

Q) What do u mean by impact of jet?

→ When a nozzle is connected with the pipe at the outlet, the fluid flowing under pressure. If some plate, which may be fixed or moving is placed in the path of the jet. The force exerted by the jet on a plate which may be stationary or moving is called the impact of jet.

Q) Derive the equation for the force exerted by the jet on a stationary vertical plate.

→ Consider a jet of water coming out from the nozzle, strikes a vertical plate.

Let V = Velocity of the jet, d = dia of jet
 $a = \text{area of c/s of the jet} = \frac{\pi}{4} d^2$

The jet after striking the plate, will move along the plate.

But the plate is at right angles to the jet.

Hence the jet after striking, will get deflected through 90° .

Hence the component of the velocity after striking in the direction of jet will be zero.

The force exerted by the jet on the plate in the direction of jet,

$F_x = \text{Rate of change of momentum in the direction of force}$

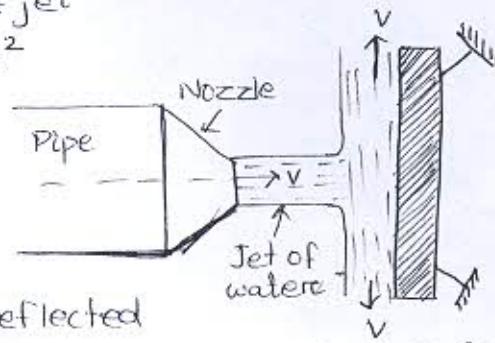
$= \frac{\text{Initial Momentum} - \text{Final momentum}}{\text{Time}}$

$= \frac{\text{mass} \times \text{initial velocity} - \text{mass} \times \text{final velocity}}{\text{Time}}$

$= \frac{\text{mass}}{\text{Time}} \times (\text{velocity of jet before striking} - \text{velocity of jet after striking})$

$= \cancel{\text{mass}} \frac{\text{av}}{\text{Time}} [V - 0]$

$= \cancel{\text{mass}} \text{av}^2$



Q) Derive the equation for the force exerted by a jet on a stationary inclined flat plate.

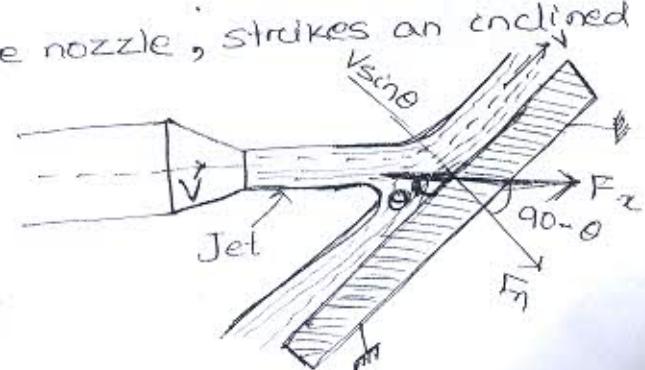
→ Let a jet of water coming out from the nozzle, strikes an inclined flat plate.

V = Vel of jet in the direction of x

θ = Angle betw the jet and plate

a = Area of c/s of the jet

Mass of water striking per sec = $\cancel{\text{mass}} \text{av}$



If the plate is smooth and if it is assumed that there is no loss of energy due to impact of the jet, then it will move over the plate after striking with a velocity equal to the initial velocity V .

Then the force exerted in the normal dirⁿ,

$$F_n = \rho AV [V \sin \theta - 0]$$

$$= \rho AV^2 \sin \theta$$

This force can be resolved in two component

$$(a) \text{ In the dir}^n \text{ of jet} = F_x = F_n \cos(90^\circ - \theta) = F_n \sin \theta$$

$$= \rho AV^2 \sin^2 \theta$$

$$(b) \text{ Perpendicular to the flow} = F_y = F_n \cos \theta$$

$$= \rho AV^2 \sin \theta \cdot \cos \theta$$

7th Oct

Q) Derive the eqn for the force exerted by a jet on stationary curved plate.

⇒ (a) Jet strikes the curved plate at the centre :-

Let a jet water strikes a fixed curve plate at the centre

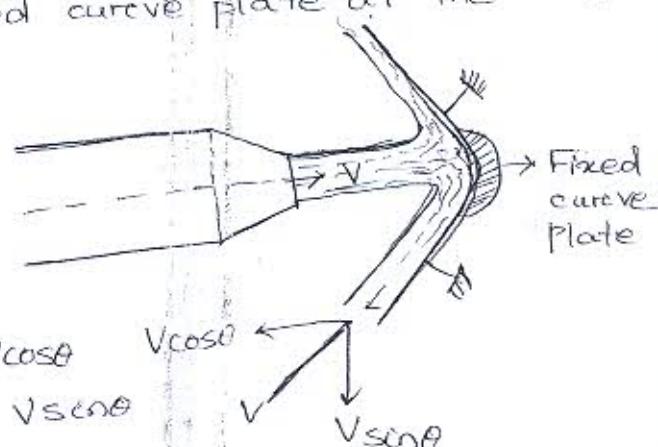
→ If the plate is smooth,

there is no loss of energy

→ The velocity at the outlet
can be resolved into two
components.

$$(a) \text{ In the dir}^n \text{ of jet} = -V \cos \theta$$

$$(b) \text{ Perpendicular dir}^n = V \sin \theta$$



Force exerted by in the jet in the dirⁿ of jet \Rightarrow

$$F_x = \text{Mass per sec} [V_{1x} + V_{2x}]$$

$$= \rho AV [V - (-V \cos \theta)]$$

$$= \rho AV^2 [1 + \cos \theta]$$

$$F_y = \rho AV [V_{1y} - V_{2y}]$$

$$= \rho AV [0 - V \sin \theta]$$

$$= -\rho AV^2 \sin \theta$$

$$V_{1x} = \text{Initial velocity}$$

$$= V$$

$$V_{2x} = \text{final velocity}$$

$$= -V \cos \theta$$

$$V_{1y} = \begin{matrix} \text{Initial} \\ \text{Velocity in } y \\ \text{dir}^n = 0 \end{matrix}$$

$$V_{2y} = \begin{matrix} \text{Final vel. in } y \\ \text{dir}^n \\ = V \sin \theta \end{matrix}$$

b) Jet strikes the curved plate at one end tangentially when the plate is symmetrical :-

$$F_x = \frac{\text{mass}}{\text{sec}} \times [v_{1x} - v_{2x}]$$

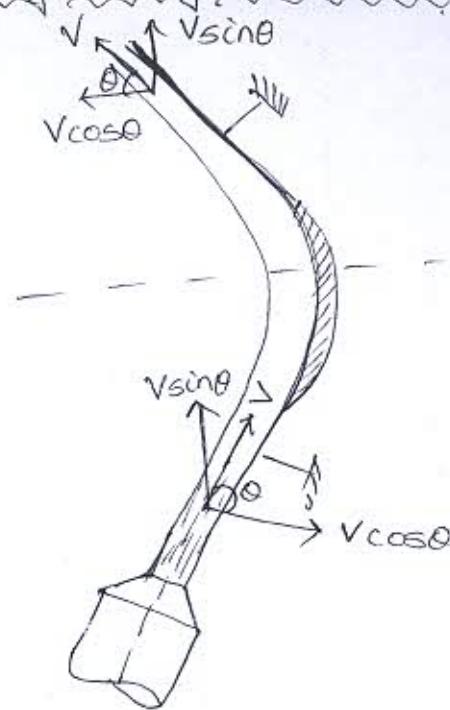
$$= \rho av [v \cos\theta - (-v \sin\theta)]$$

$$= 2 \rho av^2 \cos\theta$$

$$F_y = \rho av [v_{1y} - v_{2y}]$$

$$= \rho av [v \sin\theta - v \sin\theta]$$

$$= 0$$



c) Unsymmetrical plate condition

θ = angle made by tangent at inlet tip with x -axis

ϕ = angle made by tangent at outlet tip with x -axis

ϕ = angle made by tangent at outlet tip with x -axis

Velocity component at inlet area,

$$v_{1x} = v \cos\theta \quad \text{and} \quad v_{1y} = v \sin\theta$$

Velocity component at outlet area,

$$v_{2x} = -v \cos\phi \quad v_{2y} = v \sin\phi$$

Then, $F_x = \rho av [v \cos\theta - (-v \cos\phi)]$

$$= \rho av^2 [\cos\theta + \cos\phi]$$

$$F_y = \rho av^2 [\sin\theta - \sin\phi]$$

12th Oct
Derive the equation of force for flat vertical plate moving in the direction of jet.

Relative Velocity = $(V-u)$

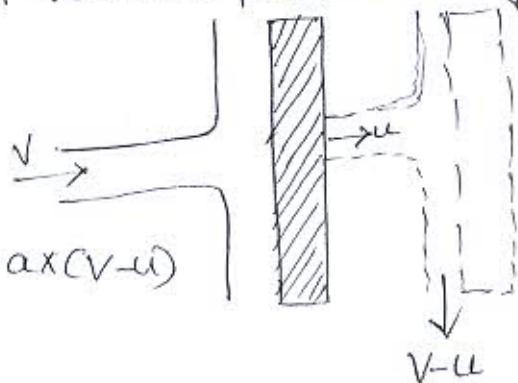
u → velocity of plate

Mass of water striking per sec. = $\rho \times a \times (V-u)$

$$F_x = \rho a (V-u) [(V-u) - 0]$$

$$= \rho a (V-u)^2$$

Work done per second by the jet = Force \times plate velocity
 $= F_x \times u = \rho a (V-u)^2 \times u$



Q) Derive the eqⁿ of force on the inclined plate moving in the dirⁿ of jet.

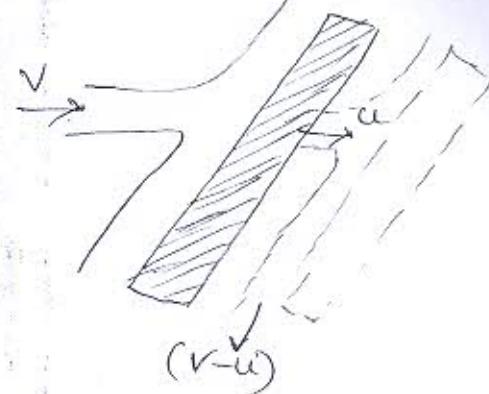
$$F_n = \rho a(v-u) [(v-u) \sin\theta - 0]$$

$$= \rho a(v-u)^2 \sin\theta$$

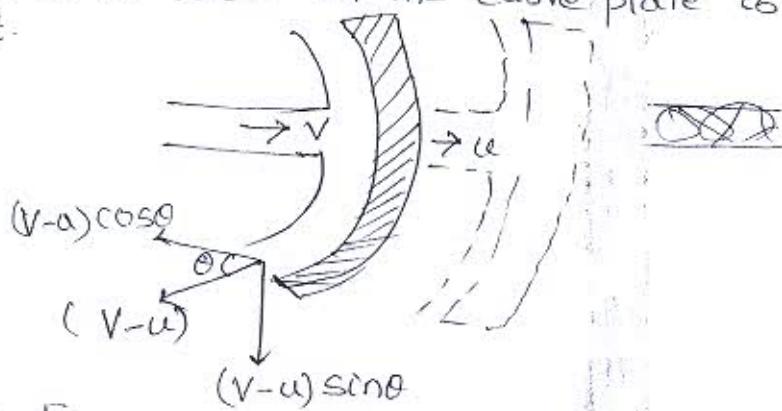
$$F_x = F_n \sin\theta = \rho a(v-u)^2 \sin^2\theta$$

$$f_y = F_n \cos\theta = \rho a(v-u)^2 \cos\theta \sin\theta$$

$$\text{Workdone per second} = \rho a(v-u)^2 \sin^2\theta \cdot u$$



Q) Derive the equation of force on the curve plate is moving in the direction of jet.



$$F_x = \rho a(v-u) [(v-u) - (- (v-u) \cos\theta)]$$

$$= \rho a(v-u)^2 (1 + \cos\theta)$$

$$\text{Workdone} = \rho a(v-u)^2 (1 + \cos\theta) \times u$$

$$\text{efficiency} = \frac{\text{Workdone by the jet}}{\text{K.E. of jet / sec}} = \frac{\rho a(v-u)^2 (1 + \cos\theta) u}{\frac{1}{2} \times (\rho a v) \times v^2}$$

$$F_y = \rho a(v-u) [0 - (v-u) \cos\theta]$$

$$\text{Problems.} \quad = -\rho a(v-u)^2 \cos\theta$$

Q) Find the force exerted by a jet of water of dia 75 mm on a stationary plate, when the jet strikes the plate normally with velocity of 20 m/s.

→ For vertical stationary flat plate,

$$F = \rho a v^2 = 1000 \times \frac{\pi}{4} \times (0.075)^2 \times 20^2$$

$$= 1766.8 \text{ N}$$

Q) A jet of water of dia 75 mm moving with a velocity of 25 m/s strikes a fixed plate in such a way that the angle between the jet and plate is 60°. Find the force exerted by the jet on the plate (i) In the dirⁿ normal to the plate and (ii) in the dirⁿ of jet.

$$\Rightarrow (i) F_{\text{N}} = \rho a v^2 \sin \theta$$

$$= 1000 \times \frac{\pi}{4} \times (0.075)^2 \times 25^2 \times \sin 60^\circ$$

$$= 2390.7 \text{ N}$$

$$(ii) F_x = \rho a v^2 \sin^2 \theta$$

$$= 1000 \times \frac{\pi}{4} \times (0.075)^2 \times 25^2 \times \sin^2 60^\circ$$

$$= 2070.4 \text{ N}$$

- Q) A jet of water of dia 10cm strikes a flat plate normally with a velocity of 15 m/s. The plate is moving with a velocity of 6 m/s in the direction of the jet and away from the jet. Find
 (i) the force exerted by the jet on the plate
 (ii) work done by the jet on the plate per second.

$$\Rightarrow (i) F = \rho a (V - u)^2$$

$$= 1000 \times \frac{\pi}{4} \times (0.1)^2 \times (15 - 6)^2 = 636.17 \text{ N}$$

$$(ii) \text{ Work done} = F_x \times u = 636.17 \times 6 = 3817.02 \text{ NM/s}$$

Hydraulic Machines Turbine 14/10/20

Definition:-

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

- The hydraulic machine which converts the mechanical energy into hydraulic energy is called pumps.
- The hydraulic machine which converts the hydraulic energy to mechanical energy, is called turbine.

Turbine

- The mechanical energy produced by a turbine is used in running an electric generator which is directly coupled to the shaft of the turbine.

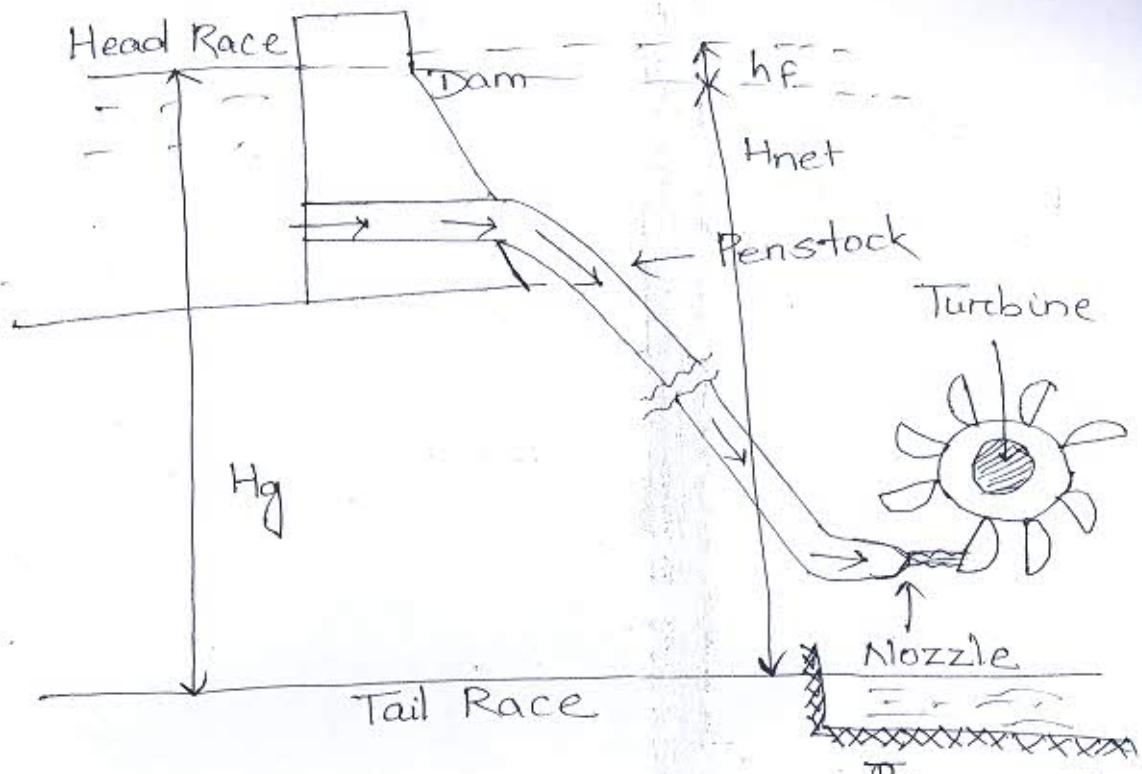
Definitions of head and efficiencies of a turbine

Gross Head:- The difference between the head race level and tail race level when no water is flowing is known as gross head.

- Denoted by ' h_g '

Net head:- Called as effective head. Defined as the head available at inlet of the turbine.

$$H_{net} = H_g - h_f$$



[Layout of a hydroelectric power plant]

14/10/20

Classification of Hydraulic Turbines

The hydraulic turbines are classified as,

- i) According to the type of energy at inlet:
 - a) Impulse Turbine
 - b) Reaction Turbine
- ii) According to the direction of flow through runners:
 - a) Tangential flow turbine
 - b) Radial flow turbine
 - c) Axial flow turbine
 - d) Mixed flow turbine.

3. According to the head at the inlet of turbine.

- a) High head turbine
- b) Medium head
- c) Low head

4. According to the specific speed of turbine.

- a) Low specific speed
- b) Medium "
- c) High "

Impulse Turbine :-

If at the inlet of the turbine, the energy available is only kinetic energy, the turbine is known as impulse turbine.

Reaction Turbine :-

If at the inlet of the turbine, the water possesses kinetic energy as well as pressure energy, the turbine is known as reaction turbine.

Tangential flow turbine :-

If water flows along the tangent of the runners, the turbine is known as tangential flow turbine.

Radial flow turbine :-

If the water flows in the radial direction through the runners, the turbine is called as radial flow turbine.

Axial flow turbine :-

If the water flows through the runners along the direction parallel to the axis of rotation, of the runners, the turbine is called axial flow turbine.

Mixed flow turbine :-

If the water flows through the runners in the radial direction but leaves in the direction parallel to axis of rotation of the runners, the turbine is called mixed flow turbine.

Pelton Wheel (or turbine)

→ It is a tangential flow impulse turbine.

→ The water strikes the bucket along the tangent of the runner. The energy available at the inlet of the turbine is only kinetic energy.

→ The main parts of the pelton wheel turbine are,

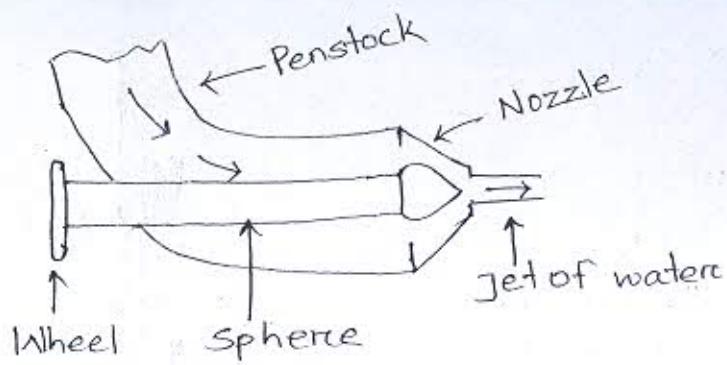
- 1) Nozzle and flow regulating arrangement
- 2) Runners and buckets
- 3) Casing
- 4) Breaking Jet

1) Nozzle and flow regulating Arrangements :-

→ The amount of water striking the buckets (vanes) of the runner is controlled by providing a spear in the nozzle.

→ The spear is a conical needle which is operated either by a hand wheel or automatically in an axial direction depending upon the size of the unit.

→ When the spear is pushed forward into the nozzle the amount of water striking the runner is reduced.



- On the other hand, if the spherical is pushed back, the amount of water striking the runner increases.

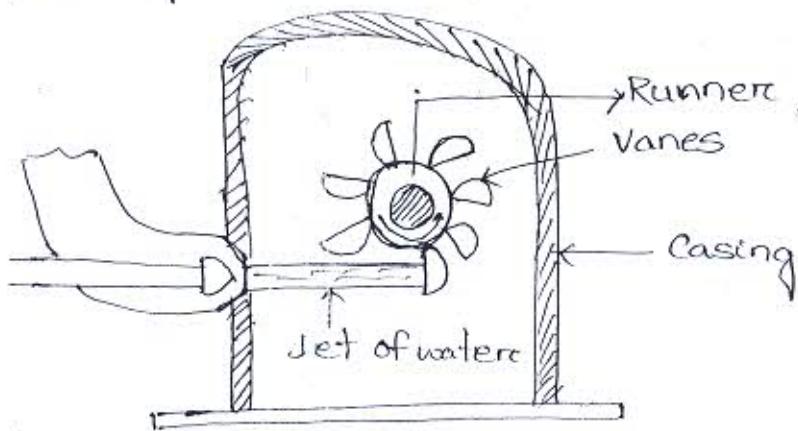
17th Oct

Runners with buckets :-

- It consists of a circular disc on the periphery of which a number of buckets evenly spaced are fixed.
- The jet of water strikes on the splitter.
- The buckets are shaped in such a way that the jet gets deflected through 160° to 170° .
- The buckets are made of cast iron.

Casing :-

- The function of the casing to prevent the splashing of the water.



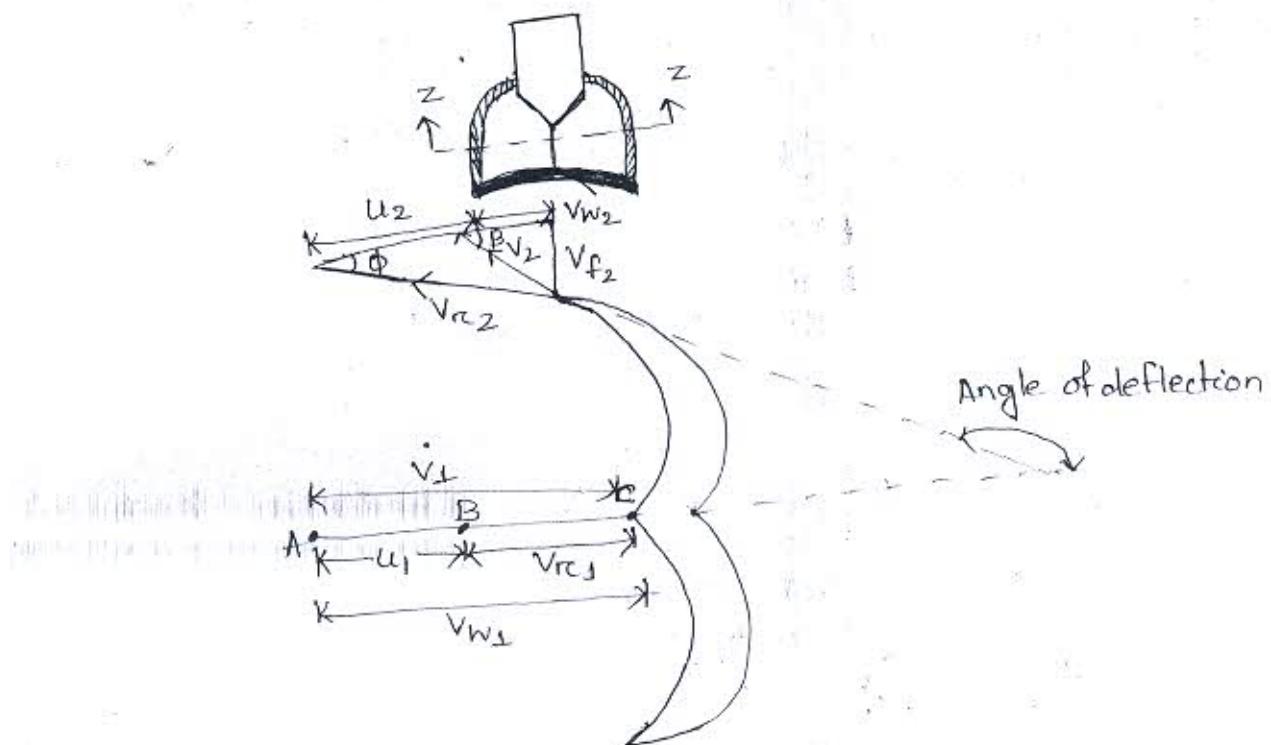
- It acts as safe guard against accident.
- It does not perform any hydraulic function.

Breaking Jet :-

When the nozzle is completely closed by moving the spear in the forward direction, the amount of water striking the runner reduces to zero.

- But the runner due to inertia goes on revolving for a long time.
- To stop the runner in a short time, a small nozzle is provided which directs the jet of water on the back of the vanes. This jet of water is called breaking jet.

Velocity triangle and Work done for Pelton Wheel



The jet of water from the nozzle strikes the bucket at the splitter, which splits up the jet into two parts.

Let, H_g = Gross head
 $h_f = \frac{4fLV^2}{2gD^2} \Rightarrow D^* \Rightarrow \text{dia of penstock}$

$$H = \text{Net head on the pelton wheel} \\ = H_g - h_f$$

$$V_1 = \text{Velocity of jet at inlet} = \sqrt{2gH}$$

$$u = u_1 = u_2 = \frac{\pi D N}{60}$$

Velocity triangle at inlet will be a straight line

$$\text{where}, V_{rc_1} = V_1 - u_1 = V_1 - u$$

$$V_{w_1} = V_1$$

$$\alpha = 0^\circ, \theta = 0^\circ$$

From the velocity triangle at outlet,

$$V_{rc_2} = V_{rc_1} \text{ and } V_{w_2} = V_{rc_2} \cos\phi - u_2$$

$$V_{rc_2} = V_{rc_1} \text{ and } V_{w_2} = V_{rc_2} \cos\phi - u_2$$

$$\text{Force exerted} \Rightarrow F_x = \rho a v_i [V_{w_1} + V_{w_2}]$$

Workdone = Force \times plate velocity

$$= \rho a v_i [V_{w_1} + V_{w_2}] \times u$$

Power given to the runner

$$= \frac{\rho a v_i [V_{w_1} + V_{w_2}] \times u}{1000} \text{ KW}$$

At Maximum hydraulic efficiency = $\frac{\text{Workdone per second}}{\text{KE. of jet per sec.}}$

$$= \frac{\rho a v_i [V_{w_1} + V_{w_2}] \times u}{\frac{1}{2} \times (\rho a v_i) \times V_i^2}$$

$$\therefore = \frac{2 [V_{w_1} + V_{w_2}] u}{V_i^2}$$

$$\text{Max } \eta_h = \frac{1 + \cos\phi}{2}$$

Points to remember for pelton wheel

(i) Velocity of jet at inlet by $V_i = C_v \sqrt{2gH}$

C_v = Co-efficient of velocity = 0.98 or 0.999

(ii) Velocity of wheel by $u = \phi \sqrt{2gH}$

ϕ = speed ratio.

= Varies from 0.43 to 0.48

(iii) The angle of deflection of the jet through buckets is taken at 165° .

(iv) Jet ratio = $\frac{\text{dia of pelton wheel}}{\text{dia of jet}}$

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

(v) No of buckets on a runner

$$\Rightarrow n = 15 + \frac{D}{2d}$$

$$= 15 + 0.5m$$

Dimension of bucket :-

Width of the buckets = $5d$

Whence $d = \text{dia of jet}$

Depth of the buckets = $1.2 \times d$

Q) A pelton wheel has a mean bucket speed of 10 m/s with a jet of water flowing at the rate of 700 lit/s under a head of 30 m.

4th Nov.

The buckets deflect the jet through an angle of 160° . Cal. the power given by water to the runners and the hydraulic efficiency of the turbine. Assume co-eff. of velocity of the turbine. Assume co-eff. of velocity as 0.98.

Given,
Speed of bucket,
 $u = u_1 = u_2 = 10 \text{ m/s}$

discharge, $Q = 700 \text{ lit/s}$
 $= 0.7 \text{ m}^3/\text{s}$

Head of water = $30 \text{ m} = H$

Angle of deflection = 160°

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

$$C_v = 0.98$$

velocity of jet = $v_1 = C_v \sqrt{2gH}$
 $= 0.98 \sqrt{2 \times 9.81 \times 30}$
 $= 23.77 \text{ m/s}$

$$v_{r1} = v_1 - u_1 = 23.77 - 10$$
 $= 13.77 \text{ m/s}$

$$v_{w1} = v_1 = 23.77 \text{ m/s}$$

At outlet velocity triangle,
 $v_{r2} = v_{r1} = 13.77 \text{ m/s}$

$$v_{w2} = v_{r2} \cos \phi - u_2$$
 $= 13.77 \times \cos 20^\circ - 10$
 $= 2.94 \text{ m/s}$

$$\text{Workdone by the jet} = \rho Q v_1 [v_{w1} + v_{w2}] x u$$
 $= 1000 \times 0.7 \times [23.77 + 2.94] \times 10$
 $= 186970 \text{ Nm/s}$

$$\text{Power given to turbine} = \frac{186970}{1000}$$

$$= 186.970 \text{ kW}$$

$$\text{Hydraulic efficiency} = \frac{2[V_{w_1} + V_{w_2}] \times u}{V_1^2}$$

$$= \frac{2[23.77 + 2.94] \times 10}{23.77^2}$$

$$= 0.9454$$

$$= 94.54\%$$

Q) A pelton wheel is to be designed for a head of 60m when running at 200 rpm. The pelton wheel develops 95.6475 kW shaft power. The velocity of the jet, overall efficiency = 0.85 and co-eff. of the velocity is equal to 0.98

Given,

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

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

$$\text{Shaft Power} = 95.6475 \text{ kW}$$

$$\text{Velocity of bucket} = u = 0.45 \times \text{Velocity of jet}$$

$$\text{Velocity of bucket} = u = 0.45 \times V_1 = 0.45 \times 0.98 \times V_1 = 0.85 V_1$$

$$\text{Overall efficiency} = \eta_o = 0.85$$

$$\text{Coefficient of velocity} = C_v = 0.98$$

$$(i) \text{ Velocity of jet} = C_v \times \sqrt{2gH}$$

$$= 0.98 \times \sqrt{2 \times 9.81 \times 60}$$

$$= 33.62 \text{ m/s}$$

$$\text{Bucket Velocity} = 0.45 \times V_1 = 0.45 \times 33.62 = 15.13 \text{ m/s}$$

$$\text{But, } u = \frac{\pi D N}{60}$$

$$\Rightarrow 15.13 = \frac{\pi \times D \times 200}{60}$$

$$\Rightarrow D = 1.44 \text{ m/s}$$

(ii) Diameter of jet (d)

$$\eta_0 = 0.85$$

$$\eta_0 = \frac{\text{Shaft Power}}{\text{Wheel Power}}$$

$$= \frac{95.6475}{\left(\frac{W.P.}{1000}\right)}$$

$$\Rightarrow 0.85 = \frac{95.6475 \times 1000}{\rho g Q H}$$

$$\Rightarrow Q = \frac{95.6475 \times 1000}{1000 \times 9.81 \times 60 \times 0.85}$$

$$= 0.1912 \text{ m}^3/\text{s}$$

$$\Rightarrow \text{Area of jet} \times \text{Velocity of jet} = 0.1912$$

$$\Rightarrow \frac{\pi}{4} \times d^2 \times V_1 = 0.1912$$

$$\Rightarrow d = \sqrt{\frac{4 \times 0.1912}{\pi \times 33.62}}$$

$$= 85 \text{ mm}$$

$$\text{(iii) Size of bucket} = 5 \times d = 5 \times 85 = 425 \text{ mm}$$

$$\text{Depth of bucket} = 1.2d = 1.2 \times 85$$

$$= 102 \text{ mm}$$

(iv) Number of bucket on the wheel

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

$$= 15 + \frac{1.44}{2 \times 0.085}$$

$$= 23.5$$

$$\approx 24$$

Francis Turbine :-

5th Nov

- The inward reaction turbine having radial discharge at outlet is known as Francis turbine.
- In the modern Francis turbine, the water enters the runner of the turbine in the radial direction at outlet and leaves in the axial direction at the inlet of the runner. Thus the modern Francis Turbine is a mixed flow type turbine.

Work done by water on the runner per second

$$\text{will be} = \rho Q [V_w, U_1]$$

$$\text{Hydraulic efficiency} = \eta_h = \frac{V_w, U_1}{gH}$$

Important Relation for Francis Turbine

The ratio of the wheel to its diameter is

- 1) The ratio of the wheel to its diameter is given as $n = \frac{B_1}{D_2}$
- 2) Flow Ratio = $\frac{V_f}{\sqrt{2gH}}$ and varies from 0.15 to 0.30
- 3) Speed Ratio = $\frac{U_1}{\sqrt{2gH}}$ varies from 0.6 to 0.9

- Q) A Francis turbine with an overall efficiency of 75% is required to produce 148.25 kW power. It is working under a head of 7.62m. 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 r.p.m. and the hydraulic losses in the turbine are 22% of the available energy. Assuming radial discharge, determine

- (i) The guide blade angle
- (ii) The wheel vane angle at inlet
- (iii) Dia of the wheel at inlet
- (iv) Width of the wheel at inlet

Given,

$$\text{Overall efficiency} = \eta_o = 75\%$$

$$\text{Power produced} = S.P = 148.25 \text{ KW}$$

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

$$\text{Peripheral velocity} \Rightarrow u_1 = 0.26 \sqrt{2gH}$$

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

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

Velocity of flow at inlet,

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

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

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

Speed,

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

Hydraulic loss = 22% of available energy

$$\text{Hydraulic efficiency} = \eta_h = \frac{\text{Total head at inlet} - \text{Hydraulic loss}}{\text{Head at inlet}}$$

$$= \frac{H - 0.22H}{H}$$

$$= \frac{0.78H}{H} = 0.78$$

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

$$\Rightarrow V_{w1} = \frac{0.78 \times g \times H}{u_1}$$

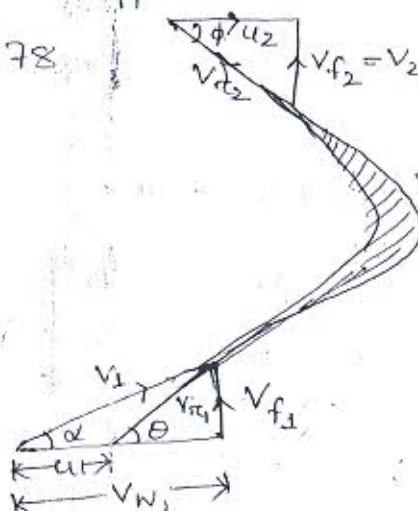
$$= \frac{0.78 \times 9.81 \times H}{3.179}$$

$$= 18.34 \text{ m/s.}$$

(c) The guide blade angle,

$$\tan \alpha = \frac{V_{f1}}{V_{w1}} = \frac{11.738}{18.34} = 0.64$$

$$\alpha = \tan^{-1} 0.64 = 32.619^\circ \text{ or } 32^\circ 37'$$



(ii) Wheel vane angle at inlet,

$$\tan \theta = \frac{V_{f1}}{V_{w1} - U_1} = \frac{11.738}{18.34 - 3.179} = 0.774$$

$$\theta = \tan^{-1} 0.774$$

$$= 37.74^\circ$$

(iii) Diameters of wheel at inlet (D_1)

$$U_1 = \frac{\pi D_1 N}{60}$$

$$\Rightarrow D_1 = \frac{60 \times U_1}{\pi \times N} = \frac{60 \times 3.179}{\pi \times 50} = 0.4047 \text{ m}$$

(iv) Width of the wheel at inlet (B_1)

$$n_0 = \frac{S.P.}{W.P.} = \frac{148.25}{W.P.}$$

$$W.P. = \frac{W.H}{1000} = \frac{\rho g \theta H}{1000} = \frac{1000 \times 9.81 \times \theta \times 7.62}{1000}$$

$$\Rightarrow \theta = \frac{W.P. \times 1000}{1000 \times 9.81 \times 7.62}$$

$$n_0 = 0.75$$

$$\Rightarrow \frac{148.25 \times 1000}{\theta \times 1000 \times 9.81 \times 7.62} = 0.75$$

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

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

$$\Rightarrow \pi \times 0.4047 \times B_1 \times 11.738 = 2.644$$

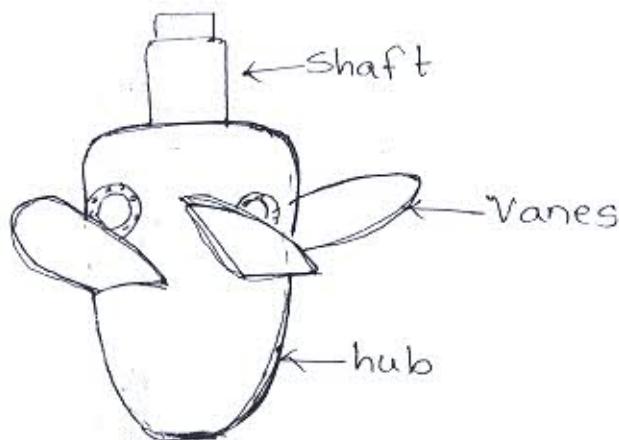
$$\Rightarrow B_1 = \frac{2.644}{\pi \times 0.4047 \times 11.738} = 0.177 \text{ m.}$$

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6th Nov.

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 head at the inlet of the turbine is the sum of pressure energy and kinetic energy, the turbine is known as reaction turbine.
- For the 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'.
- The vanes are fixed on the hub and hence hub acts as a runner for the axial flow reaction turbine.

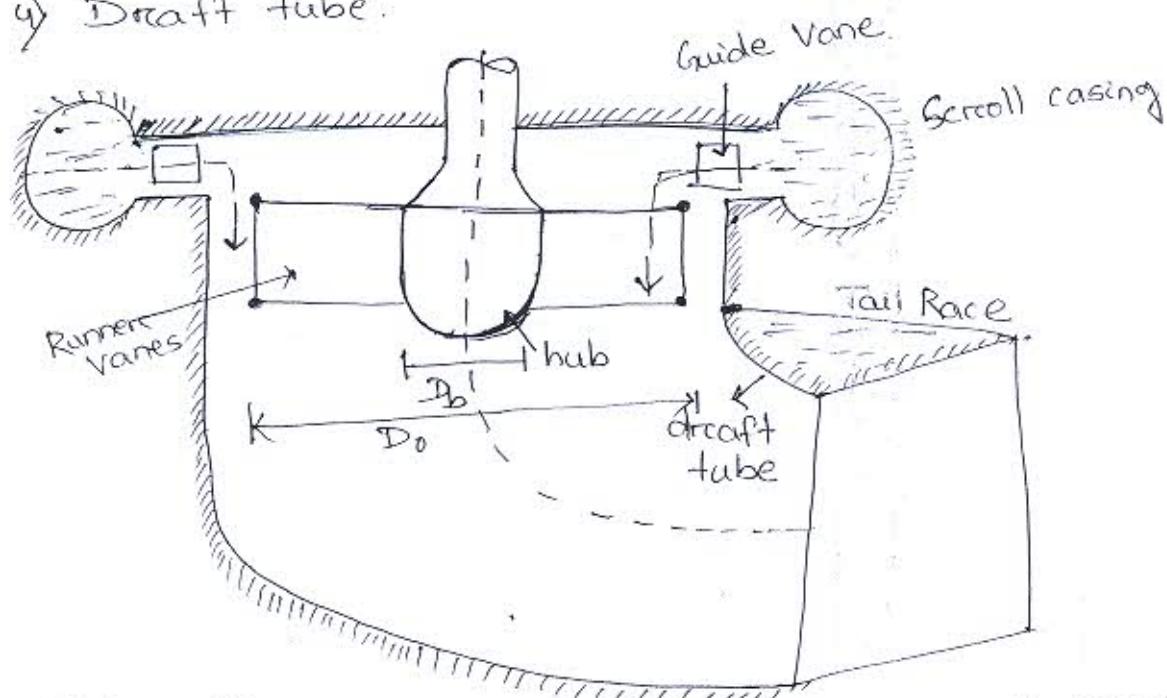


- The following are the important type of axial flow reaction turbines:-
 - 1) Propellers
 - 2) Kaplan
- When the vanes are fixed to the hub and they are not adjustable, the turbine is known as propeller turbine.
- But, if the vanes are adjustable, the turbine is known as Kaplan turbine.

Kaplan Turbine

Main parts of a kaplan turbine are :-

- 1) Scroll casing
- 2) Guide vanes mechanism
- 3) Hub with vanes or runner of the turbine
- 4) Draft tube.



- ⇒ 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.
- ⇒ The discharge through the runner is obtained as,

$$Q = \frac{\pi}{4} (D_o^2 - D_b^2) \times V_{f_1}$$

Where, D_o = Outer dia of the runner

D_b = dia of hub

V_{f_1} = Velocity of flow at inlet

Some important point for kaplan :-

⇒ Peripheral velocity at inlet and outlet are equal,

$$U_1 = U_2 = \frac{\pi D_o N}{60}$$

⇒ Velocity of flow at inlet n outlet are equal,

$$V_{f_1} = V_{f_2}$$

3) Area of flow at inlet = Area of flow at outlet

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

7th Nov.

Q) A kaplan turbine working under a head of 20m develops 11772 KN shaft power. The outer dia of the runner is 3.5 m and hub dia is 1.75 m. The guide blade angle at the extreme edge of the runner is 35° . The hydraulic and overall efficiencies of the turbines are 88% and 84% respectively. If the velocity of whirl is zero at outlet, determine the velocity of whirl at inlet and outlet at the

(i) Runner vane angles at inlet and outlet at the extreme edge of the runner

(ii) Speed of the turbine.

Given,

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

Shaft power $SP = 11772 \text{ kW}$

Outer dia of runner $\Rightarrow D_o = 3.5\text{m}$

Hub dia $\Rightarrow D_b = 1.75\text{m}$

Guide blade angle $\Rightarrow \alpha = 35^\circ$

Hydraulic eff $\Rightarrow \eta_h = 88\%$

Overall eff $\Rightarrow \eta_o = 84\%$

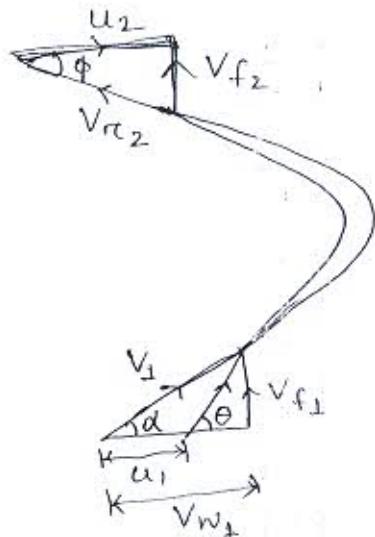
$$\eta_o = \frac{SP}{WP}$$

Where, $WP = \frac{\rho g Q H}{1000} \Rightarrow 0.84 = \frac{11772}{\frac{\rho g Q H}{1000}}$

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

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

Velocity triangle :-



$$\alpha = \frac{\pi}{4} (D_o^2 - D_b^2) V_{f_1}$$

$$\Rightarrow V_{f_1} = \frac{\pi}{4} (3.5^2 - 1.75^2)$$

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

Velocity triangle ,

$$\tan \alpha = \frac{V_{f_1}}{V_{n_1}}$$

$$\Rightarrow V_{n_1} = \frac{V_{f_1}}{\tan \alpha} = \frac{9.9}{\tan 35^\circ} = 14.14 \text{ m/s}$$

$$n_h = \frac{V_m u_1}{g H}$$

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

$$\Rightarrow u_1 = 12.21 \text{ m/s}$$

(i) Runner vane angle ,

$$\tan \theta = \frac{V_{f_1}}{V_{n_1} - u_1} = \frac{9.9}{14.14 - 12.21} = 5.13$$

$$\Rightarrow \theta = \tan^{-1}(5.13) = 78^\circ 58'$$

Outlet velocity triangle ,

$$\tan \phi = \frac{V_{f_2}}{u_2} = \frac{9.9}{12.21} = 0.811$$

$$\Rightarrow \phi = 39^\circ 2'$$

(ii) Speed of turbine $= u_1 = u_2 = \frac{\pi D_o N}{60}$

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

$$\Rightarrow N = 66.63 \text{ rpm.}$$

Performance curves of hydraulic Turbines

Performance curves of a hydraulic turbines are the curves, with the help of which the exact behaviour and performance of the turbine under different working condition.

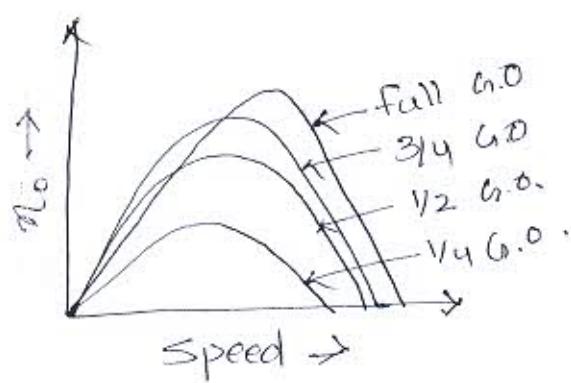
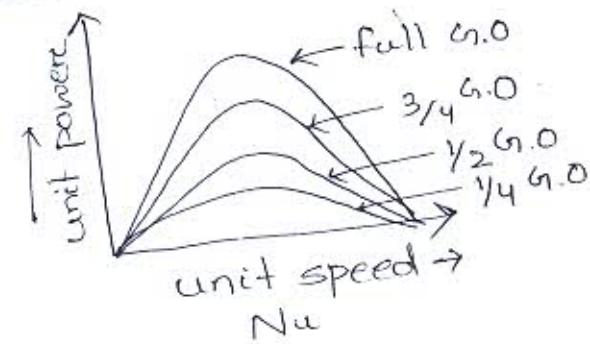
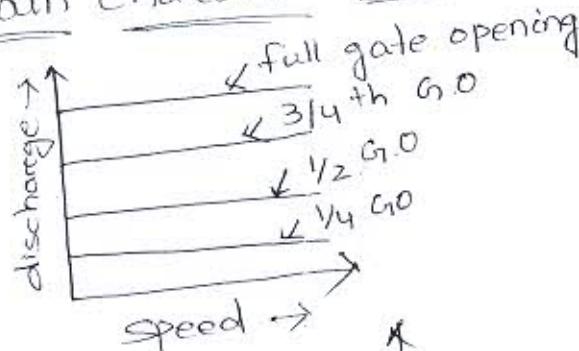
→ The important parameters which is varied during a test on a turbine are :-

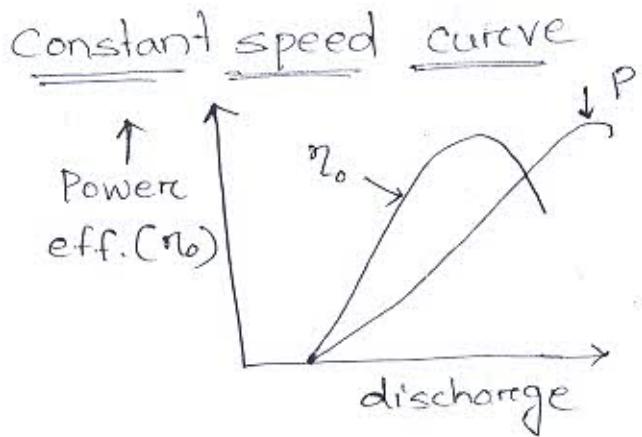
- 1) Speed
- 2) Head
- 3) Discharge
- 4) Power
- 5) Overall eff.
- 6) Gate opening

→ The following are the important characteristic curves of the turbine

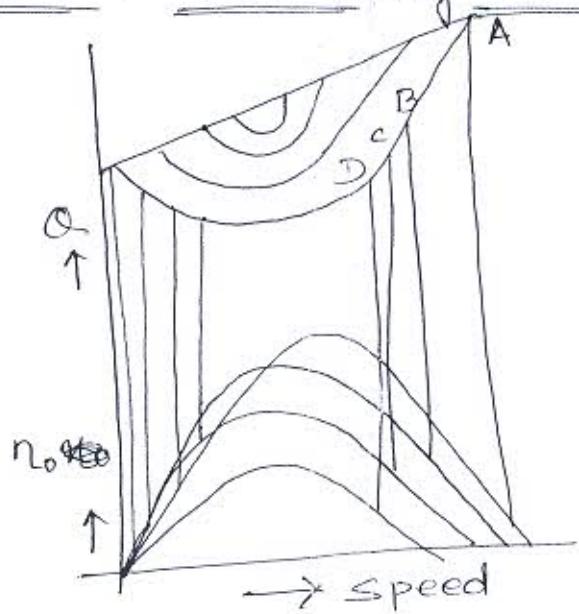
- a) Main characteristic curve or const. head curves
- b) Operating characteristic curve or const. speed curves
- c) constant efficiency curve:

Main characteristic curves for a pelton wheel





Constant efficiency curve :-



9th Nov.

Draft Tube

- The draft tube is a pipe of gradually increasing area which connects the outlet of the runner to the tail race.
- It is used for discharging water from the exit of the turbine to the tail race. The pipe of gradually increasing area is called draft-tube.
- Purpose of draft tube :-
 (i) It permits a -ve head to be established at the outlet of the runner and thereby increase the net head on the turbine.
 (ii) It converts the KE to PE.

Types of draft tube :-

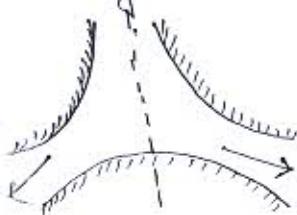
i) Conical draft tube



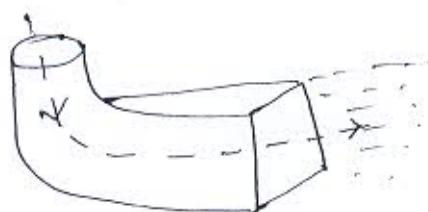
ii) Simple elbow tubes



iii) Moody spreading tubes



iv) Elbow draft tube with circular inlet and rectangular outlet.



Casing Cavitation :-

- Cavitation is defined as the phenomenon of formation of vapour bubbles of a flowing liquid in a region whence the pressure of the liquid falls below its vapour pressure in a region of higher pressure.
- When the vapour bubbles collapse, a very high pressure is created.
- The metallic surfaces above which these vapour pressure collapse, formed a cavity on the metallic surface and also noise and vibrations are produced.

Precaution against Cavitation :-

- (i) The pressure of the flowing liquid in any part should not be allowed to fall below its vapour pressure.
- (ii) Special materials like aluminium-bronze and stainless steel are used.
- In case of turbine mainly reaction turbines are subjected to cavitation.