Noisy.

Applications

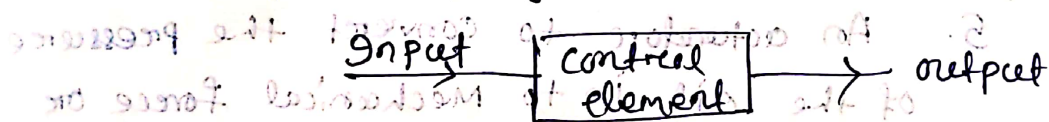
- Fluid Power drives high - wire overhead tress.
- Fluid Power is applied to harvesting soybeans.
- Fluid Power drives excavators.
- Hydraulics power robot to rescue humans.

Types of Fluid Power System

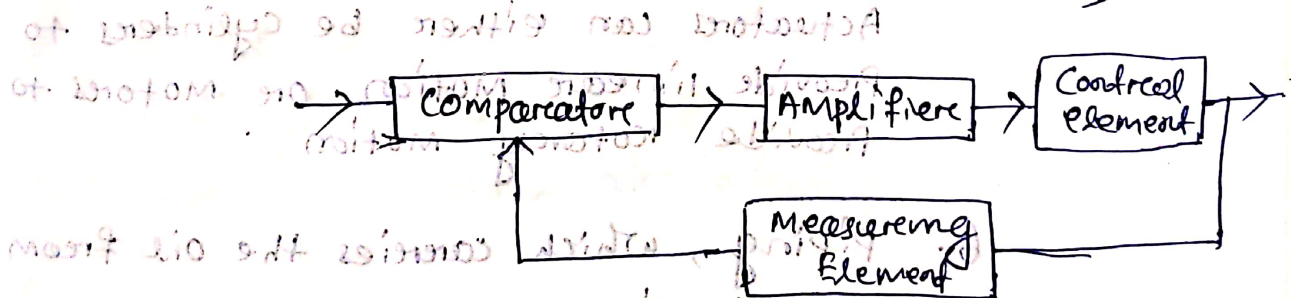
Fluid Power System can be categorised in different ways.

1. Based on Control System

- Open-loop system (No feedback)



- Closed-loop system (uses feedback)



2. Based on the type of control

- Fluid logic control: This type of fluid power system is controlled by hydraulic oil itself.
- Electrical control: It is control by ~~hydraulic~~ electrical devices.

On this type, the fluid system is controlled by microelectronic devices.

Components of a Fluid Power system

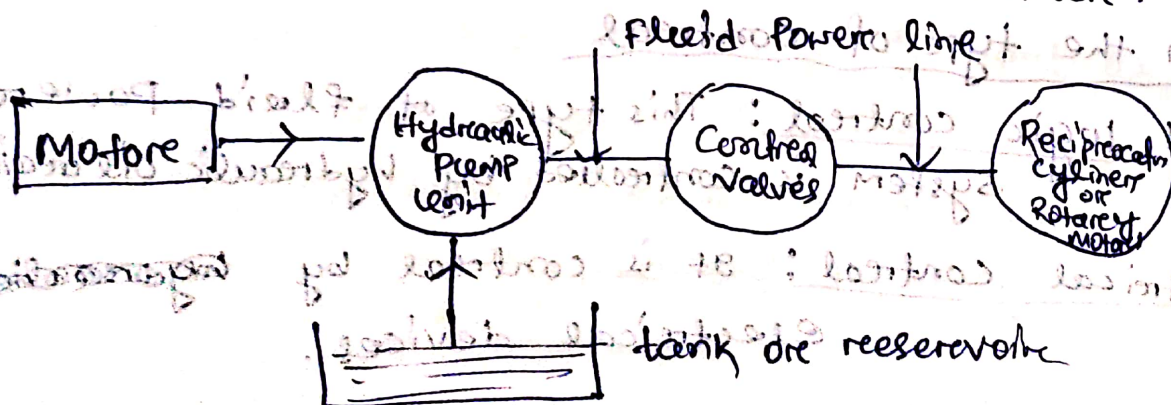
Hydraulic system :

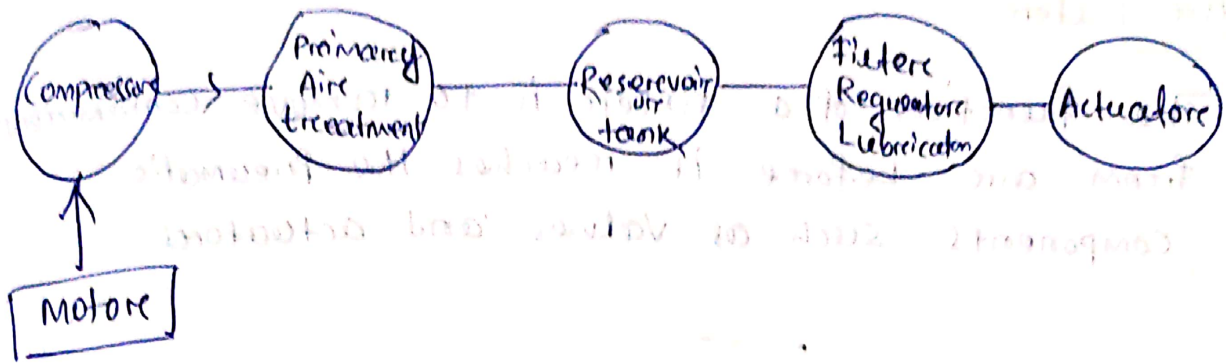
There are five basic components required in a hydraulic system.

1. A tank (reservoir) to hold the hydraulic oil
2. A pump to force the oil through the system
3. An electric motor or other power source to drive the pump
4. Valves to control oil direction, pressure and flow rate.
5. An actuator to convert the pressure of the oil into mechanical force or torque to do useful work.

Actuators can either be cylinders to provide linear motion or motors to provide rotary motion.

6. Piping, which carries the oil from one location to another.





Basic Pneumatic system

Pneumatic System

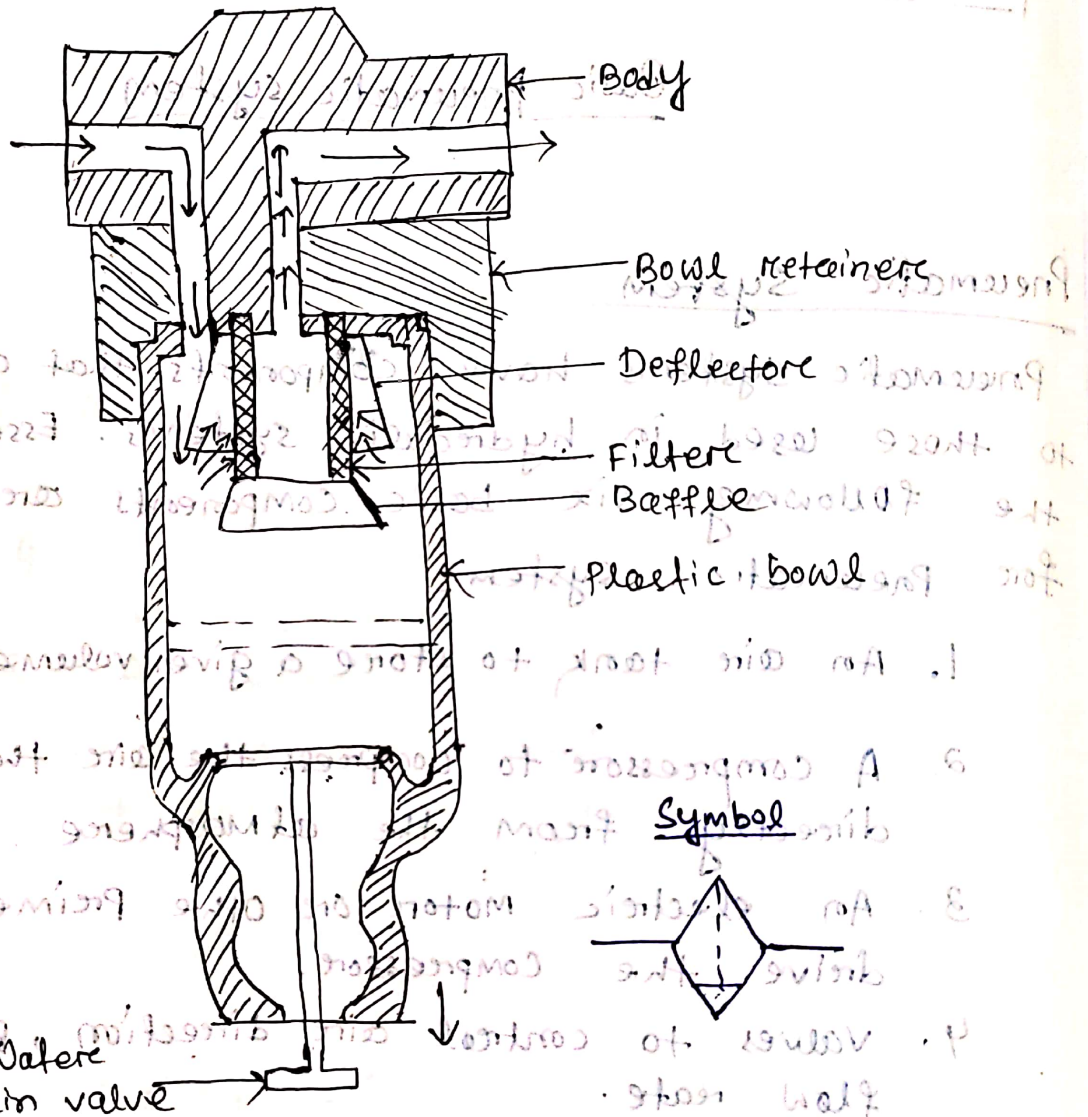
Pneumatic systems have components that are similar to those used in hydraulic systems. Essentially the following six basic components are required for pneumatic system.

1. An air tank to store a given volume of compressed air.
2. A compressor to compress the air that comes directly from the atmosphere.
3. An electric motor or other prime mover to drive the compressor.
4. Valves to control air direction, pressure and flow rate.
5. Actuators, which are similar in operation to hydraulic actuators.
6. Piping to carry the pressurised air from one location to another.

9.1 Elements Filter, Regulator, Lubrication unit

Air Filter

- The function of a filter is to remove contaminants from air before it reaches the pneumatic components such as valves and actuators.



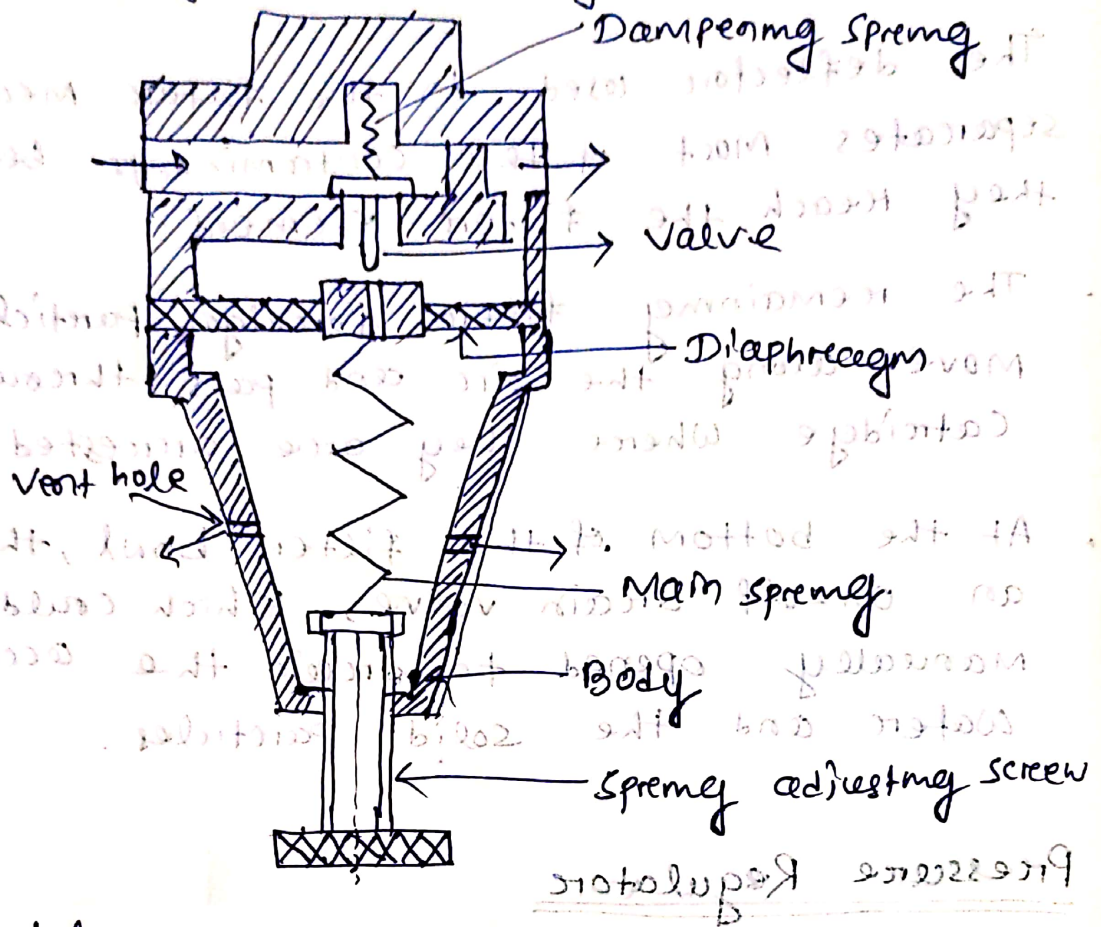
- The main components of a filter is the filter cartridge, which is mostly made of sintered brass or bronze and other materials.
- They remove contaminants in the range of 5 to 50 microns.

- Air flow entering the filter is directed downward with a swirling motion that forces the moisture and the heavier particles to fall down.
- The deflector used in the filter mechanically separates most of the contaminants before they reach the filter element.
- The remaining finer foreign particles move along the air and pass through the cartridge where they are arrested.
- At the bottom of the filter bowl, there is an on-off drain valve, which could be manually opened to drain the accumulated water and the solid particles.

Pressure Regulator

- The main function of this valve is to regulate the incoming pressure to the system so that the desired air pressure is capable of flowing at a steady condition.
- The valve has a metallic body with primary and secondary openings.
- The pressure regulation is obtained by opening the poppet valve to a measured amount for achieving the desired pressure level.
- This is done by adjusting screw. The adjusting screw will move the diaphragm upward and

thus will make the Poppet to coast, thereby creating an opening for the flow of air from the primary to secondary side.



Symbol



- The opening of the valve and the pressure of air flowing will directly be proportional to the compression of the spring under the diaphragm.
- Larger the opening greater the pressure.
- The valve has two vent holes through which the compressed air goes out to the atmosphere in case the secondary pressure increases to a level not desirable for the system.

- Spring on other side of the poppet acts as a dampening device to stabilize the pressure.

Lubricator

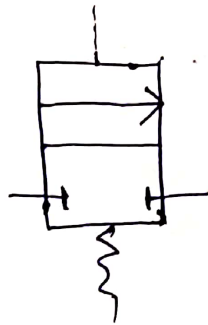
- The function of the lubricator is to insert drops of oil into the air stream.
- A small amount of air from the mainstream is diverted through the bowl pressure control valve into the bowl or reservoir.
- This air pushes the oil through the siphon tube past the adjustment screw to the drip tube.
- The drops of oil are then transferred through the center of the variable orifice and enter 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.

4.3 Directional Control valves

- Directional 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.

Two-way directional control valve

- This is an on-off type of device.
- This valve is usually provided with two external flow ports; a supply port and exhaust port.
- This valve is available to operate either normally open or normally closed.

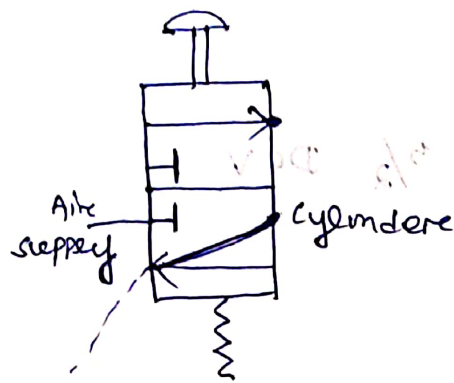


2/2 DCV

Three way directional control valve

- In this, one flow port is connected to either of the other two ports.
- It may be alternatively used to pressurise one port and exhaust the other port.
- These valves may be used to control single acting cylinders or in pairs to

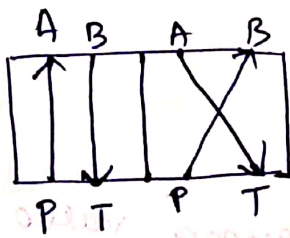
Control double acting cylinders.



$3/2$ DCV

Four-way directional control valves

- 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 working port to the exhaust.
- When the valve is shifted, the flow paths are reversed.

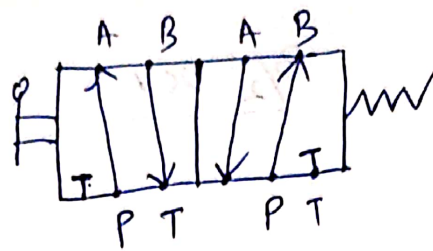


$4/2$ DCV

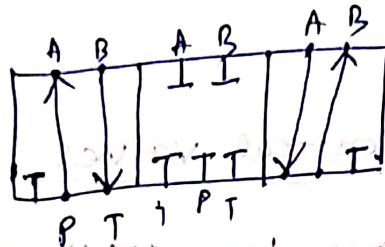
Five-way directional control valves

- In most of the designs of DCVs, five ports are preferred instead of four ports.
- 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 cylinders.

movement. Dual exhaust enables easy exhaustion of the valve.

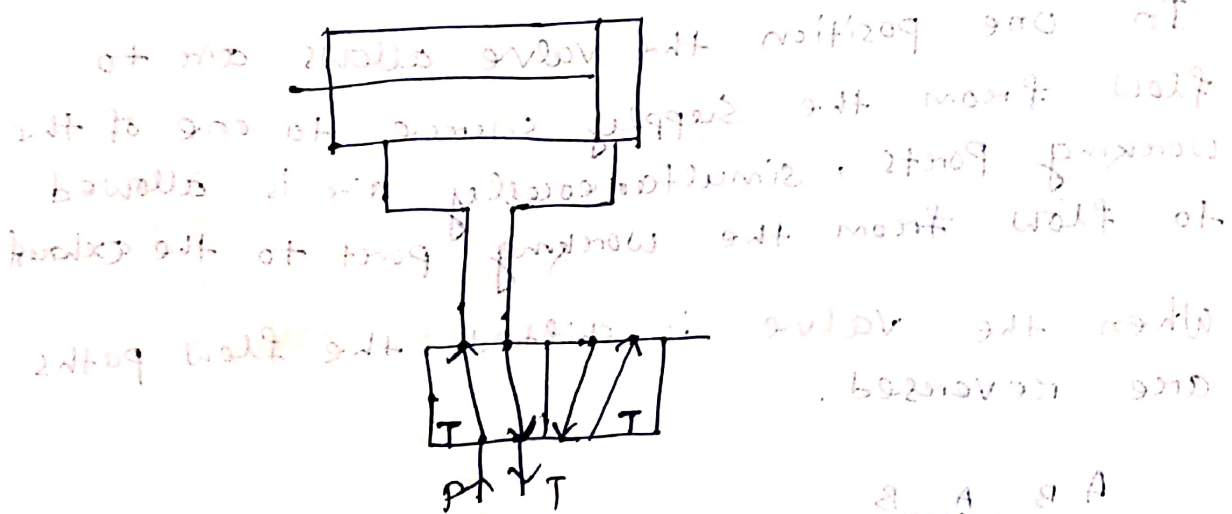


5/2 DCV



5/3 DCV

... that ... out even ... ports ...
... that ... as ... ports ...

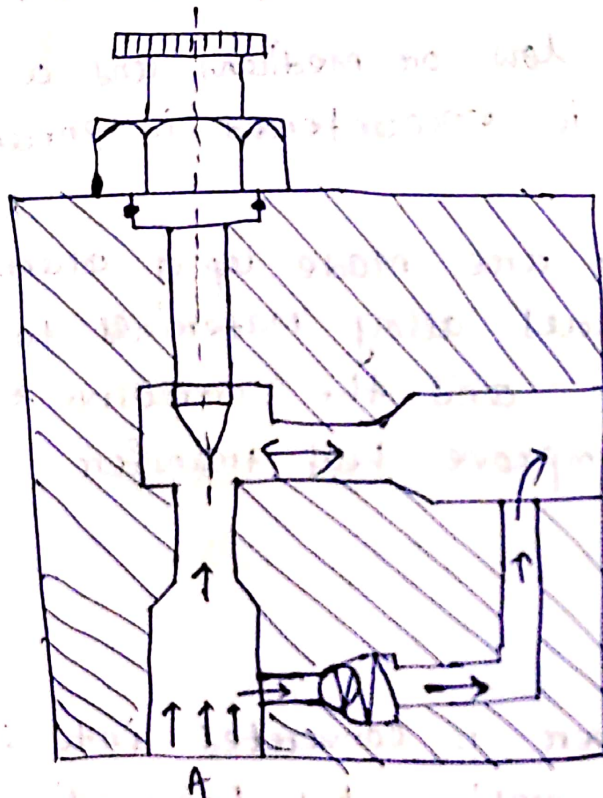


Flow Control valve

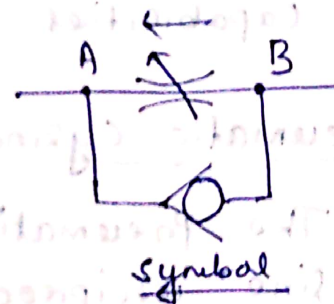
- A flow control valve is a metering valve and a check valve built in to one housing.
- on one direction the air flow is restricted as it flows through the metering valve.
- on other direction, it flows freely through the check valve.

The metering valve and check valve may be of several designs.

- The air flow through the metering orifice is controlled by a pointed needle.
- A ball and spring check valve is used for free valve.



Free flow A to B
Metering flow B to A

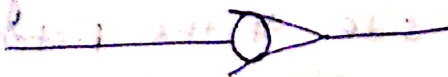


Throttle valve



Adjustable flow control valve

check valve



Pneumatic Actuators

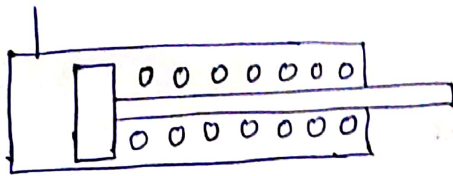
- Pneumatic systems make use of actuators (linear and rotary) similar to that of hydraulic systems.
- Pressures are either low or medium and a lighter construction is encountered in pneumatic systems.
- Pneumatic cylinders are made up of aluminium and other non-ferrous alloy materials to reduce the weight and the corrosive effects of air and to improve heat transfer capabilities.

Pneumatic Cylinders

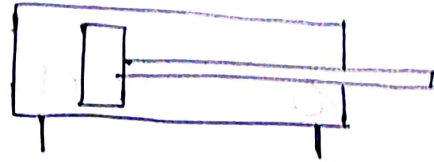
- The pneumatic power is converted into straight line reciprocating motions by pneumatic cylinders.

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 piston is affected by a coil spring mounted on the rod side of the piston or by application of an external force like gravity.
- Double acting cylinder:
 - The force exerted by the compressed air moves the piston in two directions in a double acting cylinder.



single Acting



double acting

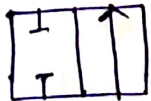
Aire motores

To generate rotational motion in a Pneumatic system, an aire motore is used.

Types of Aire motores

- Piston type motores
- Vane type motores
- Turbine aire motores

Iso Symbols of Pneumatic Components



2 position, 2-way, 2 Ported

$2/2$ DCV



2 position, 3-way, 3 Ported

$3/2$ DCV



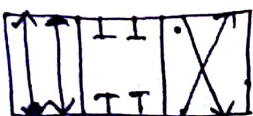
2 position, 4 way, 4 Ported

$4/2$ DCV



2 position, 4 way, 5 Ported

$5/2$ DCV



3 position, 4 way, 4 Ported

$4/3$ DCV



3 position, 4 way, 5 Ported closed centre

$5/3$ DCV

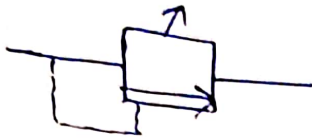
Hydraulic valves



Check valve



Flow control



Relief valve

Lines



Main line



Pilot line



Line crossing

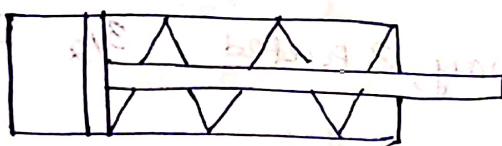


Lines joined

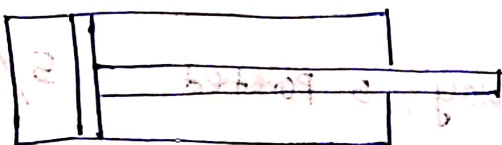


Lines joined

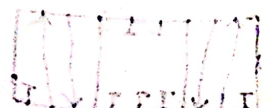
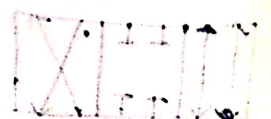
Actuators



Single Acting cylinder

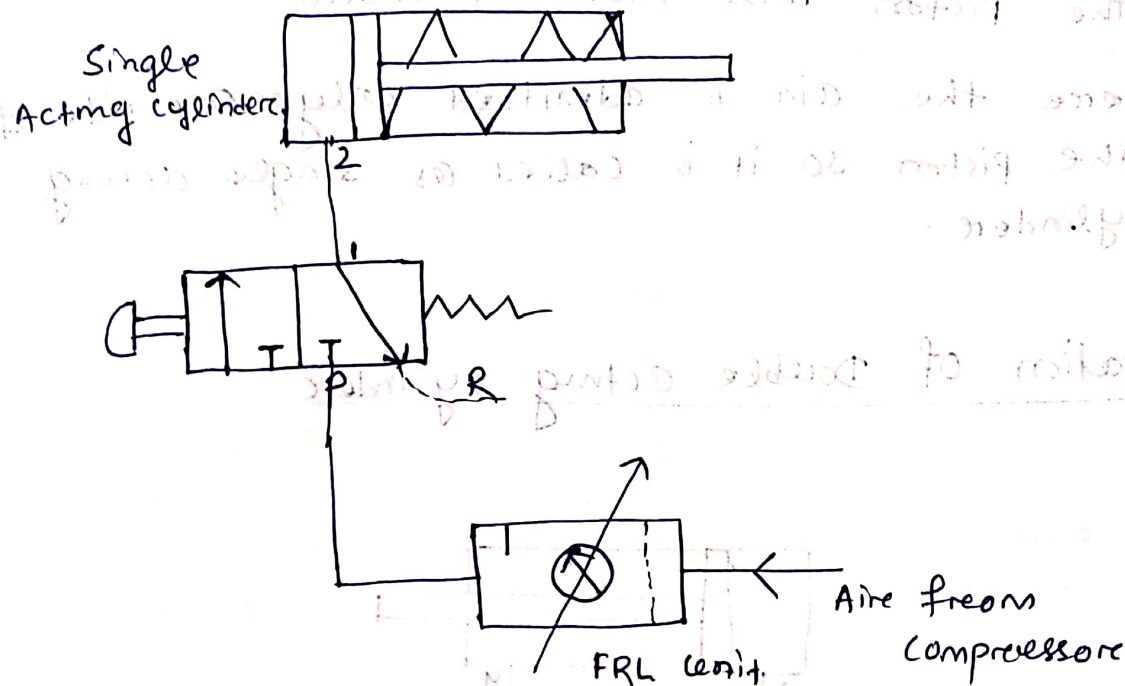


Double Acting cylinder



Pneumatic Circuits

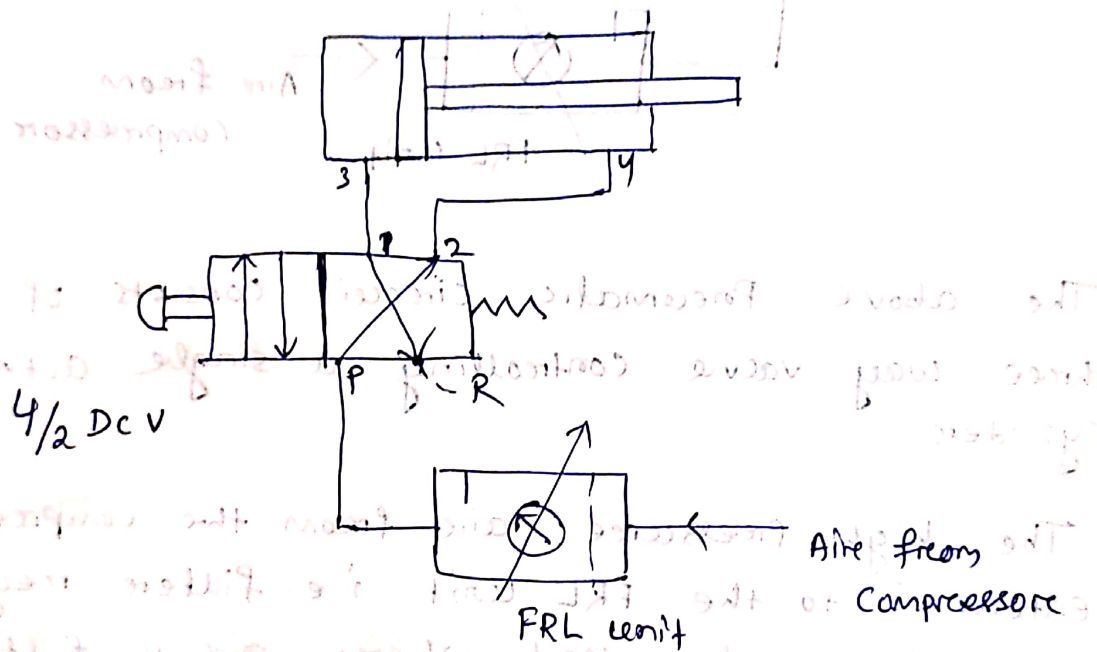
Direct control of single acting cylinder



- The above Pneumatic circuit consists of a three way valve controlling a single acting cylinder.
- The high pressure air from the compressor enters in to the FRL unit i.e filter, regulator and lubricator unit, where air is filtered, regulated and lubricated.
- Then the air enters in to a push button operated direction control valve. It is a three ways and two position direction control valve.
- When the right envelope position, the piston is retracted, the air from port 2 enters in to the port 1 and then exhausted to the atmosphere through the port R.

- When the valve is in ~~right~~ Left envelope position, the high pressure air enters in to the cylinder by the port P through the port. The piston will move forward.
- Hence the air is admitted only on one side of the piston so it is called as single acting cylinder.

Operation of Double acting cylinder



- The above Pneumatic Circuit consists of a four way valve controlling a double acting cylinder.
- The high pressure air from the compressor enters in to the FRL unit where air is filtered, Regulated and lubricated.
- Then the air enters in to a Push button operated direction control valve. It is a four way and

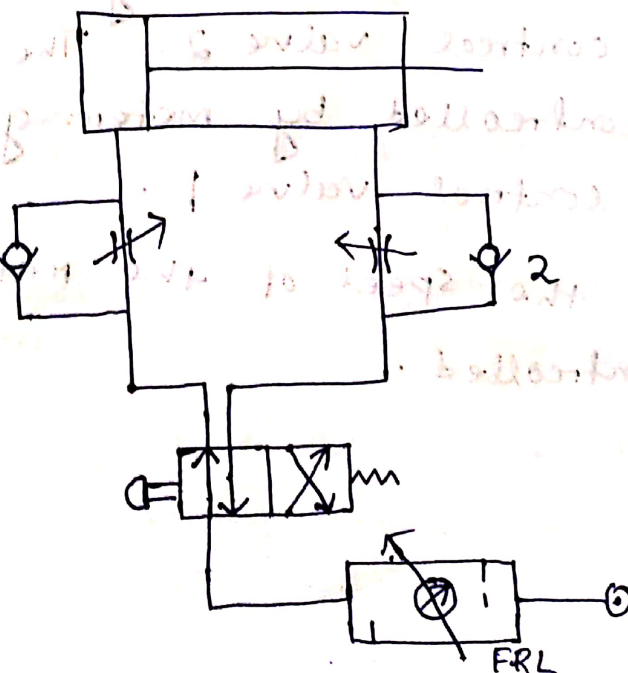
two position direction control valve.

- When the valve is in right envelope position the piston is retracted. High pressure air from FRL unit enters in to port P and then to port 2 and then, enters in to the cylinder through port 4. The air from the other side of the piston enters in to port 1 through port 3, then from port 1 enters into port R & then exhausted to atmosphere.
- When the push button is pressed, the valve is in left envelope position. The high pressure air enters the at the left side of the cylinder and the air from right side of the piston exhausted to atmosphere through the exhaust port R.
- Here air is admitted on both the side of the piston so it is called as Double acting cylinder.

Operation of Double acting cylinder with Metering in and Metering out circuit

Mentoring out

- The motion and speed of a double acting cylinder can be controlled by using flow control valves.



- In situations where out flow control is preferred Meter out flow control provides stabilising back pressure on the piston which smoothes out the jumping motion of pneumatic actuators.

When the $4/2$ DCV is operated, the air from FRL moves to the flow control valve 1. The air opens the check valve and full amount of air is fed to the blank end of the cylinder to make it forward stroke.

The air from the earlier stroke in the rod to be exhausted through the flow control valve 2. But the check valve remains closed and there is only metered flow through the metering valve.

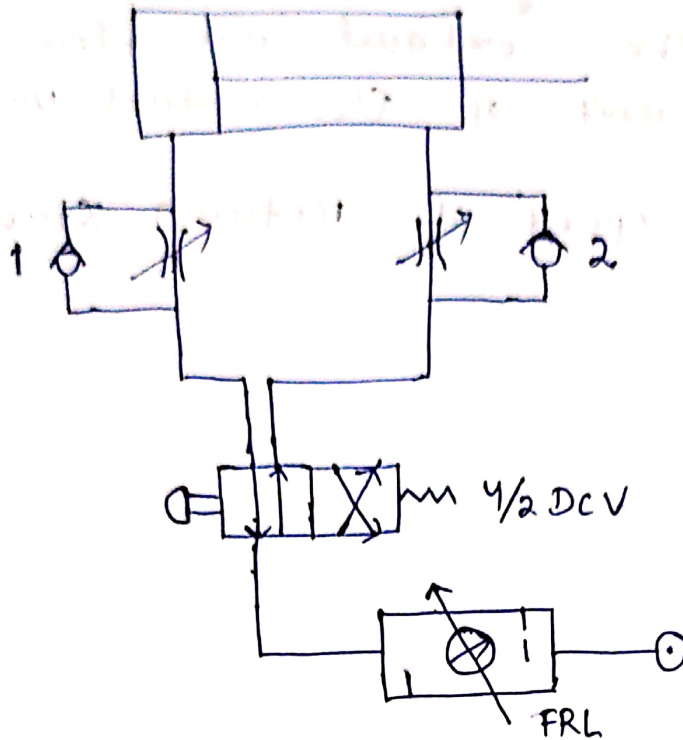
Thus the speed of the double acting cylinder is controlled during forward stroke.

When the DCV is in spring mode, air flows to the rod side through check unit of flow control valve 2. The exhaust air is controlled by metering valve of flow control valve 1.

Thus the speed of the return stroke is controlled.



Metering - in circuit



- In metering - in circuit the flow of compressed air is controlled by means of flow control valves.
- When the 4/2 DCV is operated, the air from FRL moves to the flow control valve 1, as the check valve is closed, there is only metered flow through the metering valve to make a forward stroke.
- The air from the earlier stroke in the rod side to be exhausted through the flow control valve 2, through the check valve with full amount.
- Thus the speed of the double acting cylinder is controlled during forward stroke.

- When DCV is in spring mode, the compressed air flow to the rod side is controlled by the Metering valve of flow control valve 2. The exhaust air flow through the check unit of flow control valve 1.
- Thus the speed of retraction stroke is controlled.

