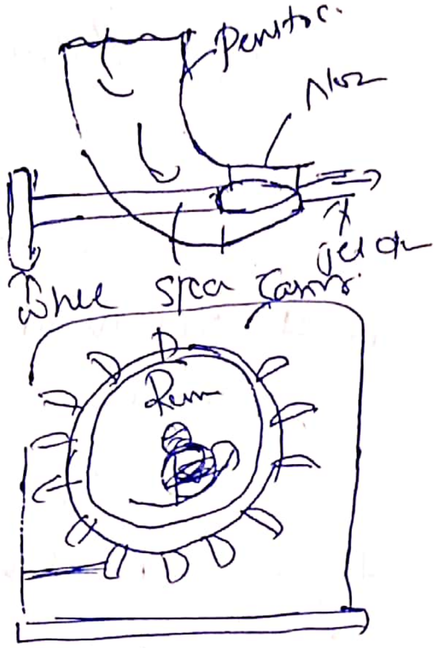
Unit-IV

Turbines

Pelton wheel:

Main Parts of Pelton wheel are
① Nozzle and flow regulating arrangement (Spear) 2. Runner & buckets
③ Casing ④ Breaking jet



shape of runner is double hemispherical cup
Buckets are made of Cast iron, Cast steel
bronze (or) Stainless Steel.

Casing:- To Prevent the Splashing of water and to discharge water to. It made of Cast iron (or) fabricated steel plates. The Casing of Pelton wheel does not perform and hydraulic function

Breaking jet when nozzle is Completely Closed by moving Spear in forward direction, The amount of water striking runner reduces to zero. But the runner due to inertia goes on revolving for 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.

efficiencies ① Hydraulic efficiency ② Mechanical efficiency
③ Volumetric efficiency ④ overall efficiency

① $\eta_h = \dfrac{\text{Power delivered to runner}}{\text{Power supplied at inlet}}$ ②

weight of water striking then

$R.P = \dfrac{\frac{W}{g}[V_{w_1}u_1 \pm V_{w_2}u_2]}{1000}$ Kw $\quad w.p = \dfrac{W \times H}{1000}$ Kw. $\quad w.p = \dfrac{\rho \times g \times Q \times H}{1000}$

② η_m : $\dfrac{\text{Power at The shaft of The turbine}}{\text{Power delivered by water to runner}} = \dfrac{S.P}{R.P.}$

③ $\eta_v = \dfrac{\text{Volume of water actualy Striking The runner}}{\text{Volume of water Supplied to turbine}}$

④ $\eta_o = \dfrac{S.P}{W.P.} = \dfrac{S.P}{W.P} \times \dfrac{R.P}{R.P} = \dfrac{S.P}{R.P} \times \dfrac{R.P}{W.P} = \eta_m \times \eta_h.$

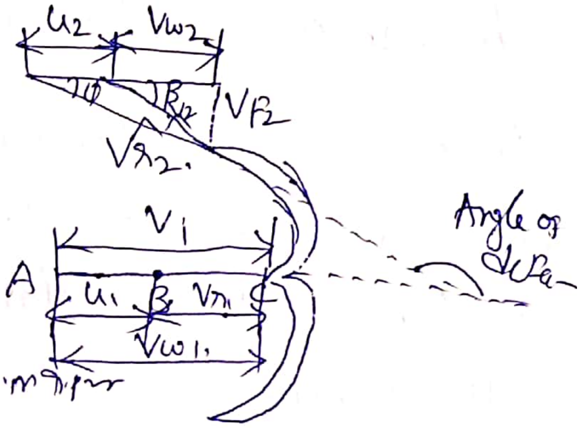
$$\eta_o = \frac{P}{\left(\frac{\rho g Q H}{1000}\right)}$$

velocity triangles & W.D of pelton wheel:

Let H = net head acting on the pelton wheel

$= H_g - h_f$

H_g = Gross head & $h_f = \dfrac{4fLV^2}{2gD^*}$



D^* = Dia. of Penstock   N = Speed of The wheel in rpm

D = Diameter of The wheel   d = Diameter of Jet

V_1 = velocity of Jet at inlet $= \sqrt{2gH}.$

$u = u_1 = u_2 = \dfrac{\pi D N}{60}$ $V_{r_1} = V_1 - u_1 = V_1 - u_1$; $V_{w_1} = V_1$; $\alpha = 0°$ & $\theta = 0°$

From outlet velocity triangle $V_{r_2} = V_{r_1}$ & $V_{w_2} = V_{r_2}\cos\phi - u_2$

The force exerted by jet of water in the direction of motion is

$F_x = \rho a V_1 [V_{w_1} + V_{w_2}]$ As The angle β is an acute angle +ve sign

As this is The Case of Series of Vanes mass of water striking is $\rho a V_1$, not $\rho a V_r$

workdone by jet on runner/sec $= F_x \times u = \rho a V_1 [V_{w_1} + V_{w_2}] \times u$ Nm/s

Power given to the runner by jet $= \dfrac{\rho a V_1 [V_{w_1} + V_{w_2}] \times u}{1000}$ kW.

workdone/s /unit of weight of water striking/s.

$$= \frac{\rho a V_1 (V_{w_1} + V_{w_2}) \times u}{\rho a V_1 \times g} = \frac{1}{g}[V_{w_1} + V_{w_2}] \times u.$$

Points to be remembered for pelton wheels

① The velocity of the jet at inlet is given by $V_1 = C_v\sqrt{2gH}$

where C_v = Coeff. of velocity = 0.98 (or) 0.99

② The velocity of wheel (u) is given by $u = \phi\sqrt{2gH}$.

where ϕ = speed ratio = 0.43 to 0.48

③ The angle of deflection of the jet through buckets is taken as 165° if no angle of deflection is given.

④ The mean diameter (or) the pitch diameter D of the wheel is

$$u = \frac{\pi D N}{60} \quad (or) \quad D = \frac{60u}{\pi N}$$

⑤ Jet ratio : $m = \frac{D}{d}$ (= 12 for most cases).

⑥ Number of buckets $Z = 15 + \frac{D}{2d} = 15 + 0.5m$

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

① A Pelton wheel is to be designed for following specification

Shaft power = 11,772 kW ; Head = 380 m ; Speed = 750 r.p.m ; η_o = 86%.

Jet dia is not to exceed 1/6 of the wheel dia. Det

(i) The wheel dia (ii) no. of jets required (iii) Diameter of jet

The energy supplied to the jet at inlet is in the form of K.E ②

$= \frac{1}{2} m v^2$

$\therefore$ K.E of jet/sec $= \frac{1}{2} \rho a v_1 \times v_1^2$

$$\therefore \eta_h = \frac{W.D/sec}{K.E/sec} = \frac{\rho a v_1 [V_{w_1} + V_{w_2}] \times u}{\frac{1}{2} \rho a v_1 \times v_1^2} = \frac{2[V_{w_1} + V_{w_2}] \times u}{V_1^2}.$$

Now $V_{w_1} = V_1$, $V_{r_1} = V_1 - u_1 = (V_1 - u)$.

$V_{r_2} = (V_1 - u)$; $V_{w_2} = V_{r_2} \cos\phi - u_2 = V_{r_2} \cos\phi - u = (V_1 - u)\cos\phi - u$.

Substituting the values of V_{w_1} & V_{w_2} in equation

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

The efficiency will be max. for given V_1 when

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

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

$$\Rightarrow 2V_1 - 4 \times u = 0 \quad \therefore u = \frac{V_1}{2}.$$

Design of pelton wheel: Design of pelton wheel means the following data is to be determined

1. Diameter of jet (d) 2. Diameter of wheel (D) 3. Width of the bucket $= 5 \times d$. 4. Depth of the bucket $= 1.2 \times d$ 5. Number of buckets on the wheel.

Size of bucket means the width & depth of bucket.

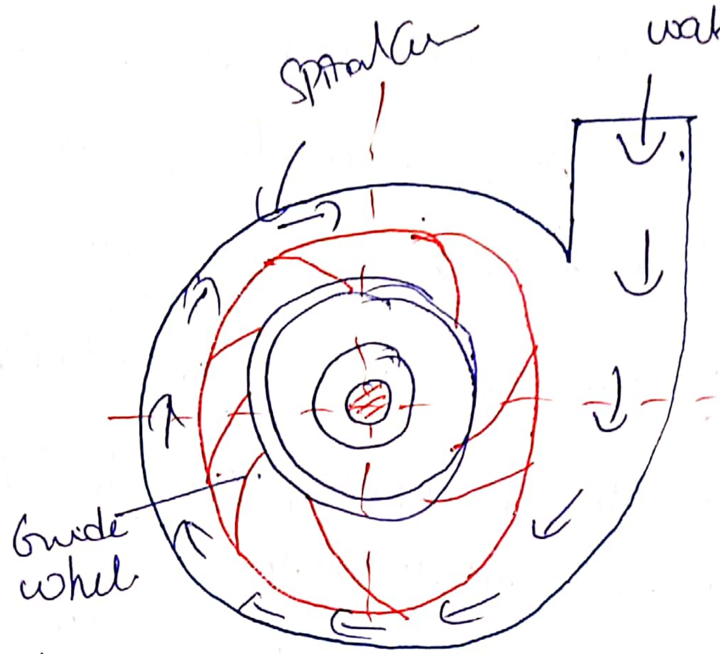
Problems

① Two jets strikes the buckets of a pelton wheel, which is having shaft power as 15450 Kw. The diameter of each jet is given as 200mm. If the net head on turbine is 400m. find the overall efficiency of turbine. Take $C_v = 1.0$ $\eta_o = \frac{S.P}{W.P}$ $= 70.8\%$; $W.P = \frac{\rho g Q H}{1000}$ $= 21817.44$ Kw ; $V_1 = C_v \sqrt{2gH} = 88.58$ m/s. $Q = 2 \times 2.78 = 5.56$ m³/s ; Discharge of each jet $= a \times V_1 = 2.78$

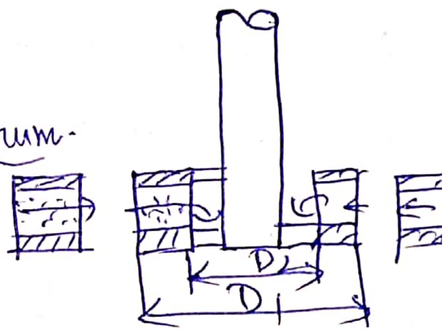
Radial flow reaction turbines

Radial flow turbines are those turbines in which the water flows in radial direction. The water may flow radially from outwards to inwards (i.e.) towards the axis of rotation (or) from inwards to outwards.

Main parts (1) Casing (2) Guide mechanism (3) Runner & (4) Draft tube



Inward flow reaction turbine - The water flows over the moving vanes in inward radial direction and is discharged at the inner diameter of the runner. The outer diameter is the inlet and inner diameter is outlet



Velocity triangles and workdone by water on runner.

The W.D/sec on the runner by water is

$$= \rho a V_1 [V_{w_1} u_1 \pm V_{w_2} u_2] = \rho Q [V_{w_1} u_1 \pm V_{w_2} u_2]$$

The W.D/sec/unit weight of water/sec $= \dfrac{W.D/sec}{\text{weight of water striking/sec}}$

$$= \frac{\rho Q [V_{w_1} u_1 \pm V_{w_2} u_2]}{\rho Q \times g} = \frac{1}{g}[V_{w_1} u_1 \pm V_{w_2} u_2]$$

Hydraulic efficiency $\eta_h = \dfrac{V_{w_1} u_1}{gH}$

Degree of Reaction:- The ratio of Pressure Energy change inside a runner to the total energy change inside the runner. It is represented by R

Francis turbine:- The inward flow reaction turbine having radial discharge at outlet is known as Francis turbine. In modern Francis turbine

W.D by water on runner/sec = $\rho Q (V_{w_1} u_1)$

And W.D/sec/unit weight of water striking/sec = $\frac{1}{g}(V_{w_1} u_1)$.

Hydraulic efficiency $\eta_h = \frac{V_{w_1} u_1}{gH}$.

Important relations for Francis turbine

(1) The ratio of width of the wheel to its diameter is given as $n = \frac{B_1}{D_1}$

n varies from 0.10 to 0.40.

(2) The flow ratio is given as $\frac{V_{f_1}}{\sqrt{2gH}}$ varies from 0.15 to 0.30.

(3) The Speed ratio = $\frac{u_1}{\sqrt{2gH}}$ varies from 0.6 to 0.9

Axial flow reaction turbine:- If the water flows parallel to the axis of rotation of the shaft, the turbine is known as axial flow turbine. During the flow of water through the runner a part of P.E is converted into K.E, the turbine is known as reaction turbine. For the axial flow reaction turbine shaft of the turbine is vertical. The lower end of the shaft is made larger which is known as hub (or) boss. Vanes are fixed on the hub hence hub acts as runner for an axial flow turbine. Important types of axial flow turbines are (i) Propeller turbine (ii) Kaplan turbine

If vanes are not adjustable - Propeller

If vanes are adjustable - Kaplan

Some important Points for ~~Re~~ Propeller (or) Kaplan turbine

① The peripheral velocities at inlet & outlet are equal

$u_1 = u_2 = \frac{\pi D_o N}{60}$ where D_o = outer dia of runner

② Velocity of flow at inlet & outlet are equal $V_{f_1} = V_{f_2}$.

③ Area of flow at inlet = Area of flow at outlet $= \frac{\pi}{4}(D_o^2 - D_b^2)$.

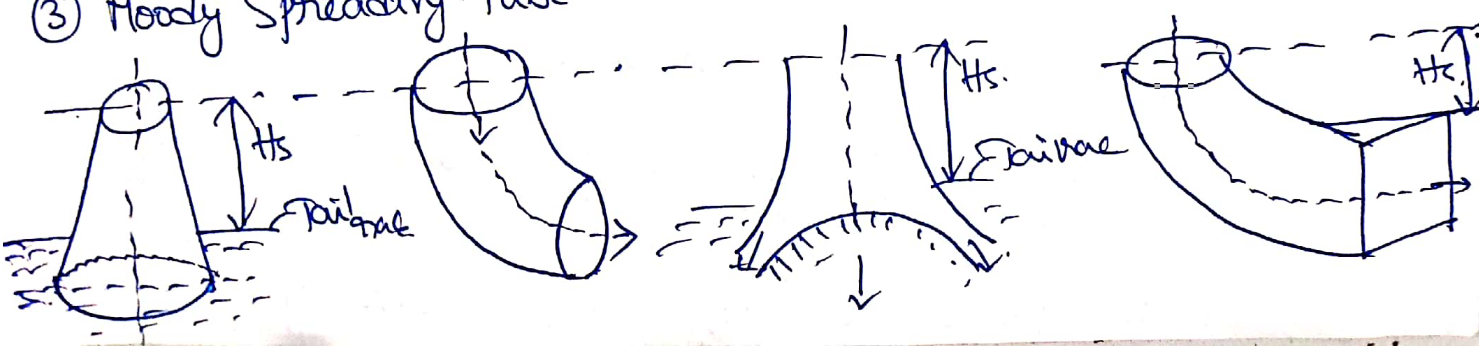
Draft tube: The draft-tube is a pipe of gradually increasing area which connects the outlet of the ~~r~~ runner to tail race. This pipe of gradualy increasing area is called draft-tube. one end of the draft tube is connected to the outlet of the runner while the other end is submerged below the level of water in the tail race. The draft tube in addition to serve a passage for water discharge, has the following two purpose

① The turbine may be placed above the tail race without any loss of hea

② It converts a large portion of K.E rejected at the outlet of the tube into useful pressure energy. without the draft tube the K.E. rejected at the outlet of the turbine go waste to the tail race

If a reaction turbine is not fitted with a draft tube, the pressure at the outlet of the runner will be not equal to atmospheric pressure. The water from the outlet of the runner will discharge freely into the tail race

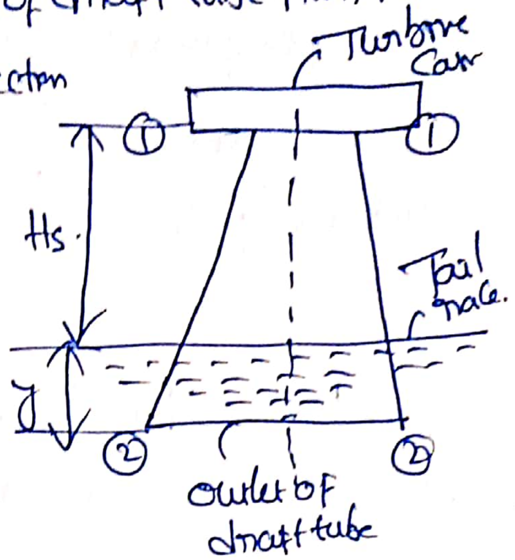
Types of draft tubes ① Conical draft tube ② Simple elbow tubes. ③ Moody spreading tube ④ elbow draft tube with circular inlet rectangul



Draft-tube Theory: H_s = Vertical height of draft tube above tail race

y = Distance of bottom of draft tube from tail race.

Applying B.E at ①-① & ②-② by taking section ②② datum line



$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+(H_s+y)=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+0+h_f$$

where h_f = loss of energy between ①-① & ②-②.

But $\frac{P_2}{\rho g}$ = Atmospheric pressure head $+y$.

$$=\frac{P_a}{\rho g}+y$$

$$\therefore \frac{P_1}{\rho g}+\frac{V_1^2}{2g}+(H_s+y)=\frac{P_a}{\rho g}+y+\frac{V_2^2}{2g}+h_f$$

$$\frac{P_1}{\rho g}=\frac{P_a}{\rho g}+\frac{V_2^2}{2g}+h_f-\frac{V_1^2}{2g}-H_s.$$

$$\Rightarrow \frac{P_1}{\rho g}=\frac{P_a}{\rho g}-H_s-\left(\frac{V_1^2}{2g}-\frac{V_2^2}{2g}-h_f\right).$$

$\therefore \frac{P_1}{\rho g}$ is less than atmospheric pressure

Specific Speed: It is defined as the speed of a turbine which is identical in shape with actual turbine but of a size that it will develop unit power when working under unit head

we have $\eta_o=\frac{P}{\frac{\rho g Q H}{1000}}$ $\Rightarrow P \propto Q \times H$ (as η_o & Power Const).

we have $u \propto V \Rightarrow u \propto \sqrt{H}$ where $V \propto \sqrt{2gH}$ But u is given by $u=\frac{\pi DN}{60} \Rightarrow u \propto DN.$

$\sqrt{H} \propto DN$ (or) $D \propto \frac{\sqrt{H}}{N}$. The discharge through turbine is given by

Q = Area × velocity $\Rightarrow$ Area $\propto B \times D \Rightarrow$ Area $\propto D^2$ ($B \propto D$)

$\therefore Q \propto D^2 \times \sqrt{H} \Rightarrow Q \propto \left(\frac{\sqrt{H}}{N}\right)^2 \times \sqrt{H} \Rightarrow Q \propto \frac{H}{N^2} \times \sqrt{H} \propto \frac{H^{3/2}}{N^2}$

$\therefore P \propto \frac{H^{3/2}}{N^2} \times H \propto \frac{H^{5/2}}{N^2} \Rightarrow P = K\frac{H^{5/2}}{N^2}$ If $P=1, H=1, N=N_s$. $1=\frac{K \times 1^{5/2}}{N_s^2}$ (or) $N_s^2 = K$

$P = N_s^2 H^{5/2}/N^2$ (or) $N_s^2 = N^2P/H^{5/2}$ (or) $N_s = \frac{N\sqrt{P}}{H^{5/4}}$

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