LECTURE NOTES

ON
HYDRAULIC MACHINE & IFP

5th SEMESTER

PREPARED BY

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SUBJECT:- HYDRAULIC MACHINE & IFP

SEMESTER:- 5^{th} SEM (DIPLOMA)

HM & IFD

(1) Turbine :-

(i) pelton wheel Turbine.
(ii) Fransis Turbine.
(iii) Kaplan Turbine.

(2) pump :-

(i) Centrifugal pump.
(ii) Reciprocating pump.

(3) IFP :-

(i) Pneumatic Control system.
(ii) Hydraulic Control system.

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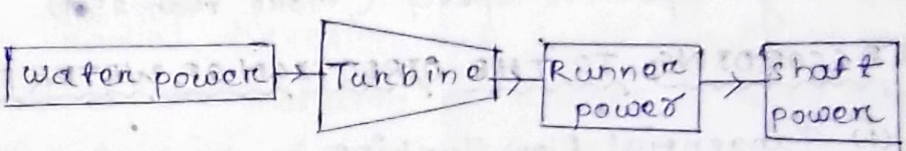
HYDRAULIC MACHINE:-

Those machines which are runs with the help of water are called hydraulic Machine.

Ex:- Turbine, pump.

TURBINE:- Turbine is a hydrulic machine Which converts water power to mechanical power / shaft power is Known as turbine.



CLASSIFICATION OF TURBINE:-

(1) ACCORDING TO THE ENERGY AT INLET:-

(i) Impulse turbine.
(ii) Reaction turbine.

(i) IMPULSE TURBINE:-

If at the Inlet of the turbine, the Energy available is only Kinetic energy Then it is called impulse turbine. Ex:- (Pelton turbine).

(ii) REACTION TURBINE:-

If at the inlet the water process Kinetic energy as well as pressure energy is called Reaction Turbine. Ex:- (Francis Turbine).

(2) ACCORDING TO THE HEAD OF WATER :-

(i) Low head of water turbine (0 - 5 m)
(ii) Medium head of water turbine (5 - 25 m)
(iii) High head of water turbine (25 - Above)

(3) ACCORDING TO THE SPECIFIC SPEED :-

(i) Low specific speed (>25 RPM).
(ii) Medium specific speed (25 - 250 RPM).
(iii) High specific speed (More than 250)

(4) ACCORDING TO THE DIRECTION OF WATER FLOW :-

(i) Tangential flow Turbine.
(ii) Radial flow Turbine.
(iii) Axial flow Turbine.
(iv) Mixed flow Turbine.

(i) TANGENTIAL FLOW TURBINE :-

If the water flows along tangent of The runner then turbine is called tangential flow Turbine. Ex:- (pelton wheel turbine).

(ii) RADIAL FLOW TURBINE :-

If the water flow in the radial Direction through the runner is called Radial flow turbine. Ex:- (Fransis turbine).

Types :- (1) Out ward radial flow.
(2) In ward radial flow.

(1) Out ward radial Flow :-

if water flows inward to out ward Radially then it is called out ward radial flow turbine.

(2) Inward radial flow Turbine :-

If water flow outward to inward Radially then turbine is called inward Radial flow turbine.

(iii) AXIAL FLOW :-

If water flows parallel to the axis of The rotation of the runner then it is called Axial flow Turbine. Ex :- (Kaplan turbine).

(iv) MIXED FLOW TURBINE :-

If the water flows through the runner in radial direction but leavs parallel to the Axis of the rotation of runner is called mixed flow turbine. (Axial + Radial flow Turbine).

EFFCIENCIES OF A TURBINE :-

(1) Hydraulic efficiency :-

It is defined as the ratio between power given by water to the Runner of a Turbine to the power supplied by the water at the inlet of turbine.

$$\eta_H = \frac{\text{Runner Power}}{\text{water power}}$$

$$\text{water power} = \frac{\rho \times g \times Q \times H}{1000} \text{ kW.}$$

(2) Mechanical efficiency :-

The power delivered by water to The runner of a turbine is transmitted to the saft of the turbine.

$$\eta_m = \frac{\text{Power at the shaft}}{\text{Runner power.}}$$

$$\therefore \text{Shaft power} = \frac{2\pi N T}{60 \times 10^3} \text{ kW.}$$

(3) Ovarall efficiency:-

$$\eta_o = \eta_m \times \eta_H$$

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

* So It is the ratio between shaft power to water power.

(4) Volumetric efficiency:-

The volume of the water striking the runner of a turbine is slightly less than volume of water supplied to the turbine.

$$\eta_{vol} = \frac{\text{Volume of water actually striking runner}}{\text{Volume of water supplied to the turbine.}}$$

SOLVED PROBLEMS:-

(Q) In a hydraulic turbine, the mechanical and hydraulic efficiencies are 83% and 89%. find the overall efficiency?

Ans:-

Given Data

$\eta_m = 83\% = 0.83$

$\eta_H = 89\% = 0.89$

we know that overall efficiency

$\eta_o = \eta_H \times \eta_m$

$\eta_o = 0.83 \times 0.89 = 0.7387$

$= 73.87\%$

Ans

(Q) Findout the overall efficiency of a hydraulic Turbine where the shaft power is 860 KW and The turbine runs under a head of 15 meters And the discharge is 2000 m^3/sec ?

Ans:-

$S.P = 860$ KW

$Q = 2000$ m^3/sec

$h = 15$ meter

we know that

water power $= \rho \times g \times Q \times h$

$w.p = 1000 \times 9.81 \times 2000 \times 15$

$= 294300000 \div 1000$

$= 294300$ KW

∴ overall efficiency

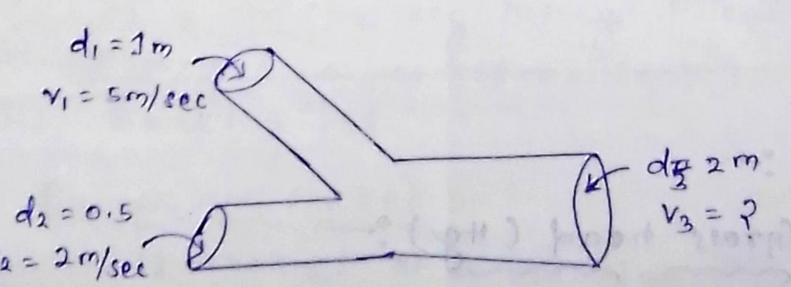
$$\eta_o = \frac{S.P}{w.P} = \frac{860}{294300}$$

$= 0.0029221 8824$

$= 0.29221 8824$ %

Ans

(Q) In a pipe line which is described as below



Find the value of V_3 ?

Ans:- Given Data.

$d_1 = 1m$, $d_2 = 0.5$ m , $d_3 = 2m$

$v_1 = 5m/sec$, $V_2 = 2$ m/sec , $V_3 = ?$

We know that

Applying continuety equation in this equation.

$$Q_1 + Q_2 = Q_3$$

$$A_1 V_1 + A_2 V_2 = A_3 V_3$$

$A_3 = \frac{\pi}{4} \times 2^2 = 3.14$

$Q_1 = \frac{\pi}{4} \times (1)^2 \times 5 = 3.9 \ m^3/sec$

$Q_2 = \frac{\pi}{4} \times (0.5)^2 \times 2 = 0.38 \ m^3/sec$

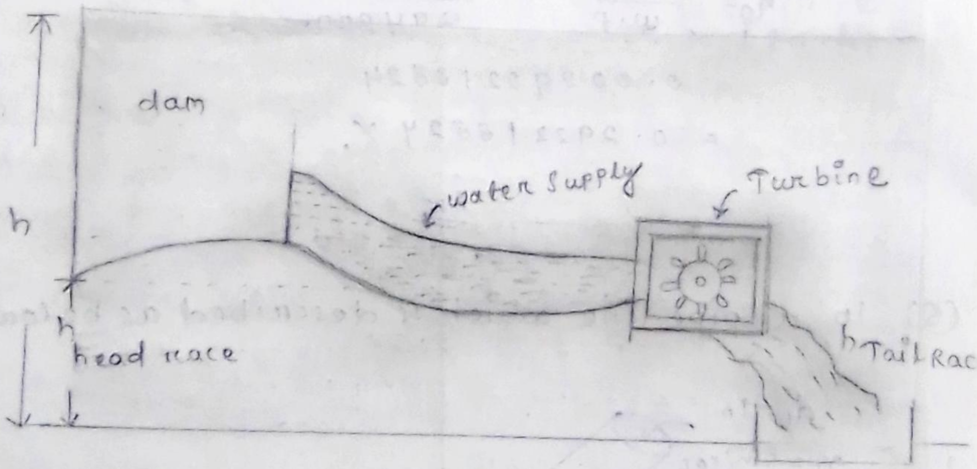
$Q_3 = 3.9 + 0.38 = 3.14 \times V_3$

$\Rightarrow 4.28 = 3.14 \times V_3$

$\Rightarrow V_3 = \frac{4.28}{3.14} = 1.36 \ m/sec$

Ans

HEAD USED IN TURBINE :-



Types :-

(i) Gross head (Hg) :-

→ h headrace − h tailrace

(ii) Net head :-

→ (Hg − HF)

where, HF = head less due to friction

Hg = Gross head.

PELTON WHEEL TURBINE :-

it is a purely impulse turbine that means The energy available at inlet is kinetic energy. it's works on high head of water. it has low Discharge. & low specific speed.

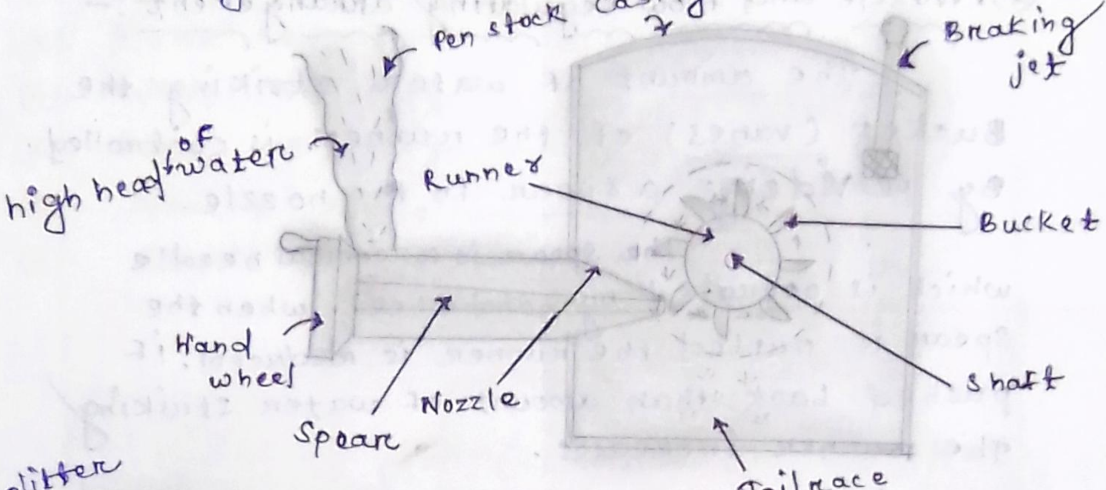


fig :- Pelton wheel turbine.

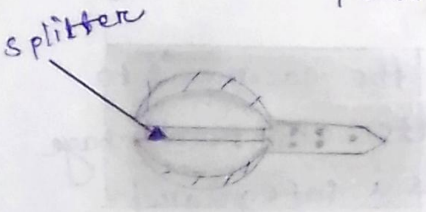


fig :- Bucket - (Double hemi - spherical shape).

IMPORTANT PARTS OF PELTON WHEEL TURBINE

(1). Runner and Bucket.
(2). Nozzle and flow Regulating Arrangement.
(3). Casing (To protect axidents)
(4). Braking jet.

(1). Runner and Bucket :-

It consist of a circular disc on the periphery with a number of buckets evenly speed are fixed the shape of bucket is Double hemi sphenical cup. each bucket is Divided its to two symmtrical parts by a Dividing wall called splitter.

The jet of water strikes the splitter which Divided the jet into two equal part. the Bucket are so shaped that the jets get Deflected at an angle of 160° to 170°.

(2). Nozzle and flow Regulating arrangement :-

The amount of water striking the Bucket (vanes) of the runner is controlled By providing a spear in the nozzle.

The spear is a conical needle which is operated by hand wheel. when the spear is pushed the runner is reduced. if pushed back than amount of water striking The runner increases.

(3) Casing :- The function of the casing is to prevent the splashing of water and to dischage It into tail race. It acts as a safeguard Against accident. It has no hydraulic function.

(4) Braking jet :-

when the nozzle is completely closed By moving the spear in forward direction The amount of water striking the runner Reduces to zero. But due to inertia the runner goes on revolving to stop it in less time a small nozzle is provided on the back of the vanes is known as Braking jet.

VELOCITY DIAGRAM:-

velocity, angle	inlet	outlet
(1). Absolute velocity	V_1	V_2
(2). Relative velocity	V_{r_1}	V_{r_2}
(3). Blade velocity	u_1	u_2
(4). Whirl velocity	V_{w_1}	V_{w_2}
(5). Flow velocity	V_{f_1}	V_{f_2}
(6). Nozzle Angle	α	β
(7). Blade Angle	θ	ϕ

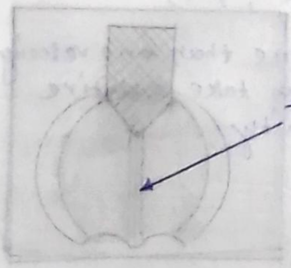
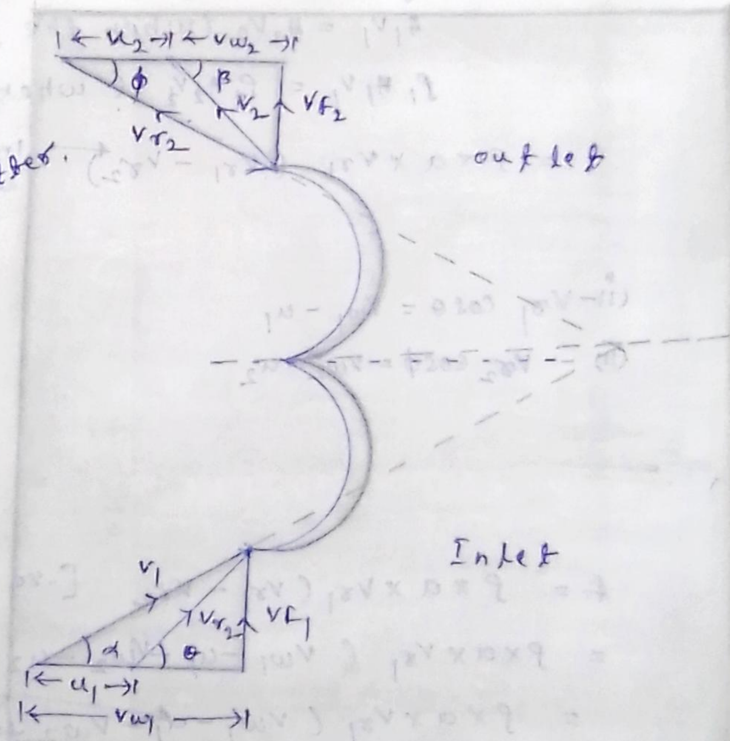


Fig:- Bucket (Blade)



Analysis :- if the blade are smooth and having velocity in the direction of motion at inlet And outlet is equal.

$u_1 = u_2 = u$ and $V_{r_1} = V_{r_2}$

Now power of the turbine.

$= F \times V$ where F = force, V = velocity.

* Force extended by the water

$f = m \times a$ [$a = \frac{dv}{dt}$ (the rate of change of velocity)

$f = m \times \frac{dv}{dt}$

$f = \frac{d}{dt} \cdot m \times V$ [momentum $= \frac{d}{dt}$

$= m \times \frac{d}{dt}(V)$

$= m \times$ (initial velocity − final velocity)

[m − mass flow rate]

Applying continuety equcation

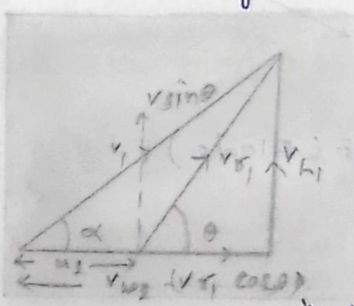
$A_1 V_1 = A_2 V_2$ (when the $\rho = c$)

$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$ (when the $\rho \neq c$)

$= \rho \times a \times V_{r_1} (V_{r_1} - V_{r_2})$ ← In more than one velocity we can take ralative velocity.

(i) − $V_{r_1} \cos\theta = V_{w_1} - u_1$

(ii) − $V_{r_2} \cos\phi = V_{w_2} - u_2$



$f = \rho \times a \times V_{r_1} (V_{r_1} - V_{r_2}$ [−ve sign due to opposite direction] & it not work (±)

$= \rho \times a \times V_{r_1} (V_{w_1} - u_1 - V_{w_2} - u_2)$ (equation is take +ve) ($u_1 = u_2$)

$= \rho \times a \times V_{r_1} (V_{w_1} - u_1 - V_{w_2} + u_2)$

$= \rho \times a \times V_{r_1} (V_{w_1} \pm V_{w_2})$

$f = \rho \times a \times V_{r_1} (V_{w_1} \pm V_{w_2})$

∴ Runner power $= f \times V = \frac{\rho \times a \times V_{r_1} (V_{w_1} \pm V_{w_2}) \times u}{1000}$ kW

where, ρ = density

a = area of the jet [$A = \frac{\pi}{4} \times d^2$

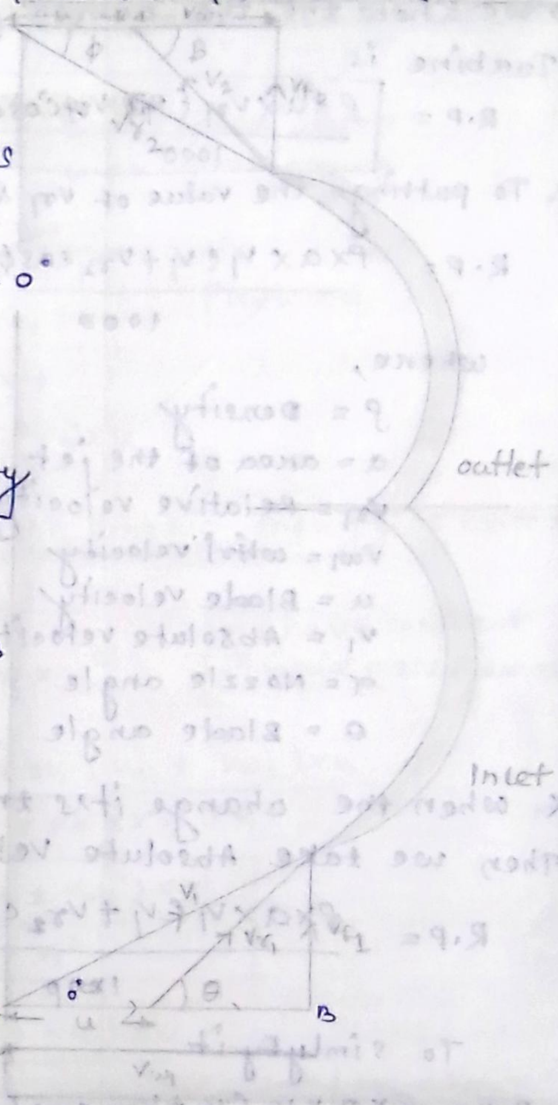
V_{r_1} = Relative velocity

V_{w_1} = whirl velocity

u = Blade velocity.

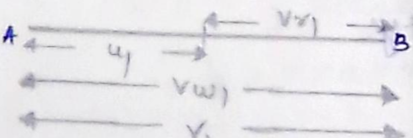
PELTON WHEEL TURBINE (RUNNER POWER):-

→ In a pelton wheel Turbine α angle is zero.



$\alpha = 0^\circ$

→ When the $\alpha = 0^\circ$ the the inlet velocity Diagram is below:-



Equations are in create :-

(1) $V_{r_1} = V_{w_1} - u_1$

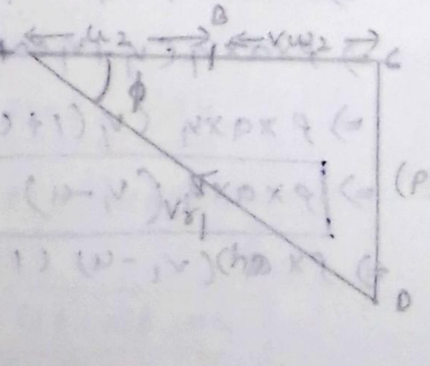
(2) $V_{w_1} = V_1$

(3) $u_1 = V_{w_1} - V_{r_1}$

(4) $u_1 = V_1 - V_{r_1}$

(5) $V_{r_1} = V_1 = u_1$

→ out let velocity diagram :-



$$\cos\phi = \frac{b}{h}$$

$$\cos\phi = \frac{u_2 - V_{w_2}}{V_{r_1}}$$

$$\Rightarrow V_{r_2}\cos\phi = u_2 + V_{w_2}$$

$$\Rightarrow V_{w_2} = V_{r_2}\cos\phi - u_2$$

→ we know the the runner power of pelton wheel Turbine is

$$R.P = \boxed{\frac{\rho \times a \times V_{r_1} (V_{w_1} + V_{w_2}) \times u}{1000} KW}$$

∴ To putting the value of V_{r_1} & V_{w_1}, V_{w_2} Then R.P is

$$R.P = \frac{\rho \times a \times V_1 (V_1 + V_{r_2} \cos\phi - u) \times u}{1000} KW$$

$\left[\begin{array}{l} (V_{w_1} = V_1) \\ V_{w_2} = V_{r_2} \cos\phi - u \\ u_1 = u_2 \end{array} \right.$

where,

ρ = Density

a = area of the jet

V_{r_1} = Relative velocity

V_{w_1} = whirl velocity

u = Blade velocity

V_1 = Absolute velocity

α = Nozzle angle

θ = Blade angle

* when the change it's traingle to a line Then we take Absolute velocity then R.P is

$$R.P = \frac{\rho \times a \times V_1 (V_1 + V_{r_2} \cos\phi - u) \times u}{1000} KW$$

$[V_{r_1} = V_{r_2}$

To simlyfy it

$R.P = \rho \times a \times V_1 (V_1 + V_{r_1} \cos\phi - u) \times u$

$\Rightarrow \rho \times a \times V_1 (V_1 + (V_1 - u) \cos\phi - u) \times u$

$\left[\begin{array}{l} V_{r_1} = V_1 - u \\ Q = a \times V \end{array} \right.$

$\Rightarrow \rho \times a \times V_1 (V_1 + V_1 \cos\phi - u \cos\phi - u) \times u$

$\Rightarrow \rho \times a \times V_1 (V_1 (1 + \cos\phi) - u (1 + \cos\phi)) \times u$

$\Rightarrow \boxed{\rho \times a \times V_1 (V_1 - u)(1 + \cos\phi) \times u}$

$\Rightarrow \rho \times Q (V_1 - u)(1 + \cos\phi) u$

HYDRAULIC EFFICIENCY OF PELTON WHEEL TURBINE:-

(1) $\eta_H = \dfrac{R.P}{W.P}$ where, R.P = Runner Power
W.P = Water power

$$= \frac{\rho \times a \times v_1 (V_{w_1} \pm V_{w_2}) \times u}{\rho \times g \times Q \times H}$$

$$= \frac{\rho \times Q (V_{w_1} \pm V_{w_2}) \times u}{\rho \times g \times Q \times H} \quad [a \times v_1 = Q]$$

$$\Rightarrow \eta_H = \frac{(V_{w_1} \pm V_{w_2}) \times u}{g \times H}$$

(2) if we consider the kinetic energy of water:-

$$K.E = \frac{1}{2} \times m \times v_1^2$$

$$= \frac{1}{2} \times \rho \times a \times v_1 \times v_1^2$$

[$m = \rho a V$ = constant
→ liquid mass flow rate]

$$\eta_H = \frac{R.P}{W.P} = \frac{\rho \times a \times v_1 (V_{w_1} \pm V_{w_2}) \times u}{\frac{1}{2} \times \rho \times a \times v_1 \times v_1^2}$$

$$\boxed{\eta_H = \frac{2 (V_{w_1} \pm V_{w_2}) \times u}{v_1^2}}$$

$$\Rightarrow \frac{2 (v_1 + V_{r_2} \cos\phi - u) \times u}{v_1^2}$$

[$V_{r_1} = V_{r_2}$
$V_{r_1} = v_1 - u$]

$$\Rightarrow \frac{2 (v_1 + V_{r_1} \cos\phi - u) \times u}{v_1^2}$$

$$\Rightarrow \frac{2 (v_1 + (v_1 - u) \cos\phi - u) \times u}{v_1^2}$$

$$\Rightarrow \frac{2 (v_1 + (v_1 \cos\phi - u \cos\phi) - u) \times u}{v_1^2}$$

$$\Rightarrow \frac{2 (v_1 (1 + \cos\phi) - u (1 + \cos\phi)) \times u}{v_1^2}$$

$$\Rightarrow \boxed{\eta_H = \frac{2 (v_1 - u) (1 + \cos\phi) \times u}{v_1^2}}$$

* What is the condition for max^m efficiency of Turbine.

so let us say
To find the max^m efficiency with respect to Blade speed.

$$= \boxed{\frac{d}{du}(\eta_H) = 0}$$

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

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

$$\Rightarrow \frac{1+\cos\phi}{V_1^2} \times 2 \times \frac{d}{du} V_1 u - \frac{d}{du} u^2$$

$$\left[\frac{d}{du} V_1 u \qquad V_1 \frac{d}{du} u = V_1\right]$$

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

$$\Rightarrow \frac{2(1+\cos\phi)}{V_1^2}(V_1 - 2u) = 0$$

$$\left[\frac{d}{du} u^2 = 2u \qquad \frac{d}{dx} x^2 = 2x\right]$$

∴ for max^m efficiency

$$u_1 - 2u = 0$$

$$V_1 = 2u$$

$$\boxed{u = \frac{V_1}{2}}$$

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

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

$$= \frac{4u - 2 \quad (1+\cos\phi)\times u}{4u^2}$$

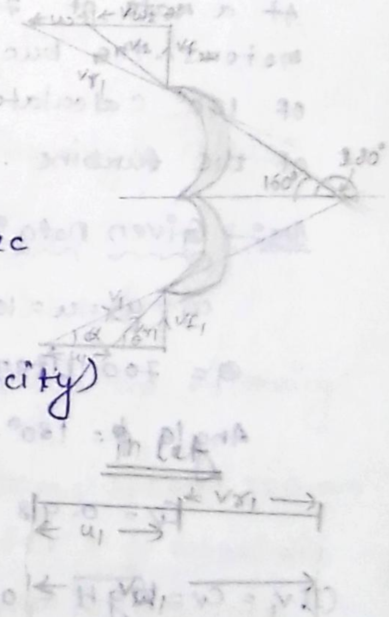
$$= \frac{2u \times u \times (1+\cos\phi)}{4u^2}$$

$$\Rightarrow \frac{2u^2}{4u^2} \times (1 + \cos\phi) \qquad [V_1 = 2u$$

$$\Rightarrow \boxed{\eta_{max} = \frac{1+\cos\phi}{2}}$$

SOLVED PROBLEMS:-

(Q1) A pelton wheel turbine having Bucket speed of 10 m/s and water flows at the rate of 700 liters/second, under a head of 30 meters. The Bucket Deflects through an angle of 160° calculate the Runner power and hydraulic efficiency when $C_v = 0.98$.



Ans:-

Given data

$u = 10\ m/sec$

$\rho = 1000\ kg/m^3$

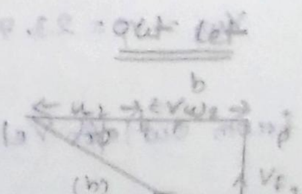
$Q = 700\ liter/sec = 700 \times 10^3\ m^3/sec$

$h = 30\ m$

$d\theta = 160°$

$C_v = 0.98$ (coefficiency of velocity)

In let



(1) $V_1 = C_v\sqrt{2 \times g \times h}$

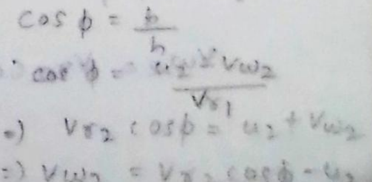
$= 0.98\sqrt{2 \times 9.81 \times 30}$

$= 23.77\ m/sec$

$\therefore \phi = 180° - 160° = 20°$

$R.P = \rho \times Q (V_1 + (V_1 - u)\cos\phi - u) \times u$

Out let



$\Rightarrow 1000 \times 700 \times 10^3 (23.77 + (23.77 - 10) \times \cos 20° - 10) \times 10$

$\Rightarrow 1000 \times 700 (23.77 + (23.77 \cos 20° - 10) \times 10$

$\cos\phi = \frac{b}{h}$

$\cos\phi = \frac{u_2 + V_{w2}}{V_{r1}}$

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

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

(2) $\eta_H = \frac{R.P}{W.P} = \frac{1000 \times 700 (23.77 + 23.77 \cos 20^\circ - 10) \times 10}{\rho \times g \times Q \times H}$

$\Rightarrow \frac{1000 \times 700 (23.77 + 23.77 \cos 20^\circ - 10) \times 10}{1000 \times 9.81 \times 700 \times 30}$

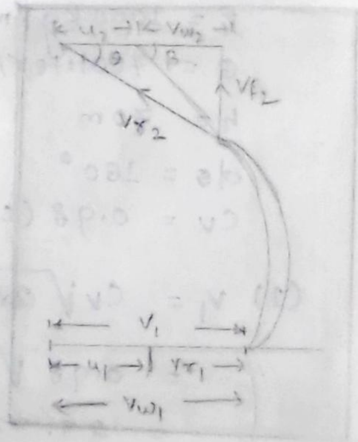
$\Rightarrow \frac{(23.77 + 23.77 \cos 20^\circ - 10) \times 10}{9.81 \times 30}$

$\Rightarrow 0.87 \simeq 87\ \%$

Ans

(Q2) A Pelton wheel turbine has a mean bucket speed of 10 meter per second with a jet of water flowing at a rate of 700 liter/second under a head of 30 meters. The bucket deflect the jet through an angle of 160° calculate the runner power, hydraulic efficiency of the turbine. Assume $C_V = 0.98$.

Ans:- Given Data :-



$u_1 = u_2 = u = 10\ m/s \quad H = 30m$

$Q = 700$ Liter/sec

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

$C_V = 0.98$

(1) $V_1 = C_V = \sqrt{2gH} = 0.98\sqrt{2 \times 9.81 \times 30}$

$= 23.77\ m/s$

$V_{w_1} = V_1 = 23.77\ m/s, \quad V_{r_1} = V_1 - u_1 = 23.77 - 10 = 13.77\ m/s$

from outlet velocity triangle

$V_{r_1} = V_{r_2} = 13.77\ m/s$

$V_{w_2} = V_{r_2} \cos\phi - u_2 = 13.77 \cos 20^\circ - 10 = 2.94\ m/s$

(2) R.P work done = $\rho \times a \times V_1 [V_{w_1} + V_{w_2}] \times u$

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

$= 186970 \; N/m^2 = 186.97 \; kW$

(3). $\eta_H = \frac{2[V_{w_1} + V_{w_2}] \times u}{V_1^2} = \frac{2[23.77 + 2.94] \times 10}{(23.77)^2} = 94\%$

Ans

POINTS TOBE REMBERED FOR PELTOL WHEEL TURBINE

(1). The velocity of Jet at inlet $V_1 = C_V \sqrt{2gH}$

C_V = Co-efficient of velocity (0.98 to 0.99)

(2). Velocity wheel (u) = $\phi \sqrt{2gH}$

$\frac{u}{V_1}$ (u = Blade, V_1 = Jet speed) $\leftarrow \phi$ = speed ratio (0.43 to 0.48)

(3). If no angle is given then jet diflection angle is 165°

(4). Jet ratio (d) = $\frac{P}{d}$ = $\frac{\text{Pitch diameter}}{\text{Jet diameter}}$

(5). No. of Buckets on the Runner (Z) = $15 + \frac{D}{2d}$

(Q3) A pelton wheel turbine is designed for the following specification:

Shaft power:- 11,722 kW, Head = 380 m, Speed = 750 rpm

Overall efficiency = 86%, Jet diameter = $\frac{1}{6}$ wheel dia.

Determine (1) wheel diameter (3) No. of jet required.

(2) Diameter of jet

Ans:-

Given Data:-

S.P = 11,722 kW, N = 750 RPM.

H = 380m, $\eta_0 = 0.86$

$d = \frac{1}{6} D$, $C_V = 0.985$

$\Rightarrow \frac{d}{D} = \frac{1}{6}$

we know that

(1) $v_1 = C_v\sqrt{2gH} = 0.98\sqrt{2\times9.81\times380} = 85.05\ m/s$

(2). $u_1 = u_2 = u = \phi\times\sqrt{2\times g\times H} = 0.45\sqrt{2\times9.81\times380}$

$= 38.85\ m/s$

(3). $u = \frac{\pi DN}{60} \Rightarrow D = \frac{60\times u}{\pi\times N} = \frac{60\times38.85}{3.14\times750} = 0.989m$

(4). $d = \frac{1}{6}D = \frac{0.989}{6} = 0.165\,m$

(5) Discharge from one jet $(q) = A\times V$

$\Rightarrow \frac{\pi}{4}\times d^2\times v_1 = \frac{\pi}{4}\times(0.165)^2\times85.05 = 1.818\ m^3/s$

(6). overall efficiency $\eta_o = \frac{S.P}{W.P}$

$\Rightarrow 0.86 = \frac{11,722}{W.P}$

$\Rightarrow W.P = \frac{11,722}{0.86}$

$\Rightarrow \frac{\rho\times g\times Q\times H}{1000} = \frac{11,722}{0.86}$

$(Q) \Rightarrow 3.672\ m^3/s$

(7). No. of jet required $= \frac{Q}{q} = \frac{3.672}{1.818} = 2$ jet

REACTION TURBINE:-

At the inlet there is kinetic energy as well as pressure energy of water is used.

Ex :- francis turbine.

$K.E = \frac{1}{2}\times m\times v^2$

$P.E = \rho\times g\times H$

FRANCIS TURBINE:—

It is a Inward flow reaction turbine having radial Discharge at outlet. In morden francis turbine the water enters in the radial direction but leaves in the axial direction thus It is also called mixed flow Type turbine.

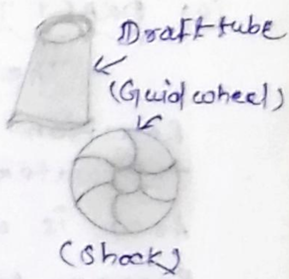
As the discharge at outlet is Radial $V_{w_2} = 0$

$$\text{So, work done} = \rho a V_1 [V_{w_1} \times u_1]$$

$$\text{Hydraulic efficiency } (\eta_H) = \frac{V_{w_1} \times u_1}{gH}$$

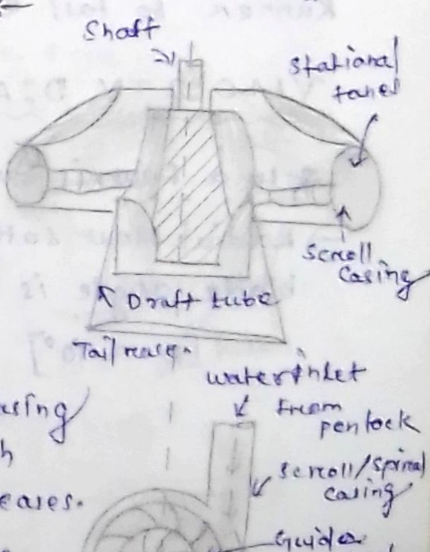
$$\eta_H = \frac{R.P}{W.P} = \frac{\rho a V_1 [V_{w_1} \times u_1]}{\rho \times g \times A \times H} = \frac{V_{w_1} \times u_1}{g \times H}$$

*** simple defination:—**



- → it is a reaction turbine.
- → it is works under the medium head
- → it has medium discharge.
- → its Radial flow / mixed flow Turbine.
- → it has mediam specific speed.

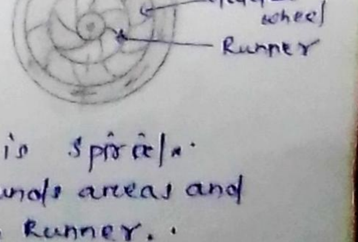
MAIN PARTS OF A FRANCIS TURBINE:—



(1) Casing.
(2) Guid mechanism.
(3) Runner with blades.
(4) Draft tube.

(1) CASING:—

In francis turbine casing and Runner are always full of water. the water from the penstock enters the casing which is spiral/scroll in shape in which Area of crossection gradually decreases. The casing Completely surrounds the Runner of the turbine.



Shorts:—

- → In a francis turbine the Casing shape is spiral.
- → it is used for to protect the surrounds areas and help to flow water from penstock to Runner.
- → it is mainly used to protect the exident.

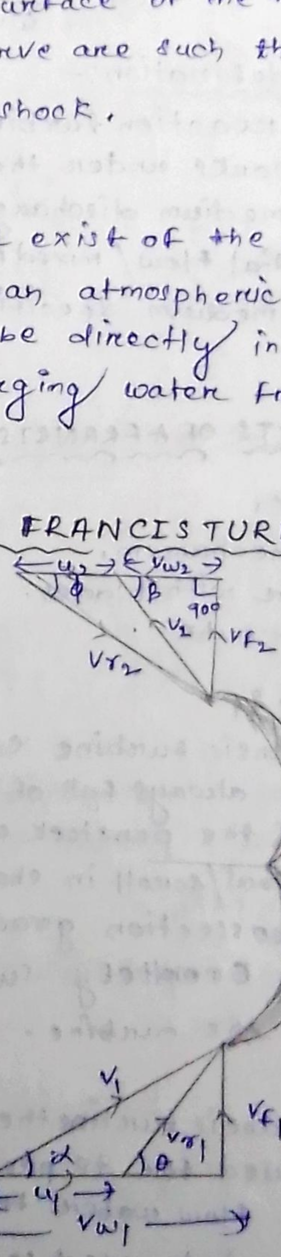
→ The runner is completely enclosed in an air-tight spiral casing.
→ The casing and runner are always full of water.

(2) GUIDE MECHANISM :-
It consists of a stationary circular wheel all round the runner of the turbine. The stationary vanes are fixed on the guide mechanism. the guide vanes allows the water to strike on vane without shock.

(3) RUNNER :-
It is of circular wheel on which a series of Radial Curved vanes are fixed. Surface of the vanes made very smooth. the Radial curve are such that the water Enters and leaves without shock.

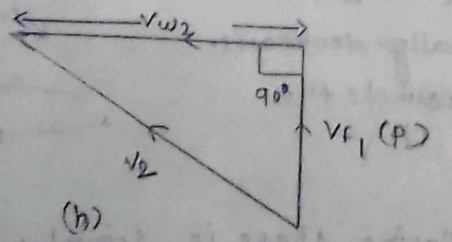
(4) DRAFT TUBE:-
The pressure at the exist of the runner of a Reaction turbine is less than atmospheric pressure The water at exist can't be directly increasing Area is used for descharging water from exist of Runner to tail Race.

VELOCITY DIAGRAM OF FRANCIS TURBINE :-



★ In a francis tube:-
→ Radial flow so the outlet blade angle is 90°
and [β = 90°]

(b)



(h)

$\cos\beta = \frac{b}{h} = \frac{V_{w_2}}{V_2} \Rightarrow \frac{V_{w_2}}{V_2} = \cos\beta$

$\Rightarrow V_{w_2} = V_2 \cos\beta$

$= V_2 \cos 90^\circ$

$V_{w_2} = V_2 = 0$

RUNNER POWER :-

Runner power $= \rho \times Q (V_{w_1} + V_{w_2}) \times u$

$\Rightarrow \rho \times Q (V_{w_1} \times u_1 \pm V_{w_2} \times u_2) \therefore V_{w_2} = 0$ } Blade are not symmetrical.

$\Rightarrow \rho \times Q (V_{w_1} \times u_1)$

$$R.P = \frac{\rho \times Q (V_{w_1} \times u_1)}{1000} \text{ kW}$$

HYDRAULIC EFFICIENCY :-

$$\eta_H = \frac{R.P}{W.P} = \frac{\rho \times Q (V_{w_1} \times u_1)}{\rho \times Q \times g \times H} = \frac{V_{w_1} \times u_1}{g \times H}$$

DISCHARGE :-

$Q = A \times V = \pi D_1 \times B_1 \times V$

where B_1 = width of the Rope.

D_1 = diameter of blades.

HEAD OF FRANCIS :-

potential energy $= H = \frac{P}{\rho \times g}$ $[v = \sqrt{2 \times g \times h}$

Kinetic energy $= \frac{1}{2} \times m \times v^2$ $\therefore w = m \times g$

$(v^2) = (\sqrt{2 \times g \times h})^2$

$= \frac{1}{2} \times \frac{w}{g} \times v^2$ $[v^2 = 2 \times g \times h$

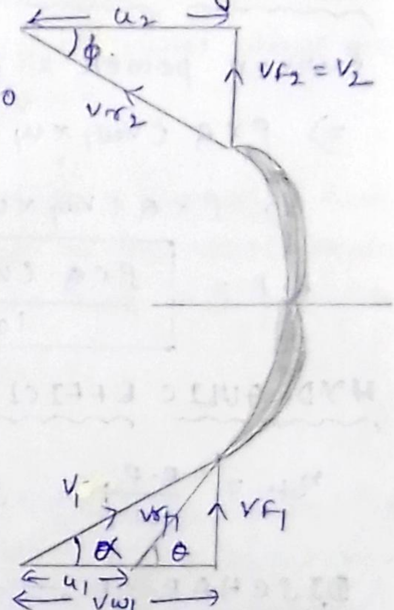
$$H = \frac{v^2}{2 \times g}$$

Total head :- $$H = \frac{P}{\rho \times g} + \frac{V_1^2}{2g}$$

or pelton wheel turbine head + $\frac{V_1^2}{2g}$

SOLVED PROBLEMS :-

(1) A francis turbine working under a head of 15m And the speed of the turbine is 2000 RPM has inlet Diameter of 900mm and width is 150mm the constant velocity of flow Through the runner is 3m/sec find Hydraulic efficiency and inlet blade angle is 90°.



Ans :-

Given data

$\beta = 90°$, $V_{w_2} = 0$

$H = 15\,m$

$N = 200\,Rpm$

$D_1 = 900\,mm = \frac{900}{1000} = 0.9\,m$

$B = 150\,mm = \frac{150}{1000} = 1.5\,m$

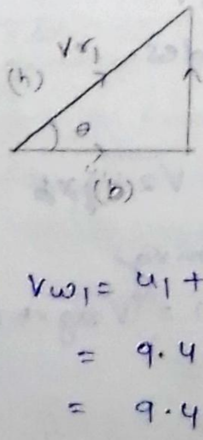
$V_{f_1} = 3\,m/sec \quad (V_{f_1} = V_{f_2})$

$\eta_H = ?$

$\theta = 90°$

(i) $u_1 = \frac{\pi D N}{60}$

$\Rightarrow \frac{3.14 \times 0.9 \times 200}{60} = \frac{3.14 \times 0.9 \times 200}{60} = 9.42\,m/sec$



$\sin\theta = \frac{p}{h} = \sin 90° = \frac{V_{f_1}}{V_{r_1}}$

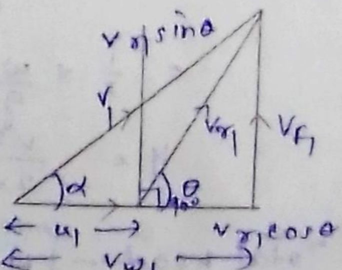
$V_{r_1} = \frac{V_{f_1}}{\sin 90°} = V_{f_1}$

$V_{w_1} = u_1 + V_{r_1}\cos\theta$

$= 9.42 + 3\cos 90°$

$= 9.42 + 3 \times 0$

$= 9.42 + 0 = 9.42\,m/sec$



$\eta_H = \frac{V_{w_1} \times u_1}{g \times H} = \frac{9.42 \times 9.42}{9.81 \times 15}$

$= 60\,\%$ **Ans**

(2) A Francis turbine having overall efficiency of 75%. Is required to produce 148.25 KW of shaft power. Head is 7.62 m peripherical velocity = $0.26\sqrt{2gH}$ and Radial velocity at Inlet (Flow) = $0.96\sqrt{2gH}$. wheel speed is 150 RPM Determine

(1) Find Inlet guide blade angle.

(2) Vane angle at Inlet.

Whe the Condition of turbine is that there is Hydraulic loss of 22% of Total energy.

Ans:–

(Blade speed – peripherical velocity)

Given Data :–

[Inlet guide blade angle – α

Vane angle – θ]

$\eta_0 = 75\% = 0.75$

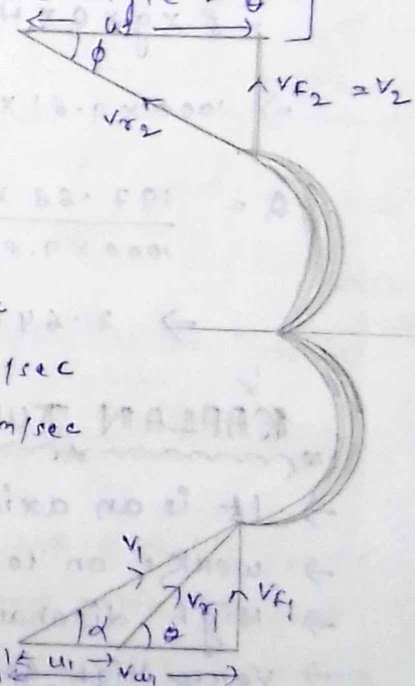
S.P = 148.25 KW

H = 7.62 m

$u = 0.26\sqrt{2gH}$

$V_{f_1} = 0.96\sqrt{2gH}$

N = 150 RPM



(1) $V_1 = \sqrt{2 \times g \times H} = 12.22$ m/sec

(2) $u_1 = 0.26\sqrt{2 \times g \times H} = 3.17$ m/sec

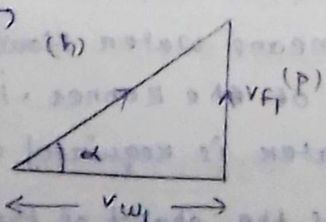
(3) $V_{f_1} = 0.96\sqrt{2 \times g \times H} = 11.73$ m/sec

(4) $\eta_H = \dfrac{V_{w_1} \times u_1}{g \times H}$

(condition) $\eta_H = 100 - 22 = 78\% = 78$

$\Rightarrow 0.78 = \dfrac{V_{w_1} \times 3.17}{9.81 \times 7.62} = V_{w_1} = 18.39$ m/sec

(5)



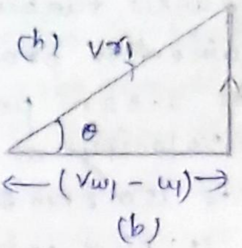
$\tan\alpha = \dfrac{p}{b} = \dfrac{V_{f_1}}{V_{w_1}}$

$= \dfrac{11.73}{18.39} = 0.63 = \tan^{-1} 0.63$

$\Rightarrow \alpha = 32.1$

(7)

$\tan\theta = \frac{P}{b} = \frac{V_{f_1}}{(V_{w_1} - u_1)}$



$\Rightarrow \frac{11.73}{(18.39 - 3.17)}$

$\Rightarrow 0.77 \Rightarrow \tan^{-1} 0.77$

$\theta = 37.5^\circ$.

(7) Discharge :-

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

$W.P = \frac{148.25}{0.75} = 197.66 \text{ KW}$

$= \rho \times g \times Q \times H = 197.66 \times 1000$

$\Rightarrow 1000 \times 9.81 \times Q \times 7.62 = 197.66 \times 1000$

$Q = \frac{197.66 \times 1000}{1000 \times 9.81 \times 7.62} = \frac{197.66 \times 1000}{74752.2}$

$\Rightarrow 2.64 \text{ m}^3/\text{sec}$ Ans

KAPLAN TURBINE

- → It is an axial flow turbine.
- → works on low head (5m-10m)
- → High discharge.
- → Very high specific speed.
- → comes under the reaction turbine.

* It is axial flow turbine it means water flows parallel to the axis of Rotation of the Runner. it is used when large volume of water is required at low head for axial flow turbines the shaft of the Turbine is verticle. The lower end of the shaft is made larger which is known as hub/Boss

* PROPELLOR & KAPLAN TURBINE :-

When the vanes are fixed on the hub it is called as propellor turbine, when they are adustable is called as Kaplan Turbine.

→ The turbine extracts energy from a moving fluid, while the other two add energy to a moving fluid.

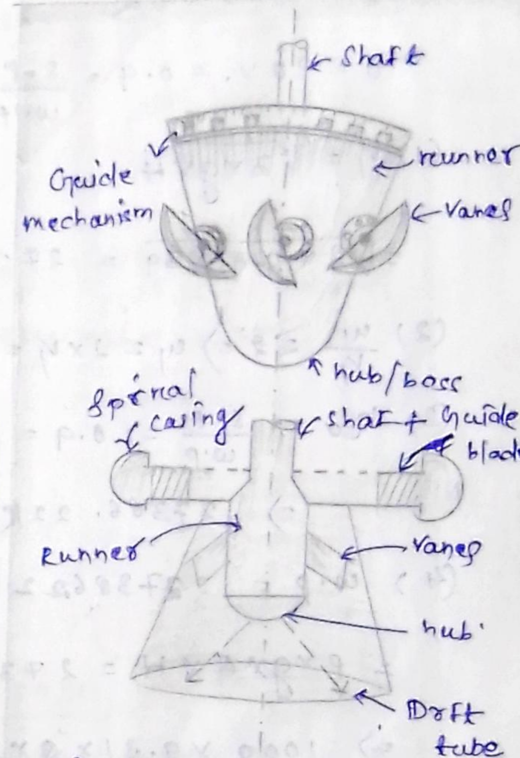


Fig:- Kaplan Turbine.

DISCHARGE :-

$Q = A \times V$

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

$\Rightarrow \frac{\pi}{4} \times (D_R^2 - D_B^2) \times V$

since this is an axial flow type $V_{f_1} = V_{f_2}$

$$Q_{kap} = \frac{\pi}{4} \times (D_R^2 - D_B^2) \times V_{f_1}$$

where,

D_R = Dia. of the runner.

D_B = Dia. of the Boss.

Blade speed ($u_1 = u_2$)

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

SOLVED PROBLEMS :-

(1) A Kaplan turbine develop 24647.6 kW of power At a head of 39 m. Assuming speed ratio of 2, flow ratio 0.6 diameter of the boss is equal to 0.35 times the diameter of the runner and overall efficiency is 90% calculate diameter of hub and runner and the speed of the Turbine.

Ans :-

Given Data :-

S.P = 24647.6 kW

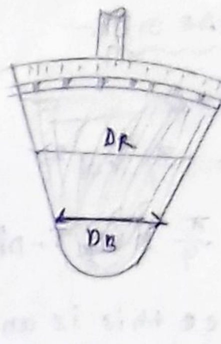
H = 39 m

Speed ratio = $\frac{\text{Blade}}{\text{water jet}} = \frac{u_1}{V_1} = 2$

Flow Ratio = $\frac{\text{velocity of flow at inlet}}{\text{water jet velocity}} = 0.6 = \frac{V_{f_1}}{V_1}$

$D_B = 0.35 \times D_R$

$\eta_o = 90\% = 0.9 = \frac{S.P}{W.P}$



(1) $V_1 = \sqrt{2 \times g \times H}$

$= \sqrt{2 \times 9.81 \times 39} = 27.66\ m/sec.$

(2) $\frac{u_1}{V_1} = 2 \Rightarrow u_1 = 2 \times V_1 = 2 \times 27.66 = 55.32\ m/sec.$

(3) $\eta_o = \frac{S.P}{W.P} \Rightarrow 0.9 = \frac{24647.6}{W.P} \Rightarrow W.P = \frac{24697.6}{0.9}$

$\Rightarrow 27386.22\ KW$

(4) $W.P = 27386.22\ KW$

$= \rho \times g \times Q \times H = 27386.22 \times 10^3$

$\Rightarrow 1000 \times 9.81 \times Q \times 39 = 27386.22 \times 1000$

$= Q = \frac{27386.22 \times 1000}{1000 \times 9.81 \times 39} = \frac{27386.22}{9.81 \times 39}$

$\Rightarrow 71.58\ m^3/sec$

(5) $\frac{V_{f_1}}{V_1} = 0.6 \Rightarrow V_{f_1} = 0.6 \times V_1$

$\Rightarrow 0.6 \times 27.66$

$\Rightarrow 16.59\ m/sec$

(6) $Q = A \times V$

$\Rightarrow \frac{\pi}{4} \times (D_R^2 - D_B^2) \times V_{f_1}$

$\Rightarrow 71.58 = \frac{\pi}{4} \times (D_R^2 - (0.35 \times D_R^2)) \times 16.59$

$\Rightarrow 71.58 = \frac{\pi}{4} \times De^2 (1-0.122) \times 16.59$

$\Rightarrow 71.58 = \frac{\pi}{4} \times D_R^2 \times 0.878 \times 16.59$

$\Rightarrow 71.58 = 0.785 \times 0.878 \times 16.59 \times D_R^2$

$\Rightarrow 71.58 = 11.43 \times D_R^2$

$\Rightarrow De^2 = \frac{71.58}{11.43} \Rightarrow D^2_R = 6.25$

$\Rightarrow D_R = \sqrt{6.26} = 2.50\,m$

$\Rightarrow D_B = 0.35 \times D_R$

$\Rightarrow 0.35 \times 2.50 = 0.875\,m$

(7) Speed :- $u_1 \Rightarrow \frac{\pi D_R N}{60} = \frac{3.14 \times 2.5 \times N}{60}$

$\Rightarrow 55.32 = 0.130 \times N$

$N = \frac{55.32}{0.130} = 425.53$ RPM

Ans

PUMP 16/09/2025

*** Pump :-** It is a hydraulic machine. which is convert mechanical energy to hydraulic energy.

Types :-

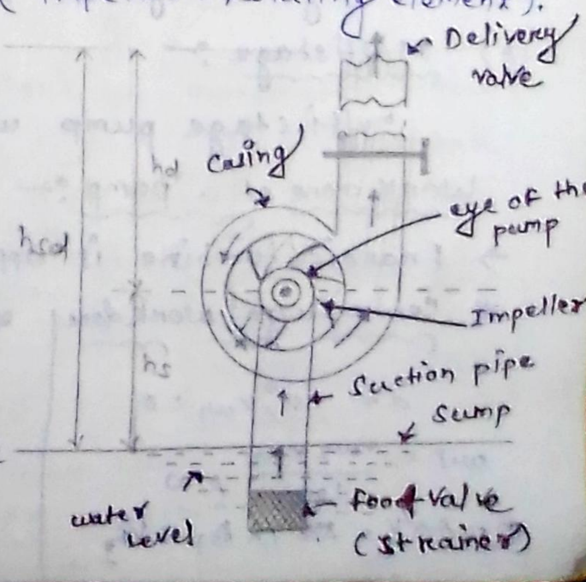
(1). Reciprocating pump. (Reciprocating motion of piston T.D.C to B.D.C.)

(2). Centrifugal pump. (Impelar - Rotating element).

(2). CENTRIFUGAL PUMP :-

IMPORTANT PARTS :-

1 - Casing
2 - eye of the pump
3 - Impeller
4 - Sump



*** Suction pipe :-**

→ Create pressure difference (vaccume).

* hs:- From water level to eye of the pump is known as Suction head (hs).
* hd:- From eye of the pump to delivery pipes is known as Delivery head (hd).
* Total head (Suction head + Delivery head) is know as static head (hsd).

*MANOMETRIC HEAD:- (Actual head).

→ (Head loss due to friction in both pipes)

Suction (hfs) — Discharge (hfd)

$$H_m = h_s + h_d + h_{fs} + h_{fd} + \frac{v^2}{2g}$$

Where,

h_s - Suction head.

h_d = Discharge head.

H_m = manomatric head.

h_{fs} = Suction head loss deu to Friction.

h_{fd} = Discharge head loss deu to friction.

$\frac{v^2}{2g}$ = water head. (Kinatic energy).

Single stage & Multi stage:-

(1) single stagle :- (pump)

A single stage pump uses one impeller.

(2) Multistage :-

multi stage pump uses 2 or more impellers.

Work done of a pump :-

→ Fransis' turbine is oppose of Centrifugal pump.

* Centrifugal work done	* Fransis turbine :-
	Radial Discharge
$\alpha = 90^\circ, V_{w_1} = 0$	$\phi = 90^\circ, V_{w_2} = 0$
$W.D = \frac{V_{w_2} \times u_2}{1000}$ KW	$W.D = \frac{V_{w_1} \times u_1}{1000}$
$Q = A \times V = \pi D_1 \times B_1 \times V_{f_1}$	

PRIMING :-

It is the process of Filling the pipe And casing with water so that the air accumalated In the pipe can be removed and the fuction on the pump becomes Normal.

CASING SHAPES :-

1:- Sprial
2 — Volute
3 — Vertex

$$\left[K.E = \frac{V^2}{2 \times g} \longrightarrow \text{pressure energy} \right.$$
$$= \frac{(r \times \omega)^2}{2 \times g} = \frac{r^2 \omega^2}{g} \quad [V = r \times \omega$$
V = linear velocity.

* EFFICINCIES OF CENTRIFUGAL PUMP :-

(1). Manometric efficiency :-

$$\eta_{mano} = \frac{\text{Manometric head}}{\text{Impeller head}}$$

(2). Mechanical efficiency :-

$$\eta_{mech} = \frac{\text{Impeller power}}{\text{Shaft power}}$$

(3). Overall efficiency :-

$$\eta_o = \eta_{mano} \times \eta_{mech}$$

(1). Manometric efficiency :-

$$\eta_{mano} = \frac{h_m}{I.h} = \frac{\left(h_s + h_d + h_{fs} + h_{fd} + \frac{V^2}{2g}\right)}{\frac{V_{w_2} \times u_2}{g}}$$

$$= \boxed{\frac{g \times h_m}{V_{w_2} \times u_2}}$$

where, h_m = manometric head,
$I.h$ = Impeller head.

(2). Mechanical efficiency :-

$$\eta_{mech} = \frac{I.P}{S.P} = \frac{\frac{V_{w_2} \times u_2}{g}}{\frac{2\pi N T}{60}} = \boxed{\frac{V_{w_2} \times u_2}{g} \times \frac{60}{2\pi N T}}$$

where, I.P = Impeller Power
S.P = Shaft power.

(3). overall efficiency:-

$$\eta_o = \eta_{mano} \times \eta_{mech} = \frac{h_m}{\frac{V_{w_2} \times u_2}{g}} \times \frac{\frac{V_{w_2} \times u_2}{g}}{\frac{2\pi NT}{60}} = \frac{h_m}{S.P}$$

$$= \frac{h_s + h_d + h_{fs} + h_{fd} + \frac{V^2}{2g}}{\frac{2\pi NT}{60}}$$

$$\Rightarrow \boxed{\frac{60\left(h_s + h_d + h_{fs} + h_{fd} + \frac{V^2}{2g}\right)}{2\pi NT}}$$

SOLVED PROBLEMS:-

(Q1) In a Centrifugal pump. the manometric and mechanical Efficiencies are 75% and 85%, Findout the overall efficiency?

Ans:-

Given data

$\eta_{mano} = 75\% = 0.75$

$\eta_{mech} = 85\% = 0.85$

we know that overall efficiency

$\eta_o = \eta_{mano} \times \eta_{mech} = 0.75 \times 0.85$

$= 0.6375 \approx 63.75\%$ Ans

(vertex Casing)

(Q2) In a Centrifugal pump internal and external dia- of the impeller are 200 mm and 400 mm. The pump is Rotating at 1200 rpm. The vane angle at inlet and out let is 20° and 30°. The water enters Radially and velocity of flow is constant find the work Done by the impeller (unit weight of water).

Ans:-

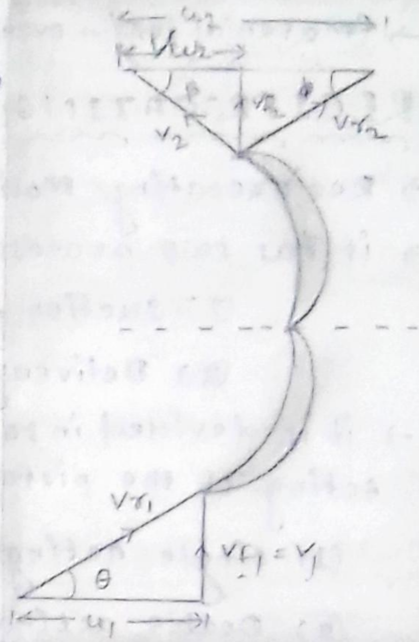
Given Data

$d = 200\,mm = \frac{200}{1000} = 0.2\,m$, $N = 1200$ R.P.M

$D = 400\,mm = \frac{400}{1000} = 0.4\,m$

$\theta_1 = 20^\circ$

$\phi_2 = 30^\circ$



when Radial flow $\alpha = 90^\circ$, $V_{w1} = 0$

$V_{f1} = V_{f2}$

we know that

$$u_1 = \frac{\pi d N}{60} = \frac{\pi \times 0.2 \times 1200}{60}$$

$\Rightarrow 12.56$ m/sec

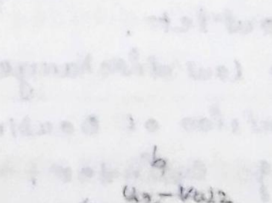
$$u_2 = \frac{\pi D N}{60} = \frac{\pi \times 0.4 \times 1200}{60}$$

$\Rightarrow 25.13$ m/sec

we know that work done

$$W.D = \frac{V_{w2} \times u_2}{g} =$$

* Inlet velocity traingle :-



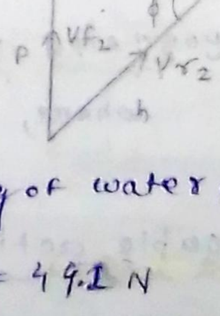
$$\tan\theta = \frac{p}{b} = \tan 20^\circ = \frac{V_{f1}}{u_1}$$

$\Rightarrow V_{f1} = u_1 \times \tan 20^\circ$

$\Rightarrow V_{f1} = V_{f2}$

$$\Rightarrow \frac{V_{f1}}{u_1} = \frac{V_{f1}}{12.56} = 4.47 \text{ m/s}$$

* Outlet velocity trangle :-



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

$$= 25.13 - V_{w2} = \frac{4.57}{\tan 30^\circ}$$

$= V_{w2} = 17.215$ m/s

$\therefore$ workdone by the impeller per kg of water per second

$$\Rightarrow \frac{V_{w2} \times u_2}{g} = \frac{17.215 \times 25.13}{9.81} = 44.1 \text{ N}$$

Ans

CAVITATION :-

→ (material loss - over water is straight on Blade)

RECIPROCATING PUMP :-

→ Reciprocating Motion of piston T.D.C to B.D.C.

→ it has two processes is
 (1) suction process.
 (2) Delivery process.

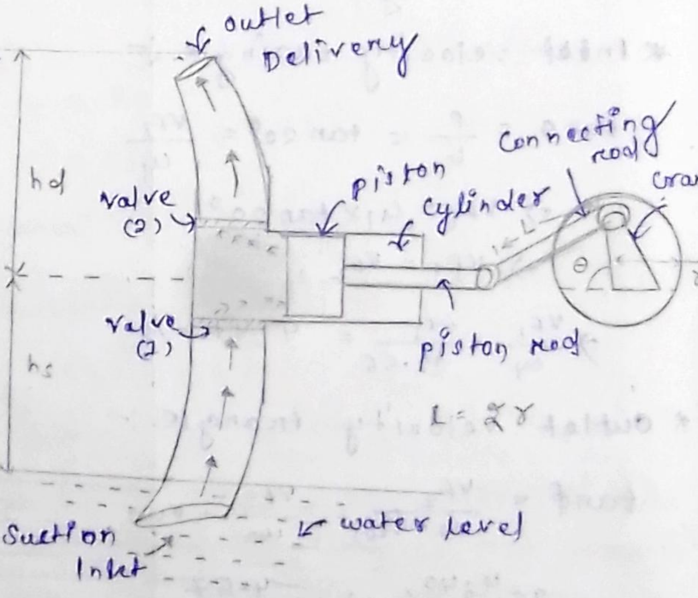
→ it is devided in to two type according to the force Acting of the piston cylinder :-
 (1) single acting Reciprocating pump.
 (2) Double acting Reciprocating pump.

(1) Single Acting Reciprocating pump :-

→ In a single acting Reciprocating pump force acting on the one side of piston cylinder.

→ it has one inlet & one outlet.

→ it is low discharge comparision of Double acting cylinder.



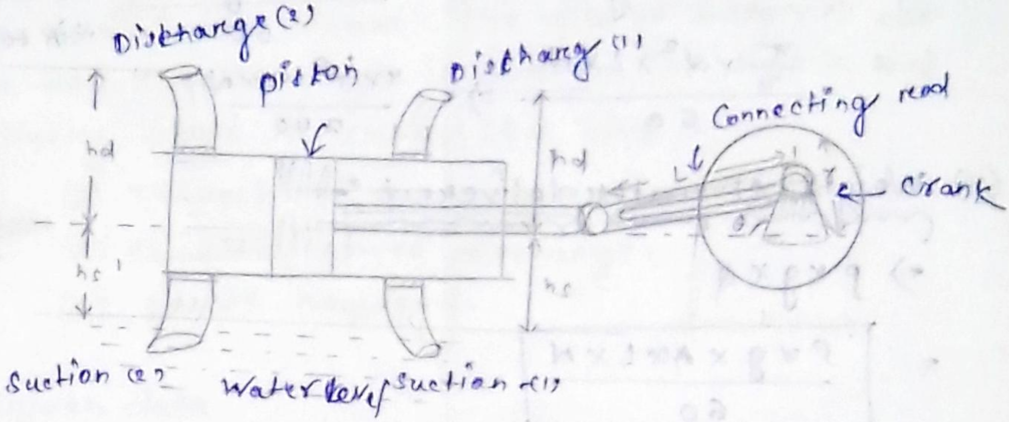
→ Total head = hs + hd

where, hs = suction head
 hd = delivery head.

(2) Double acting Reciprocating pump :-

→ In a Double acting reciprocating pump force acting on the both side of piston cylinder.

→ it has two inlet & outlet ways.
→ it is used for generate high discharge.
→ Total head = $2\times(h_s + h_d)$.



* DIFFERENCE BETWEEN CENTRIFUGAL & RECIPROCATING

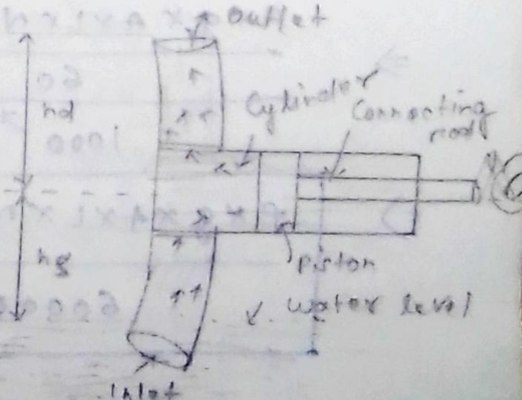
CENTRIFUGAL PUMP	RECIPROCATING PUMP
1. due to centrifugal force	1. due to reciprocating motion of piston T.D.C to B.D.C.
2. used Impeller to generate power.	2. used engine to generate power.
3. Low maintainess required.	3. High maintainess required.
4. Low cost	4. High cost
5. Low discharge	5. high discharge.
6. Less pollution	6. high pollution comparision of centrifugal pump.

DISCHARGE IN SINGLE ACTING RECIPROCATING PUMP

r = radius of crank

$L = 2r$ (Length of the stroke)

$A = \frac{\pi}{4}\times d^2$ (d = piston or cylinder)



(1) Volume of water delivered:-

$= A\times L \Rightarrow \frac{\pi}{4}\times d^2\times L$

where, A = Area of the cylinder.
L = Length of the stroke.

(2). "Q" = discharge :—

$Q = \text{Area} \times \text{Length} \times N \Rightarrow \frac{\text{Area} \times \text{length} \times N}{60}$ (to convert min to sec)

$= \frac{\frac{\pi}{4} \times d^2 \times L \times N}{60} \Rightarrow \frac{\pi \times d^2 \times L \times N}{240}$

(3). Weight of water delivered :—

$\Rightarrow \rho \times g \times Q$

$$= \boxed{\frac{\rho \times g \times A \times L \times N}{60}}$$

(4). Workdone by single acting reciprocating pump :—

$\boxed{W = \text{force} \times \text{displacement}}$ (workdone = force × distance travel)

$\Rightarrow$ weight of water delivered × $(h_s + h_d)$

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

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

(5). Power delivered :—

$P = \frac{\text{work done}}{1000}$ (According to the law of machine) According to the law of mechanics $\rightarrow \left(\frac{\text{workdone}}{\text{time}}\right)$

$\Rightarrow \frac{\frac{\rho \times g \times A \times L \times N \times (h_s + h_d)}{60}}{1000}$

$$\Rightarrow \boxed{\frac{\rho \times g \times A \times L \times N \times (h_s + h_d)}{60000} \text{ kW}}$$

SOLVED PROBLEMS :-

problem - 1 :- A single acting reciprocating pump Running at a speed of 60 rpm delivers water At 0.53 m³ per minute. The dia. of piston is 200 mm and stroke Length is 300 mm. The suction and Delivery head is 4m and 12 m. find :

(1) Theoritical discharge.

(2) Co-efficient of discharge.

(3) power required.

Ans :- Given data

$N = 60$ rpm

$Q = 0.53 \ m^3/min = \frac{0.53}{60} = 0.00883 \ m^3/sec.$

$d = 200mm = \frac{200}{1000} = 0.2 \ m$

$L = 300mm = \frac{300}{1000} = 0.3 \ m$

$h_s = 4m$

$h_d = 12m$

we know that

$A = \frac{\pi}{4} \times d^2 = \frac{\pi}{4} \times (0.2)^2 = 0.0314 \ m^2$

(1) Discharge (theoritical.) :-

$Q = \frac{A \times L \times N}{60} = \frac{0.0314 \times 0.3 \times 60}{60}$

$= 0.00942 \ m^3/sec.$

(2) Co-efficient of discharge :-

$C_d = \frac{Q \ actual}{Q \ theorytical} = \frac{0.00883}{0.00942}$

$C_d = 0.934$

(3). Power delivered :-

$$= \frac{\rho \times g \times Q \times (h_s + h_d)}{1000}$$

$$= \frac{1000 \times 9.81 \times 0.00942 \times (4 + 12)}{1000}$$

$$= 9.81 \times 0.00942 \times 16$$

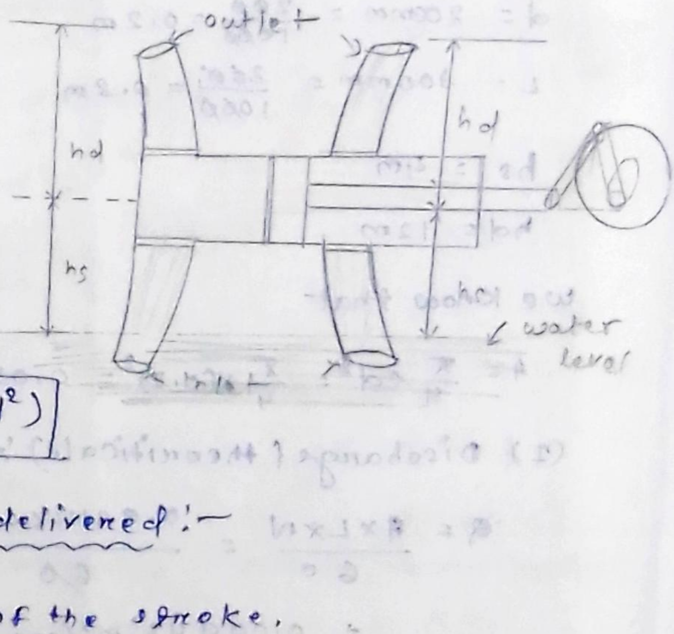
$$= 1.478 \text{ Kw}$$

Ans

* Work done by double acting reciprocating pump :-

D = piston diameter

$\Rightarrow \frac{\pi}{4} \times D^2$



d = piston rod diameter

$\Rightarrow \frac{\pi}{4} \times (D^2 - d^2)$

Total Area :-

$$\Rightarrow \boxed{\frac{\pi}{4} \times D^2 + \frac{\pi}{4} \times (D^2 - d^2)}$$

(1). Volume of water delivered :-

$\Rightarrow$ Area x length of the stroke.

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

(2) Discharge :-

$$Q = \frac{A \times L \times N}{60} = \boxed{\frac{\frac{\pi}{4} \times D^2 + \frac{\pi}{4} \times (D^2 - d^2) \times L \times N}{60}}$$

CONDITION:—

If the diameter of the piston rod can be Neglected.

(1) Discharge :—

$$Q = \frac{\left(\frac{\pi}{4} \times D^2 + \frac{\pi}{4} \times D^2\right) \times L \times N}{60}$$

$$\Rightarrow \frac{2 \times \frac{\pi}{4} \times D^2 \times L \times N}{60}$$

$$\Rightarrow \frac{2 \times A \times L \times N}{60}$$

(2) work done :—

⇒ force × displacement

= weight of water delivered × ($h_s + h_d$)

= $\boxed{2 \times \rho \times g \times Q \times (h_s + h_d)}$ (3) (power delivered) :—

$$= \boxed{\frac{2 \times \rho \times g \times A \times L \times N \times (h_s + h_d)}{1000}} \text{ kW}$$

SLIP IN RECIPROCATING PUMP:—

slip = Theorytical discharge − Actual discharge.

Nagative slip / slip = $\boxed{Q_{theo} - Q_{actual}}$

* slip is percentage :—

$$\text{slip} = \frac{Q_{th} - Q_{act}}{Q_{th}} \times 100 \Rightarrow \left(1 - \frac{Q_{act}}{Q_{the}}\right) \times 100$$

$$= \boxed{(1 - C_d) \times 100}$$

$$\left[C_d = \frac{Q_{actual}}{Q_{theorytical}} \right]$$

INDUSTRIAL FLUID POWER :-

In the fluid power industries, fluid is used To generate power and this power can be utilised in various industries.

Types :-

(1) Hydraulic Control System.

(2) pnematic Control System.

(1) Hydraulic control system :-

In hydraulic control system. Hydraulic oil is used to generate power. with the help of pump.

→ In this Control System the Capacity of power Generation is high.

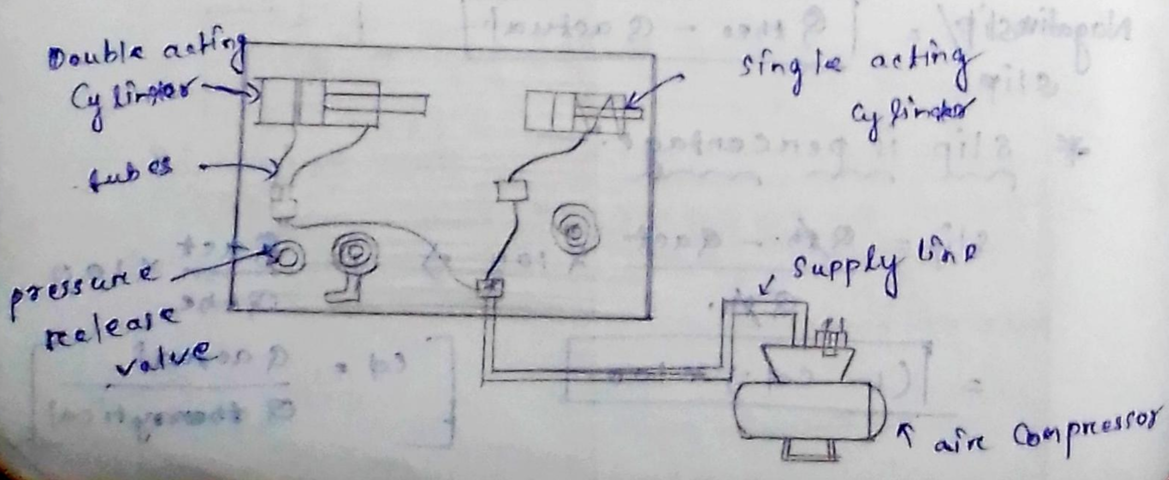
→ it is widely used in bigger industrial application.

(2) Pneumatic Control System :-

In pnematic Control system. Air is used to generate power. with the help of Air Compressor.

→ It is widely used in smaller industrial application.

(2). PNEUMATIC CONTROL SYSTEM :-



ELEMENTS OF PNUEMATIC CONTROL SYSTEM:—

(1) Compressor :—

It takes the air from the atmosphere then Compress it and supply to the pneumatic system. Various types of compressor Can be used according to the required operation.

Types of compressor:—

(1). Reciprocating compressure.
 (i) single stage / multi stage.
 (ii) single acting / Double acting.

(2). Rotary type:-
 (i) centrifugal pump.

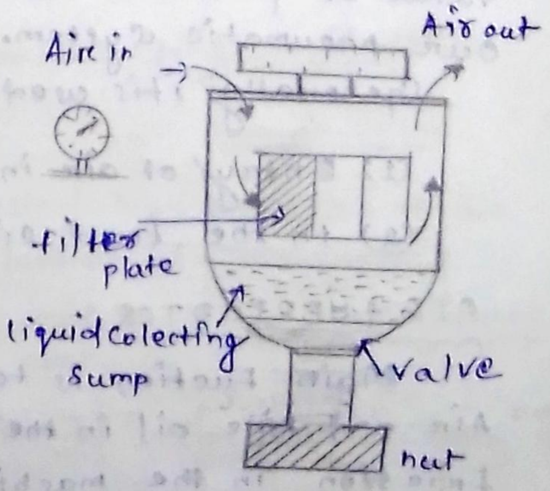
(3). Flow type :-
 (i) Axial flow.
 (ii) Radial flow.

(4). Diaphgram type:-
-> Here piston and Cylinder section is delivered by a Diaphgram.

PARTS OF COMPRESSOR PARTS :—

(1). Air filter:—

-> It allows pure air to the Compressor by restricting moisture, duct particle, water particle etc.



* Important parts used to filter and heat control in Neumatic system:-

(1). Inlet filter:-

→ 1st protecting device of pneumatic control system,

→ it is protect from duct, moisure etc.

(2). After - Cooler:- (Tube types)

Types:- (1) water cooler

(2) Air cooler.

(3). Inter - cooler:-

→ Cooling system used in different stages of Compressor. it is in tubular form.

AIR DRYERS:-

→ when the air contains moisture in large amount Air dryers are used to soak. the water vapour form air.

REGULATOR:-

It is used to regulate the pressure of air when there is fluctuation in air pressure. It keeps the value of pressure at a value which is safe for our pneumatic system.

Generally it is used in

(1) Entry of air into pneumatic.

(2) In the load circuit.

AIR LUBRICATOR:-

Main fuction is to supply the mixture of Air and fine oil in the form of spray to that friction in the machine parts can be reduced.

Generally it is used in

(1) valves, (2) machine packings, (3) other moving parts

MUFFLER:—

It is also called silencer, which is used to Reduce the noise of the outlet high pressure of Air. it is the form of a small cylindrical nut which is tighnend on the outlet of air.

They are made from Bronze material.

FRL UNIT:—

F = Filter.

R = Regulator

L = Lubricator.

PNEUMATIC ACTUATOR:—

→ Actuator are the components which convert one form of energy to another form of energy.

→ Here the high pressure of air is converted to Mechanical action.

→ In pneumatic system actuators are divided into two types:

(1) Linear

(2) Rotary.

(1). Linear:—

The action will be in linear or Reciprocating types.

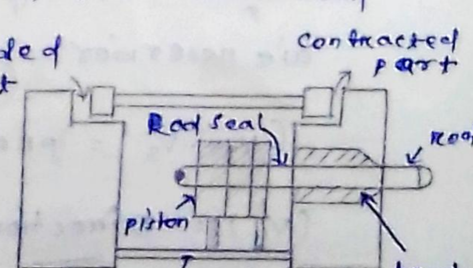
Ex:- single acting & Double acting cylinders.

(2). Rotary type:—

Here the Compressed high pressure of air produced the rotary motion the mechanical System.

Ex:- Air motors.

Double acting Cylinder:—



PRESSURE CONTROL VALVE :-

→ PCV :- Basically in pneumatic control system pressure control valves are used for safety purpose their main objective is to provide pressure of air within certain limit. Various condition arises while operating are:

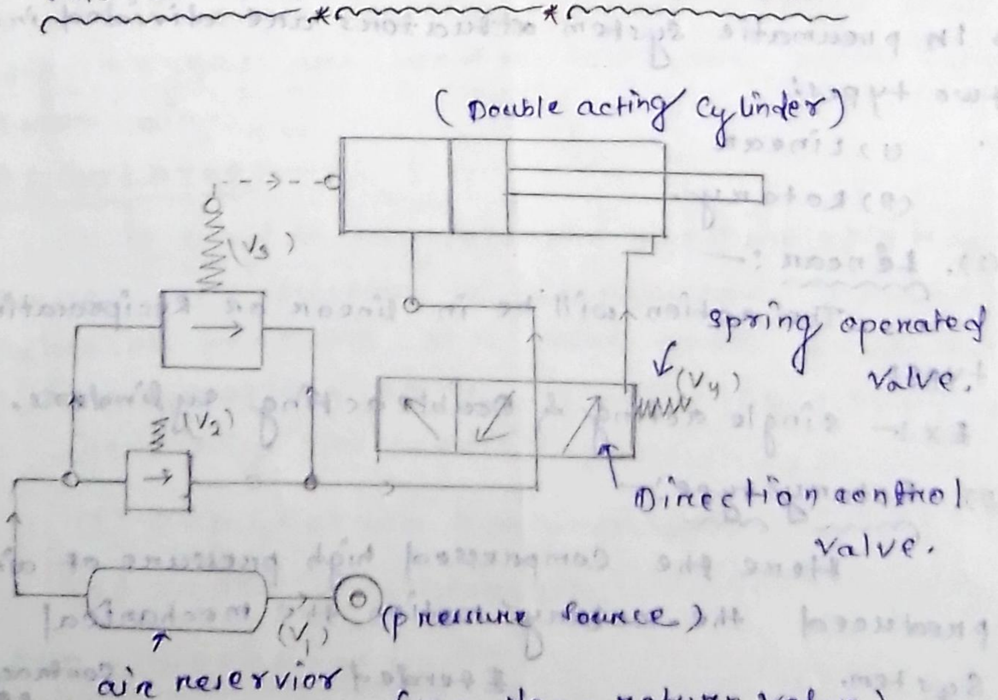
- → high pressure in the circuit.
- → Low pressure in the circuit.
- → Delivery pressure is very high load fluctuation.

Valves:-

(1) Non return valve.
(2) Spring operated valve.
(3) Needle operated valves.

CASE - I

PROTECTION AGAINST LOW PRESSURE :-



(V_1 = Non - return valve)

(V_2 - V_3) = pressure control valve)

(V_4) = Direction Control valve - DCV

Direction Control Valve (DCV):—

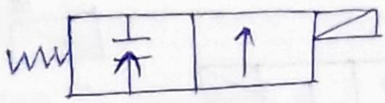
In pneumatic control system direction valves are used to control the direction of flow generally these valve are either hand operated or solenoid operated.

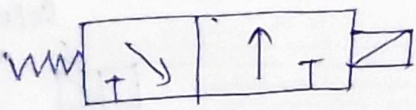
These are classified based upon the inlet and outlet condition of air like

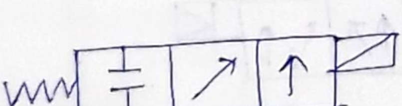
(i) 2 way 2 direction.

(ii) 3 way 2 direction.

(T = Block path.) (way - inlet, outlet)

(1).  - (3 way 2 position solenoid spring Return DCV)

(2).  - (3 way 2 position solenoid spring return)

(3)  - (5 way 2 position solenoid valve spring return)

PNEUMATIC SYMBOLS :—

* All are ISO (indian standard organization) symbols:

(1) pressure port (P).

(2) Drain port (L).

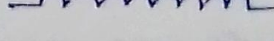
(3) working port (A, B, C).

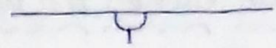
(4) Exhaust port (R, S, T).

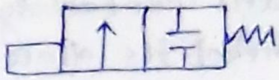
Symbols used in pneumatic system:—

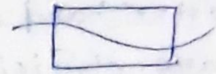
(1). pressure gauge - 

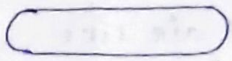
(2). Cooler - 

(3). coil tube 

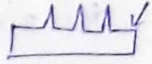
(4). Connection point - 

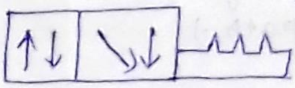
(5). 2/2 mechanical valve - 

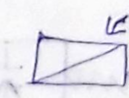
(6). Solenoid activator - 

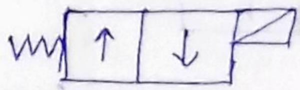
(7). Reservior - 

Valve operation diagram :-

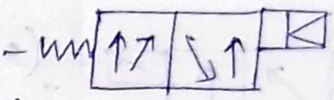
 manual control.

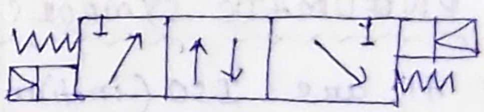
(1). (4 way 2 position manual control) - 

 Normally closed

(2). (2 way 2 position spring return Normally closed) - 

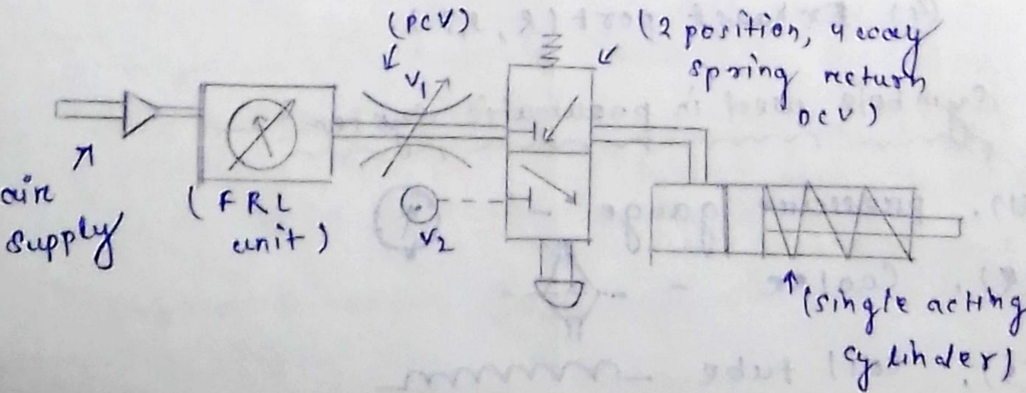
Solenoid valve. 

(3). (4 way 2 position pilot solenoid valve spring return valve.) - 

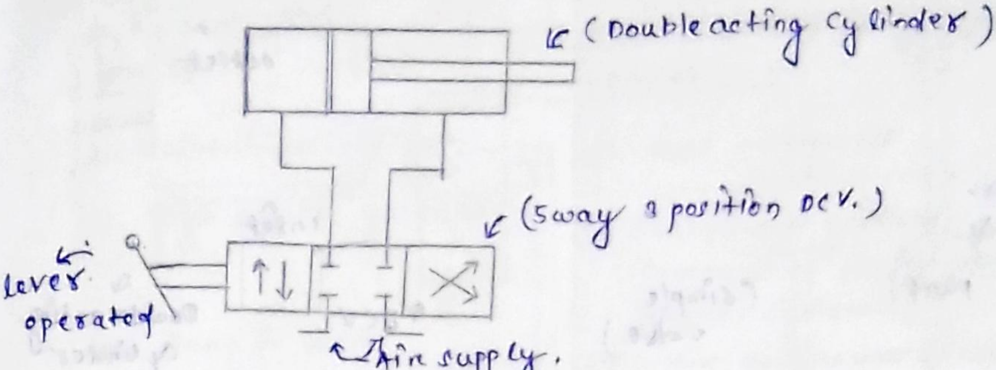
(4). (4 way (5 port) 3 position spring return centre, Double-pilot solenoid valve.) - 

Circuit diagram to control pneumatic Components :-

(1) Operate single acting cylinder :-



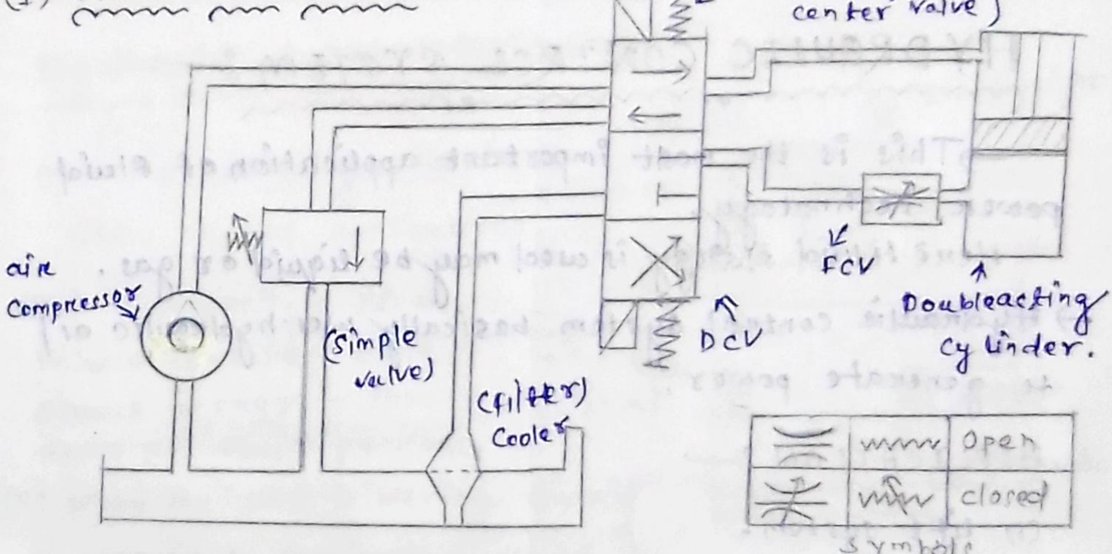
(2) operate double acting cylinder :-



Operation on double acting cylinder :-

* Meter-in and meter-out Connection :-

(1) Meter in conection :-



*it has two processes :-

(1) extraction
(2) Retraction

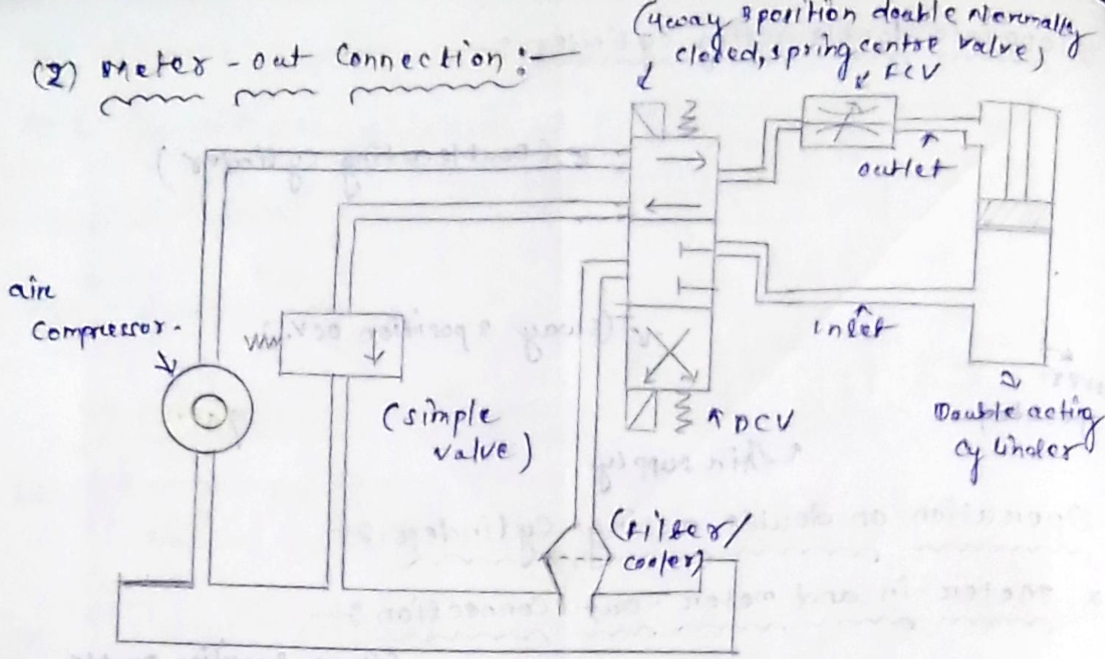
* FCV = flow control valve -(flufol).

[meter-in - on
meter-out - off
(conditions)]

(MQ) Circuit diagram -

(1) meter out (2) Extension ↓ (3) meter - in	↑ (1) meter - out (2) Retract (3) meter in

(2) Meter - out Connection :—



HYDRAULIC CONTROL SYSTEM :—

→ This is the most important application of fluid power technology.

→ Here, fluid is used may be liquid or gas.

→ Hydraulic control system basically use hydraulic oil to generate power.

APPLICATION :—

(1) Lift system.
(2) cranes and hoist.
(3) industrial application
(4) operate single / double acting cylinder.

Important parts in hydraulic control system :—

(1) Hydraulic oil.
(2) pump.
(3) high Quality Connecting pipes.
(4) valves (DCV, FCV)
(5) Actuators (single acting / double acting cylinder).
(6) FRL unit (Filter, regulator, lubricanator).

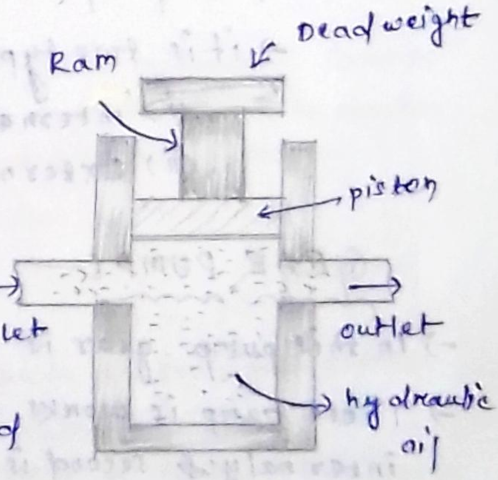
Hydraulic	Pneumatic
(i). hydraulic oil used to generate power.	(i) Air is used to generate power.
(2). maintainess is high	(2). Less maintaness,
(3). High power generate	(3) low power generat comparision of hydraulic control system.
(4). Pump is used	(4). Air compressor is used
(5). High Cost	(5). low cost.
(6). used in bigger industrial Application	(6). used in smaller industrial application

Hydraulic Accumulator :—

(1) it is basically used in lift; cranes applications.

(2) it is generally a Fixed volume container which stores energy in the form of fluid pressure.

(3) when the lift is moving upward it requires continues supply of hydraulic oil.



pump in Hydraulic Control system :—

it is a hydraulic machine which is convert mechanical energy to hydraulic energy.

Mechanical energy → Hydraulic oil → fluid power.

Classification of pump :—

(1) positive displacement pump.

(2) Rotary type (Reto-dynamic) pump.

(1) positive displacement pump :—

→ Reciprocating pump.

(2) Rotary - tube :

→ centrifugal pump.

orther specified pump like :

(1) Vane pump.

(2) secrew pump.

(3) Rotary pump.

(4) Jet pump.

(5) Gear pump (it is basically used in industrial sector).

→ it is two types :

(i) internal pump

(ii) External gear pump

GEAR PUMP :—

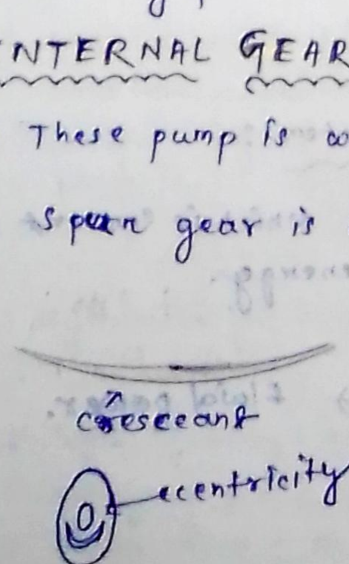
→ In this pump gear is used to generate power.

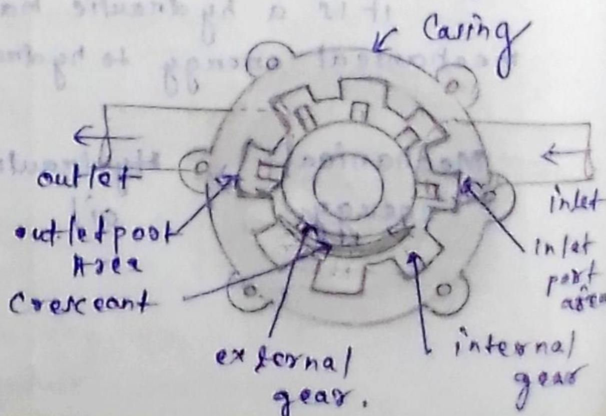
→ These pump is works on gear Arrengements one is internaly & second is externaly.

INTERNAL GEAR PUMP :—

→ These pump is work on internaly gear arrengement.

→ Spurn gear is used.





EXTERNAL GEAR PUMP :-

→ These pump is work on external gear arrangement.
→ Spur gear is used.

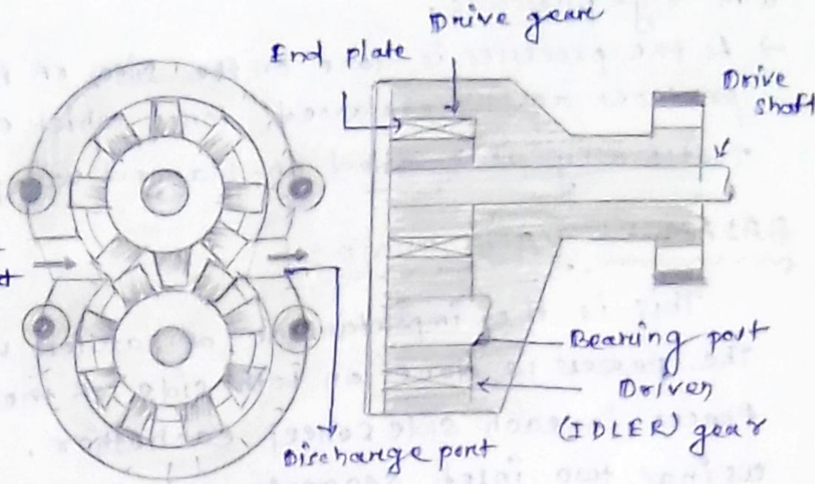


Fig:- External Spur gear pump.

VANE PUMP :-

This pump is also widely used in the hydraulic control system which consists of vanes cut into the rotor to produce power. These pump can be devided into two types:-

(1) Balanced vane pump.
(2) Unbalance vane pump.

(1) UNBALANCED VANE PUMP :-

→ Here also power produced due to centrifugal action.
→ it is consists of Rotor, Vanes, Cam ring etc.
→ Initially due to pressure difference oil is trapped into the Rotor.
→ Vane is connected in Camring (Vane is move inward or outward).
→ it has two process
  (i) suction.
  (2) Delivery.
→ Rotor - one side - force act. (to create Vibration)

(1). SUCTION :- when in starting the Rotor is rotates in the shaft Bearing and the vanes moves outward causing pressure difference and let the fluid in (During 1st half of Rotation).

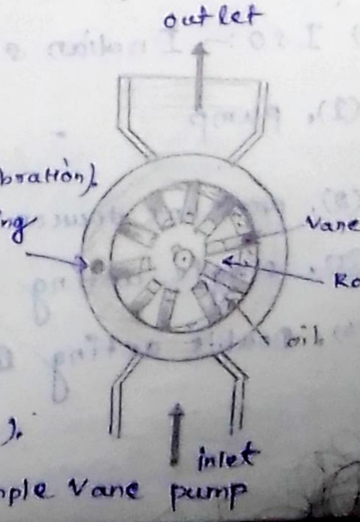


Fig:- Simple Vane pump

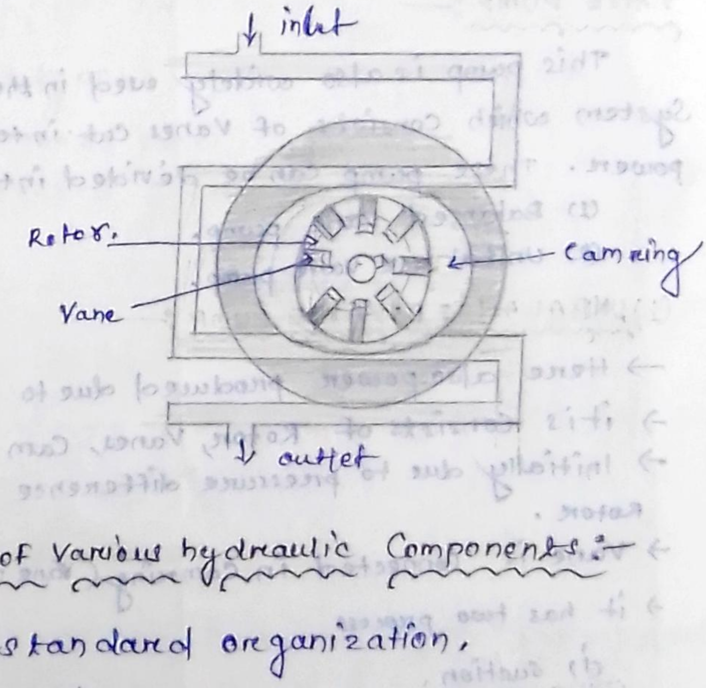
(2) Delivery :—

During the 2nd half Rotation of the Rotor the Vanes Moves in ward Causing a large force to eject that fluid with high pressure.

→ As the processes is done on the side of the Rotor, It produces an un-balanced force which causes Vibration. That's why it is called un-blanced vane pump.

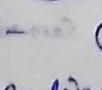
BALANCED VANE PUMP :—

This is the improvement of earlier Vane pump here The process is done on both side of the rotor so that forces in each side concel eachother. Here we are using two inlet segment and outlet segment for Better delivery.

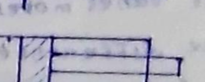


"ISO" sysembles of Various hydraulic Components :—

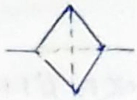
→ ISO :- Indian standard organization.

(1). pump - 

(2). pressure source - 

(3). single acting cylinder - 

(4). Double acting cylinder - 

(5). filter circuit - 

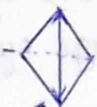
(6). pressure gauge - 

(7). Temperature gauge - 

(port - connection of tubes in the circuit)

(T - Blocked path)

(8). Electric Motor - 

(9). Cooler - 

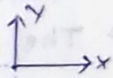
(10). Heater - 

(11). 2-port 2 position Normaly closed (DCV). - 

HYDRAULIC ACTUATORS :-

it is convert pressure energy (oil) to mechanical Energy.

Types of actuator :-

1. - Leaner - motion is transmitted in linear axis - 

2. - Rotary - motion is transmitted through rotation - 

1-Leaner cylinder :-

(i) Telescopic cylinder.

(ii) Tandem cylinder.

(2). Rotary Cylinder :-

(i) screw motors, (ii) Gear motors.

TELESCOPIC CYLINDER :-

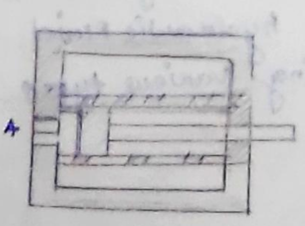


fig:- Retracted position.

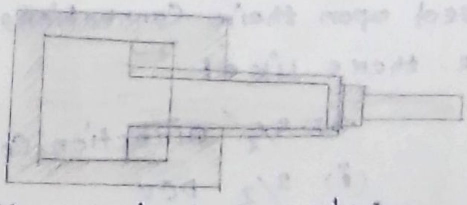


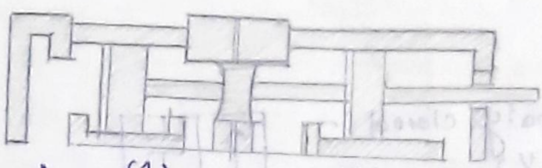
fig:- Extended position

-) The piston rod for the first stage is used as piston Barrel for Second stage.

→ it can be up to six stage.
→ it is used in hydraulic Jacks, Lifting, Crans.

TANDEM CYLINDER :- (Tandam = 1 + 1)

This types of cylinder is used in medium level Application. here two or more cylinder connected in line so that when work is done by the cylinder gives Two times stroke then Normal operating cylinder.



→ it can be up to six stage cylinder.

PRESSURE CONTROL VALVE (PCV) :-

These valve are either hand operated, pilot, selenoid, spring operated valves.
→ The main fuction of these valve is to regulate the pressure in the hydraulic circuit.

used :-
(1). when the pressure in the circuit is more than the rated pressure.
(2). when there is reduction in pressure due to fluctuation in Load.

(DCV) DIRECTION CONTROL VALVE :-

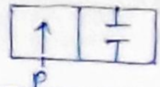
These are the most important valves. in hydraulic circuit as it controls the direction of hydraulic fluid Based upon their connections and working various types Are there like :

(i) 3/2 Direction Control valve.
(ii) 2/2 DCV
(iii) 5/3 DCV

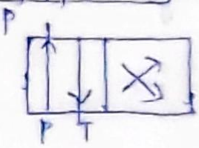
(They may be operated by hand, spring solenoid, pilot valves)

Circuit Diagram's of DCV :—

where,
(P = pressure port)
(T - Temperature port)

(1). 2/2 way Valve — 

(2). 3/3 way Valve — 

(3). 4/4 way valve — 

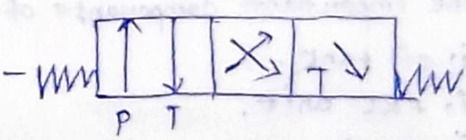
[2 / 3
position / way/flow path]

(4). 3/4 way DCV

(i) 1 p-port, 1 Temperature port
2, flow path, 2 Block path — 

[if one block path then [T↘]]

(5). 3/4 way Valve

1 p-port, 1 Temperature port
1-Block path, 3 flow path.
spring return valve. — 

FLOW CONTROL VALVE :—

The main fuction of the flow control valves is To regulate the hydraulic fluid in the circuit.

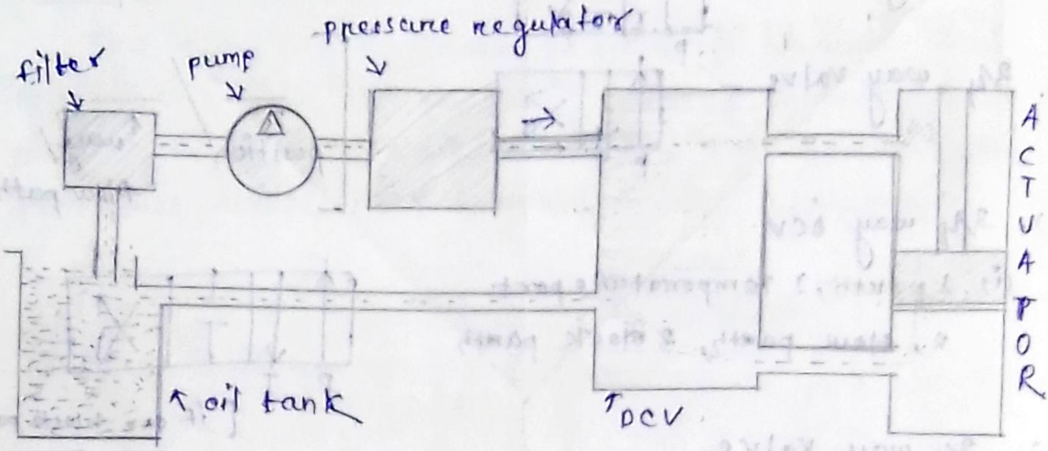
→ when we need to supply more fluid or less fluid According to the variable load condition.

→ when the excessive low pressure in the circuit in that condition FCV is immediatly stop/Brake the machine work.

Throttle valve :—

It working is same as used in case of governors, when the load on the circuit is low, it supplies less hydraulic fluid to the Actuators where as when the Load in the circuit is very high, it supplies more hydraulic fluid to the actuator.

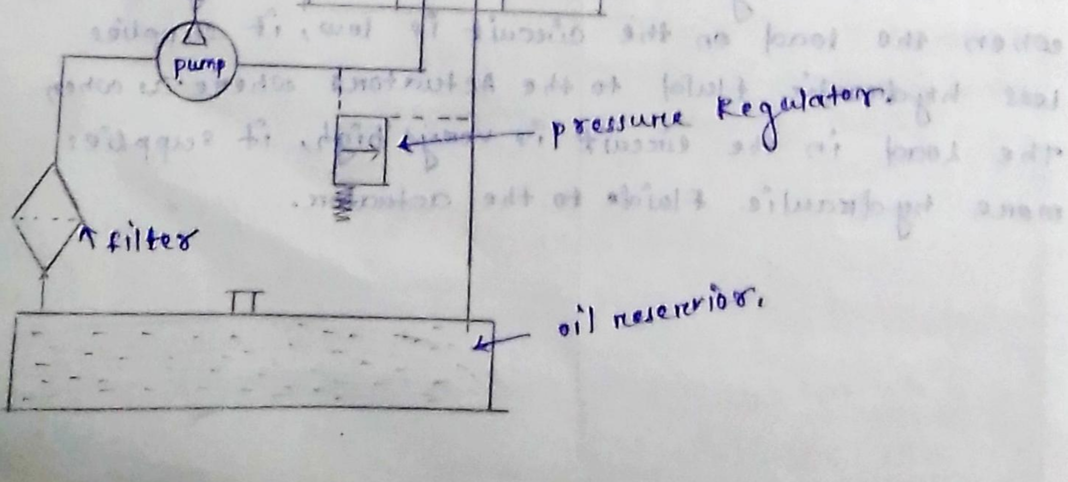
ESSENTIAL COMPONENTS OF HYDRAULIC CIRCUIT:-



* The important componants of hydraulic Control system are :-
  - (i) oil tank.
  - (ii) FRL unit.
  - (iii) DCV.
  - (iv) pump.
  - (v) Actuator.
  - (vi) pressure regulature.

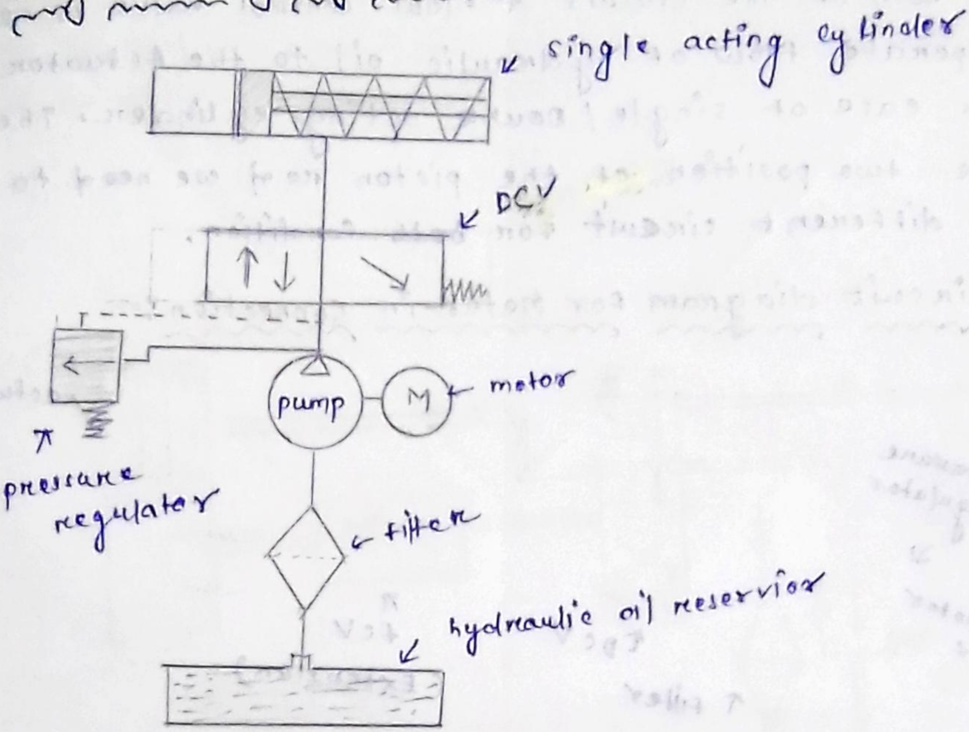
Direct control of Double acting cylinder in hydraulic:-

* circuit diagram:-

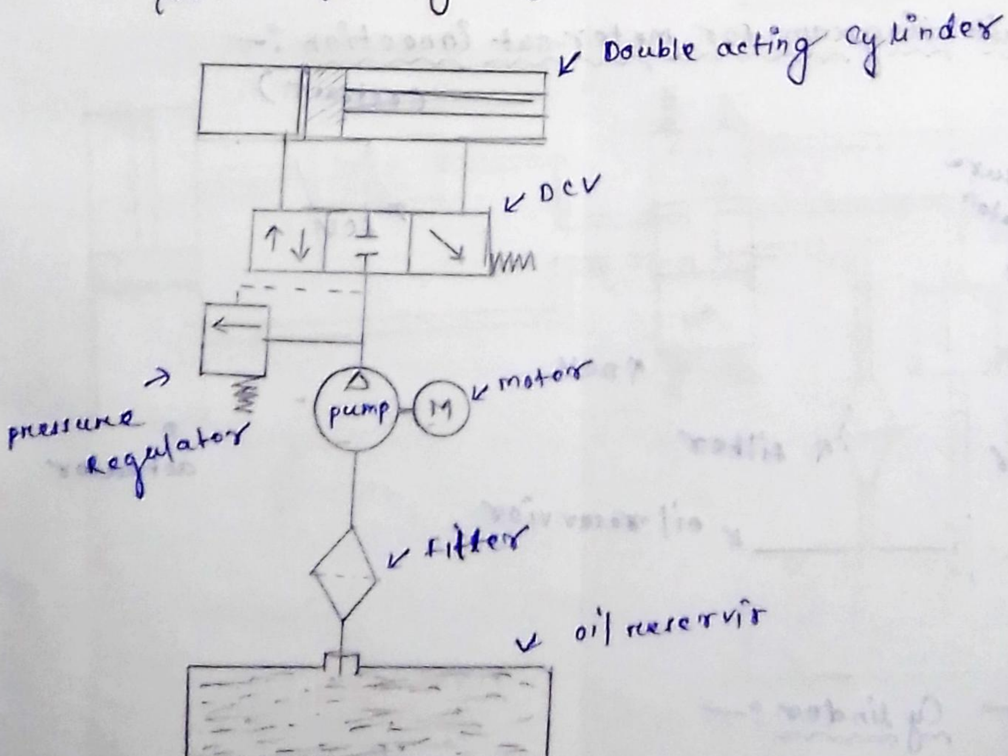


* Direct Control of single & Double acting Cylinder :-

(1). single acting Cylinder :-



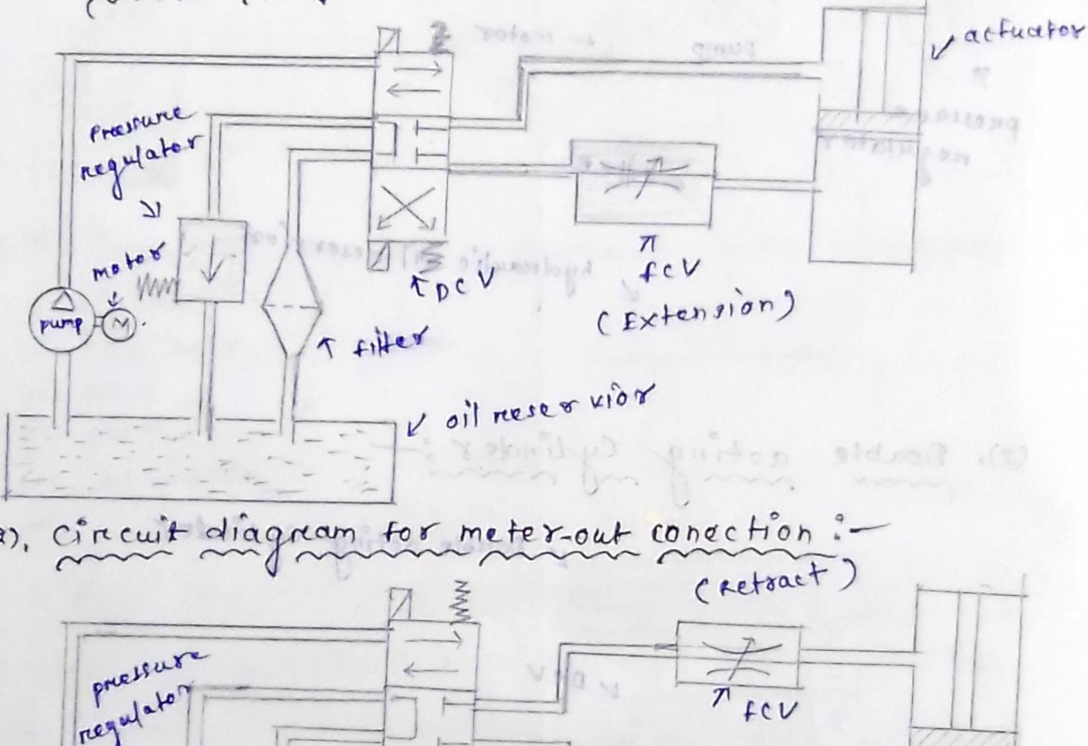
(2). Double acting Cylinder :-



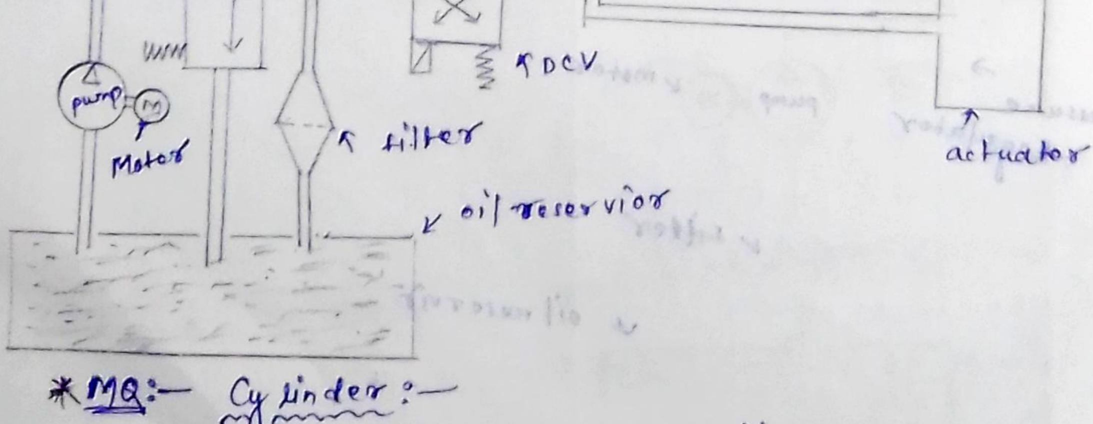
Meter-in & meter-out Connection in hydraulic Control system:-

In both of the circuit a flow control valve is used to operate flow of hydraulic oil to the Actuator. As in case of single / Double acting cylinder. These is the two position of the piston rod we need to Draw different circuit for both condition.

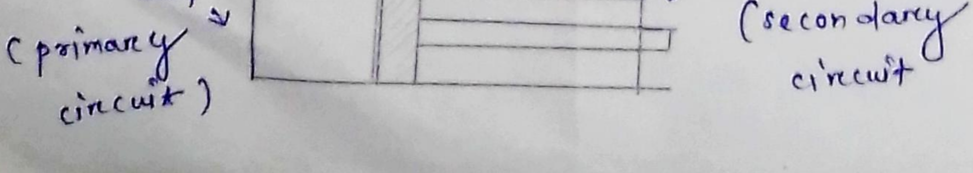
(1). Circuit diagram for meter-in Connection :-



(2). Circuit diagram for meter-out conection :-
(Retract)



*MQ:- Cylinder :-



* Meter-in - flow is supplied before the load.
* meter-out - flow is supplied After the load.

→ To control the speed of actuator is to used meter-in and meter-out connections.