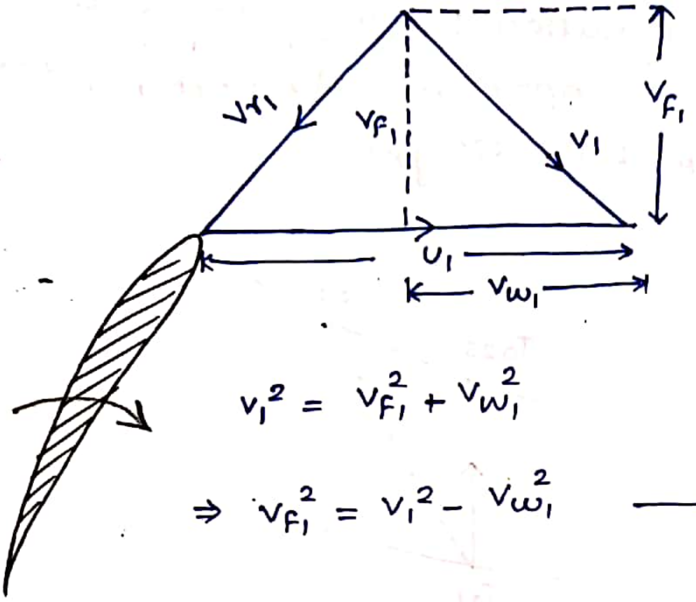
Turbo Machinery

Generalised equation for any rotodynamic Machine:



$$V_1^2 = V_{f_1}^2 + V_{w_1}^2$$

$$\Rightarrow V_{f_1}^2 = V_1^2 - V_{w_1}^2 \quad \text{——— (1)}$$

$$V_{r_1}^2 = V_{f_1}^2 + (U_1 - V_{w_1})^2$$

$$\therefore V_{f_1}^2 = V_{r_1}^2 - (U_1 - V_{w_1})^2 \quad \text{——— (2)}$$

From equation (1) & (2)

$$V_1^2 - V_{w_1}^2 = V_{r_1}^2 - (U_1 - V_{w_1})^2$$

$$V_1^2 - \cancel{V_{w_1}^2} = V_{r_1}^2 - U_1^2 - \cancel{V_{w_1}^2} + 2V_{w_1}U_1$$

$$\Rightarrow V_{w_1}U_1 = \frac{V_1^2 + U_1^2 - V_{r_1}^2}{2}$$

similarily

$$V_{w_2}U_2 = \frac{V_2^2 + U_2^2 - V_{r_2}^2}{2}$$

$$\boxed{\text{Work} = V_{w_1}U_1 - V_{w_2}U_2 \Rightarrow \frac{V_1^2 - V_2^2}{2} + \frac{U_1^2 - U_2^2}{2} + \frac{V_{r_2}^2 - V_{r_1}^2}{2}}$$

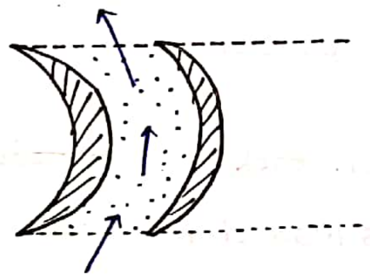
$$W = \underbrace{\frac{V_1^2 - V_2^2}{2}}_{\text{Impulse effect}} + \underbrace{\frac{U_1^2 - U_2^2}{2}}_{\text{centrifugal effect}} + \underbrace{\frac{V_{r_2}^2 - V_{r_1}^2}{2}}_{\text{Reaction effect}}$$

Impulse Turbine:

[1] In pure impulse turbine there is no reaction effect ($V_{r_1} = V_{r_2}$).

[2] No centrifugal effect ($U_1 = U_2$)

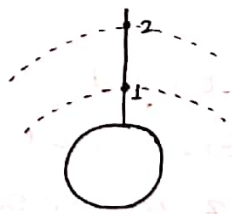
In impulse turbines as the fluid flows through blade passages Static pressure remains constant, it is the kinetic energy which is responsible for rotation or developing power.



b/c of area const. b/w the two blades relative velocity at inlet & exit remains same. i.e. No Reaction effect

Flow passage area remains constant

Impulse blading.



Work developed by impulse turbine

$$\boxed{W = \frac{V_1^2 - V_2^2}{2}}$$

static pr.

$$\frac{P_1}{\omega} + \frac{V_1^2}{2g} + \cancel{z_1} = \frac{P_2}{\omega} + \frac{V_2^2}{2g} + \cancel{z_2}$$

$z_1 = z_2$

$V_1 > V_2$

total pressure at head exit ↓ but static pressure remains constant.

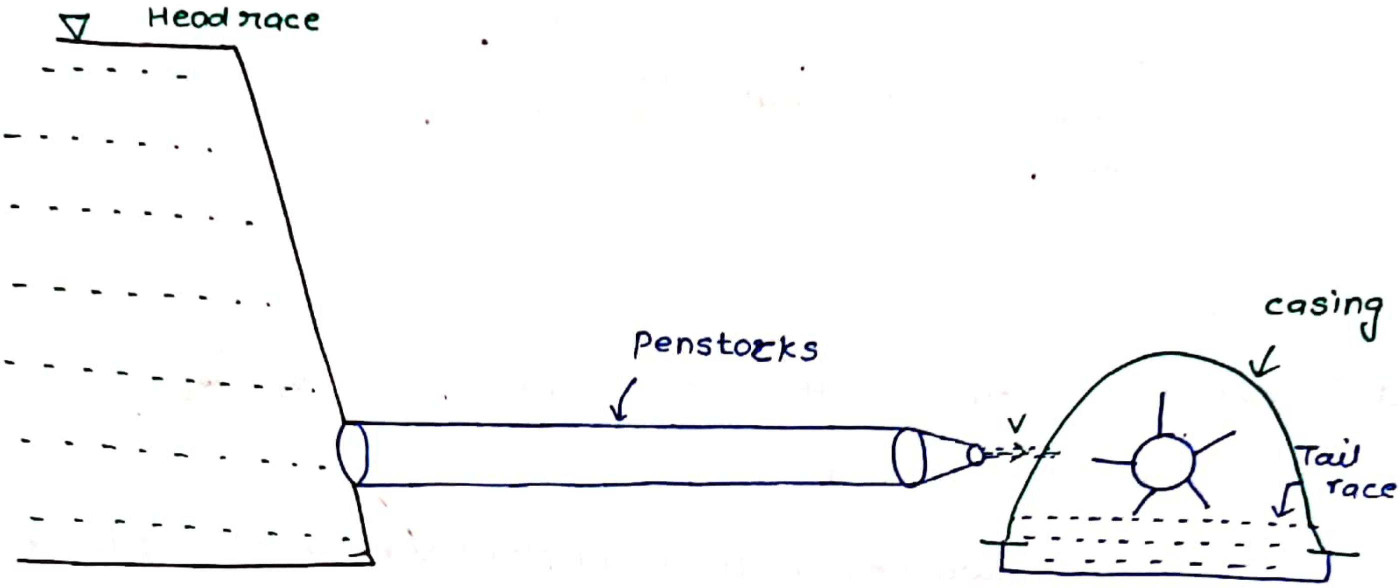
$D_2 > D_1$

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

so $U_2 > U_1$

but we want $U_1 = U_2$ to get pure impulse so entry & leaving should be at same dia. c/s.

Pelton wheel:



The level of water in the storage reservior is called Head Race the water leaving the runner blade flow through a channel leading to downstream is called tail race. the difference between Head race & tail race when no water is flowing is known as Gross head or Total head or static head. [H_1]

As the fluid flows through penstocks there are friction losses and hence the available head is less than Gross head.

$$H = H_1 - h_L$$

H = Net head or available head

H_1 = Gross head

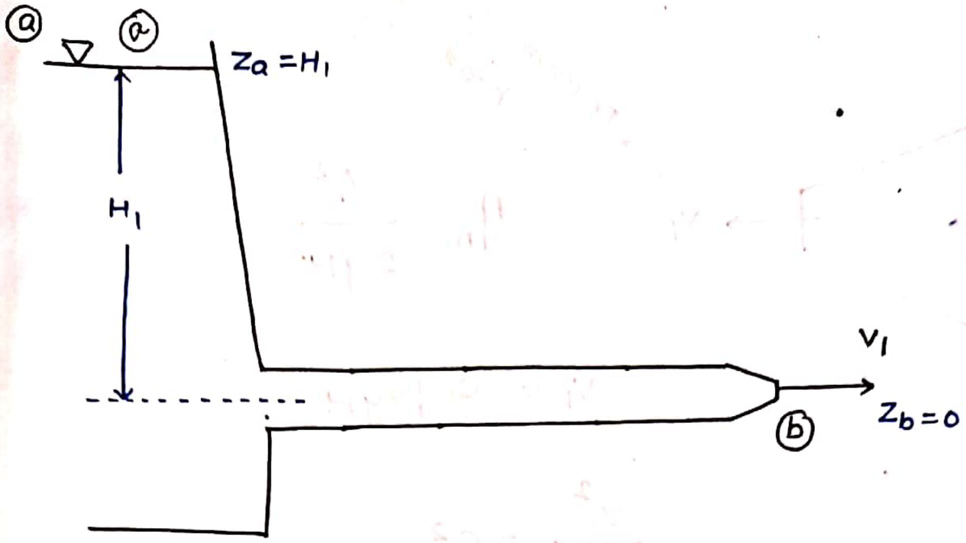
h_L = Head loss due to friction in penstocks.

Based on the available head turbines are classified as-

(a) High head ($H > 250m$)

(b) Medium head ($60 < H < 250m$)

(c) low head ($H < 60$ m)



Apply bernoullis equation between a & b

$$\cancel{\frac{P_a}{\omega}} + \cancel{\frac{V_a^2}{2g}}^{0} + Z_a = \cancel{\frac{P_b}{\omega}} + \frac{V_b^2}{2g} + \cancel{Z_b}^{0} + h_L$$

$(\because P_a = P_b = P_{atm})$

$V_b = V_1$

$a_a V_a = V_b a_b$

$V_a = \dfrac{V_b a_b}{a_a \text{(very large)}}$ $\qquad V_a = 0$

$$\Rightarrow \quad H_1 = \frac{V_b^2}{2g} + h_L$$

$$\frac{V_1^2}{2g} = H_1 - h_L = H$$

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

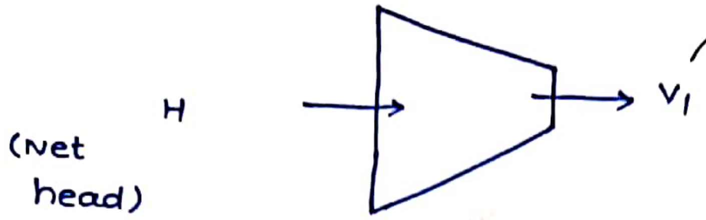
$$\boxed{V_1 = C_v\sqrt{2gH}}$$

V_1 = Jet speed or spouting velocity

Generally C_v is 0.96 to 0.99

<u>Note</u>: In impulse turbine the fluid enter's and leaves the turbine blades at atm. pressure. therefore casing in impulse turbine has no hydraulic function. but it is used to prevent splashing of water.

Nozzle efficiency: (η_n):



In terms of head $= \frac{V_1^2}{2g}$

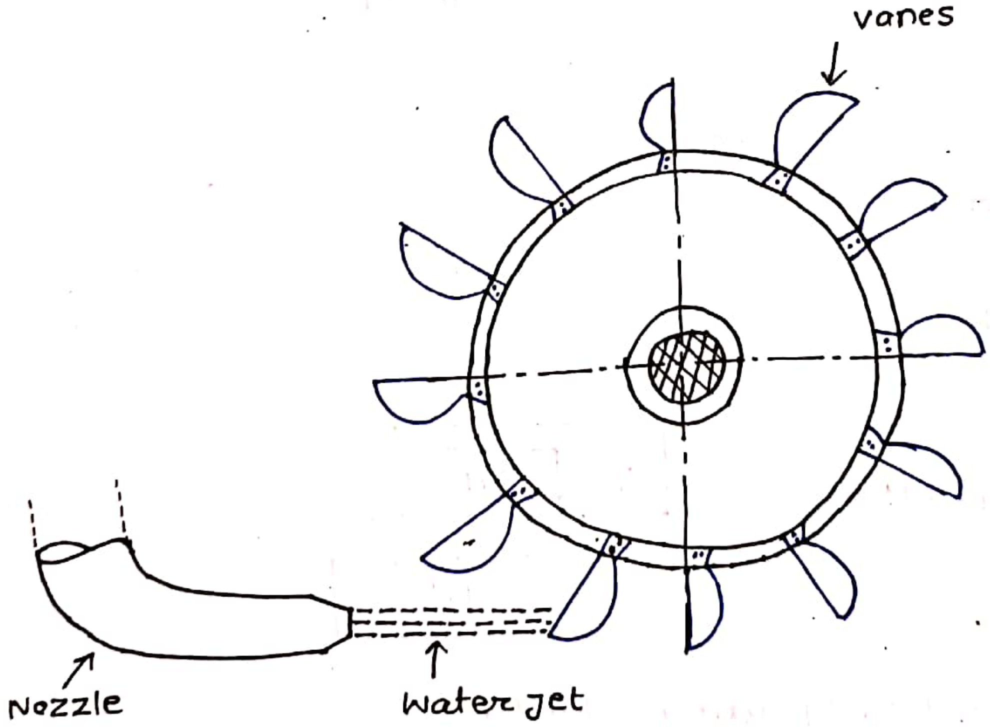
$$\eta_n = \frac{V_1^2}{2gH}$$

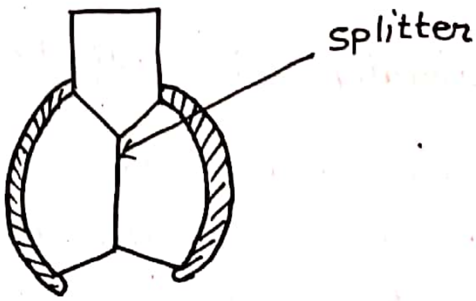
$$V_1 = C_v\sqrt{2gH}$$

$$\frac{V_1^2}{2gH} = C_v^2$$

$$\boxed{\eta_n = C_v^2}$$

Figure: Pelton turbine





side view of bucket

Pelton wheel is

$P = wQH = \text{const.}$

$QH = \text{const.}$

(1) Impulse

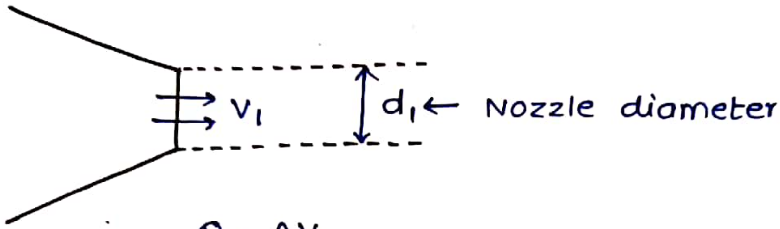
(2) Tangential Flow

(3) High head

(4) Low discharge

(5) Low specific speed hydraulic turbine.

Discharge of pelton wheel:



$Q = AV_1$

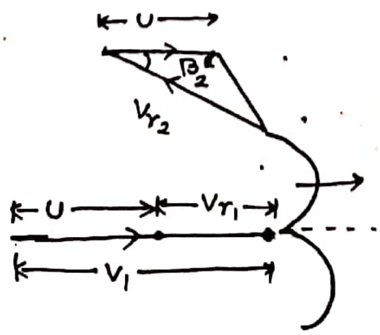
$$\boxed{Q = \frac{\pi}{4} d_1^2 V_1}$$

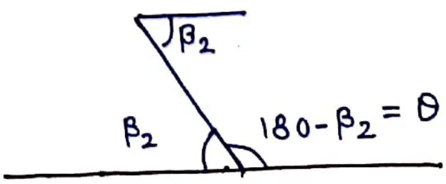
If it is a multijet pelton wheel then the total discharge Q is equal to .

$$\boxed{Q = \frac{\pi}{4} d_1^2 V_1 N}$$ N= No. of jets.

Note: the Max. No. of jets that can be used on pelton wheel is 6.
if the max. No. jet or Nozzles are More than 6, the Fluid coming From one jet May interfair with the fluid coming from the other jet. therefore it is restricted to 6.

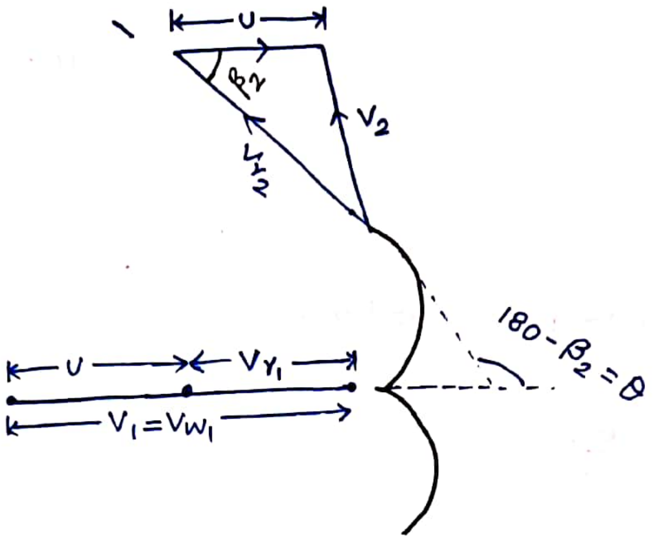
Velocity triangle's for pelton wheel:





θ = Jet deflection angle

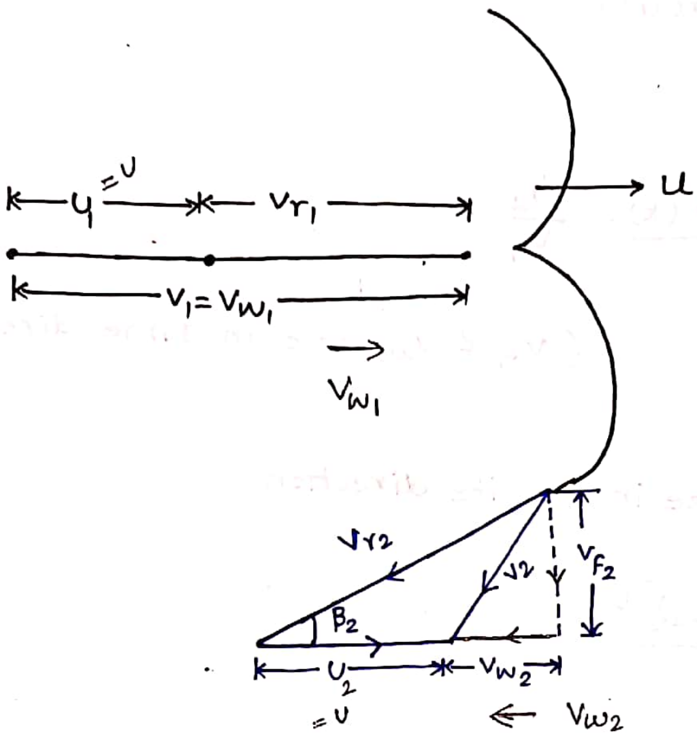
$\beta_2 = 180 - \theta$



β_2 = blade angle at exit

- The blades are of double semi-ellipsoidal cups. Double cups are taken ~~to~~ in order to neutralise axial thrust on bearings.
- The deflection angle is generally kept at 165° but it is Never kept at 180° because if the deflection angle is 180°, the jet leaving the vane will exert a retarding Force on the succeding Vane. therefore the blade angle at the exit is generally kept at 15°. In case of pelton wheel, the inlet velocity triangle is straight line.

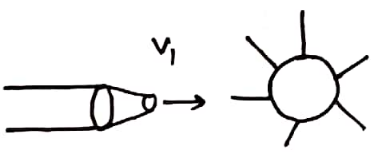
Diagram or blading efficiency (η_d)



$U_1 = U_2 = U$

$V_{r_1} = V_{r_2}$

Input energy $= \frac{1}{2}\dot{m}V_1^2$



$$W = V_{w_1}U_1 - V_{w_2}U_2$$

$$P = \dot{m}W$$

$$P = \dot{m}\left[V_{w_1}U_1 - V_{w_2}U_2\right]$$

$$P = \dot{m}\left[V_{w_1} - V_{w_2}\right]U \qquad \{U_1 = U_2\}$$

$$\eta_b = \frac{\dot{m}\left[V_{w_1} - V_{w_2}\right]U}{\frac{1}{2}\dot{m}V_1^2}$$

$$\boxed{\eta_b = \frac{2U\left[V_{w_1} - V_{w_2}\right]}{V_1^2}}$$

Condition for max. blading efficiency:

In case of an ideal impulse turbine $V_{r_1} = V_{r_2}$ but in actual case as the fluid flows through blade passages to overcome friction the relative velocity decreases.

i.e. $V_{r_2} < V_{r_1}$

blade friction coefficient (K): $\dfrac{V_{r_2}}{V_{r_1}}$

$$\eta_b = \frac{2(V_{w_1} - V_{w_2})U}{V_1^2}$$ (V_{w_1} & V_{w_2} are in same direction)

as V_{w_1} & V_{w_2} are in opposite direction

$$\eta_b = \frac{2[V_{w_1} - (-V_{w_2})]U}{V_1^2}$$

$$\eta_b = \frac{2[V_{w_1} + V_{w_2}]U}{V_1^2}$$ (when V_{w_1} & V_{w_2} are in opposite dirn)

$$V_{w_1} = V_1$$

$$V_{w_2} = V_{r_2} \cos\beta_2 - U$$

$$V_{w_2} = K V_{r_1} \cos\beta_2 - U$$

$$V_{w_2} = K(V_1 - U)\cos\beta_2 - U$$

$$\eta_b = \frac{2[V_1 + K[V_1 - U)\cos\beta_2 - U]U}{V_1^2}$$

$$\eta_b = \frac{2(V_1 - U)[1 + K\cos\beta_2]U}{V_1^2}$$

$$\eta_b = 2\left[\frac{U}{V_1} - \frac{U^2}{V_1^2}\right](1 + k\cos\beta_2)$$

$\frac{U}{V_1}$ = blade speed ratio (ρ)

$$\eta_b = 2(\rho - \rho^2)(1 + k\cos\beta_2)$$

$K = \frac{V_{r_2}}{V_{r_1}}$ = blading Friction coefficient

For max. η_b ; $\frac{d\eta_b}{d\rho} = 0$

$$\frac{d\eta_b}{d\rho} = 2[1-2\rho][1+k\cos\beta_2] = 0$$

$$1 - 2\rho = 0$$

$$\rho = 1/2$$

$$\frac{U}{V_1} = \frac{1}{2} \Rightarrow \boxed{U = \frac{V_1}{2}}$$ **

(Remember-1)

$$\eta_{max,b} = 2\left[\tfrac{1}{2} - \tfrac{1}{4}\right][1 + k\cos\beta_2]$$

$$\boxed{\eta_{max,b} \Rightarrow \frac{1 + k\cos\beta_2}{2}}$$ — (R2).

$\rho = 0$

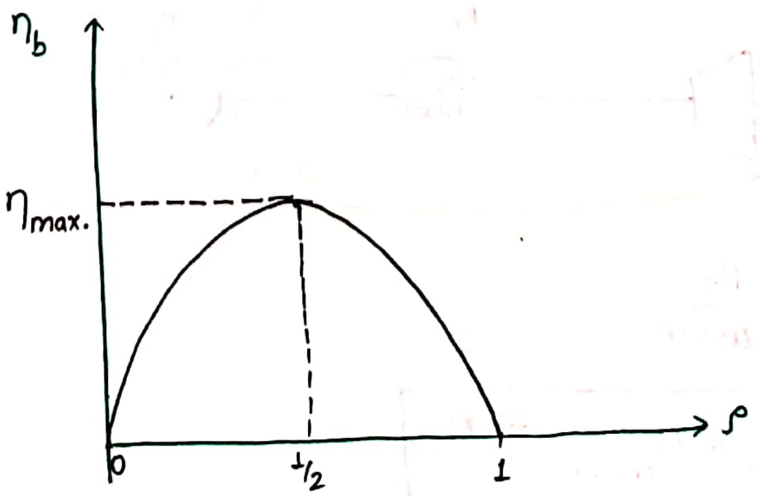
$\frac{U}{V_1} = 0$; $U = 0$

$\eta_b = 0$

$\rho = 1$

$V_1 = U_1$ power $= 0$

$\eta_b = 0$



⇒ For max. blading efficiency the blade speed must be half of the jet speed. (4)

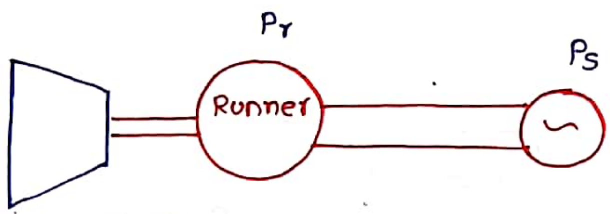
Various efficiencies in hydraulic turbine :

Hydraulic efficiency: ($\eta_{hyd.}$)

$$\eta_{hyd.} = \frac{\text{Runner power } (P_r)}{\omega Q H}$$

$$P_r = \dot{m}\left[V_{w_1}U_1 - V_{w_2}U_2\right]$$

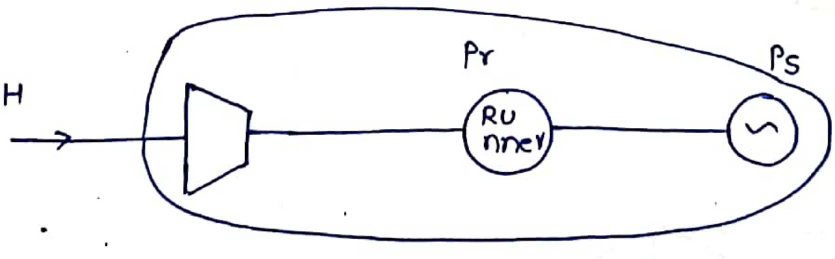
Mechanical efficiency (η_m):



$$\eta_m = \frac{P_s}{P_r} = \frac{\text{shaft power}}{\text{Runner power}}$$

$$P_r = \dot{m}\left[V_{w_1}U_1 - V_{w_2}U_2\right]$$

Overall efficiency (η_o)



$$\eta_o = \frac{P_s}{\omega Q H}$$

$$\boxed{\eta_{hyd.} \times \eta_{mech} = \eta_o}$$

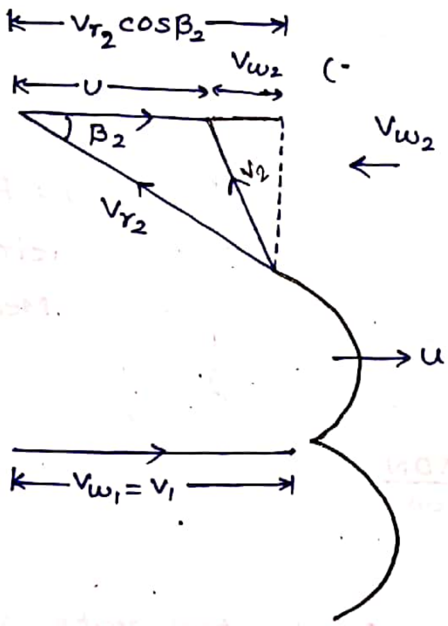
Limitation of pelton wheel:

(1) pelton wheel is efficient when operating under high heads. to generate given power (WQH), the discharge must be high if the head is low. this results in increase in jet diameter. and subsequently increase in runner diameter therefore the system becomes bulky under low heads and hence pelton wheel is suitable for high heads.

Note: if the power developed ~~be~~ with single jet 'p' then the power developed with 'n' number of jets is "np"

Exit velocity triangles

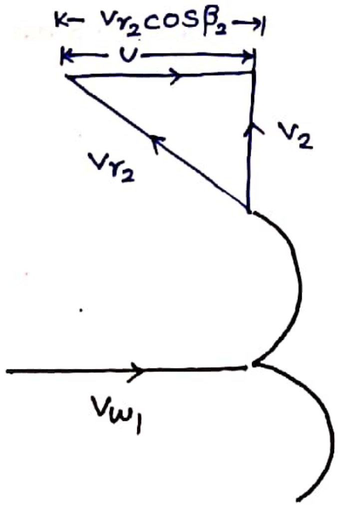
(1)



$P_r = \dot{m}\,[V_{w_1} + V_{w_2}]\,u$

$\boxed{V_{r_2}\cos\beta_2 > U}$

(2)



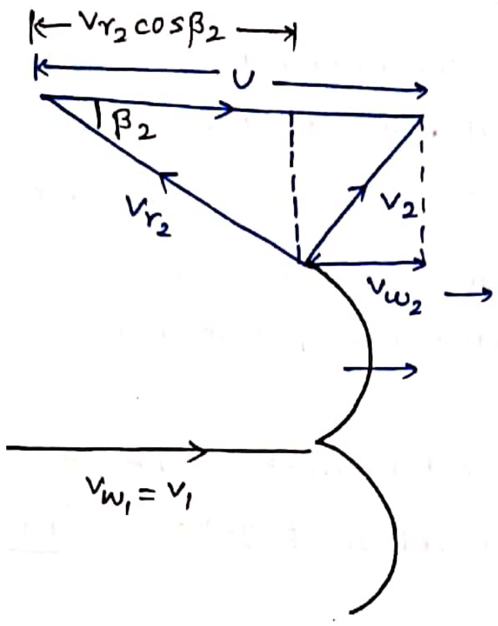
$V_{w_2} = 0$

$P_r = \dot{m}\,[V_{w_1} U]$

$\Rightarrow \boxed{V_{r_2}\cos\beta_2 = U}$

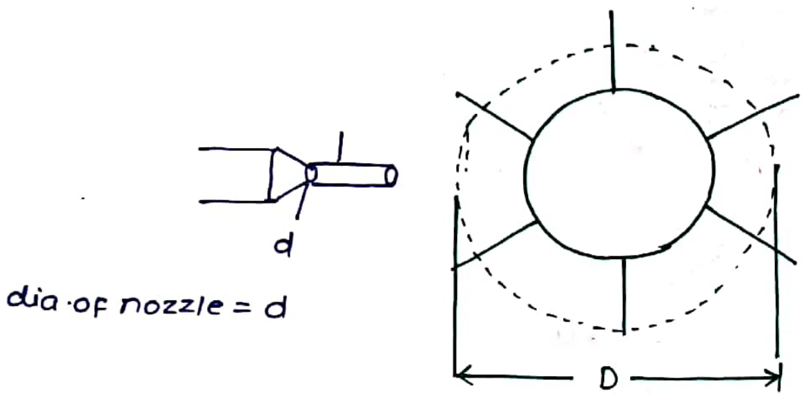
(3)

$V_{r_2}\cos\beta_2 < U$



$P_R = \dot{m}[V_{w_1} - V_{w_2}]\,U$

Question:



D = PCD (Pitch circle diameter or Mean dia.

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

Q. The mean bucket speed is 15 m/s, the rate of flow of water under a head of 42 m is 1 m^3/sec. the Jet deflection angle is 165°. the coefficient of velocity 0.985 Find ~~to~~

(1) Runner power

(2) hydraulic efficiency.

Solution:

Given that $U = 15$ m/s

$H = 42$ m

$Q = 1$ m^3/s

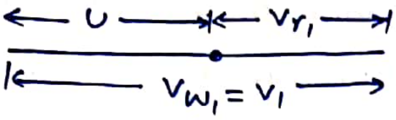
$\beta_2 = 15°$

$C_v = 0.985$

$V_1 = C_v\sqrt{2gH}$

$V_1 = 0.985 \times \sqrt{2 \times 9.81 \times 42}$

$V_1 = 28.27 \text{ m/s}$

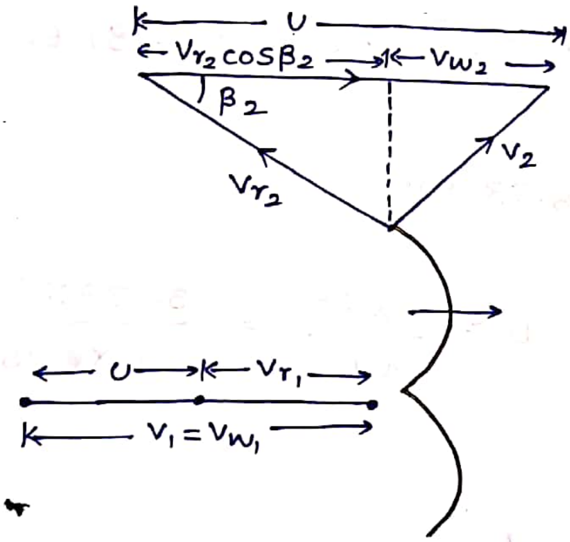


$V_{r_1} = V_1 - U = 28.27 - 15 = 13.27 \text{ m/s}$

$V_{r_2} = V_{r_1} = 13.27 \text{ m/s}$

$V_{r_2}\cos\beta_2 = 13.27 \cos 15^\circ = 12.81 \text{ m/s}$

$V_{r_2}\cos\beta_2 < U$



$V_{w_2} = U - V_{r_2}\cos\beta_2$

$= 15 - 12.87$

$\Rightarrow 2.176 \text{ m/s}$

$P_r = \dot{m}[V_{w_1} - V_{w_2}]U$

$P_r \cdot \Rightarrow \dfrac{10^3[28.27 - 2.176] \times 15}{1000}$

$\boxed{P_r = 391.2 \text{ KW}}$

$\rho = \dfrac{\text{mass}}{\text{Vol.}}$

$\dfrac{m}{t} = \rho \cdot \dfrac{\text{vol.}}{t}$

$\dot{m} = \rho Q = 10^3 \times 1 = 10^3 \text{ kg/s}$

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Hydraulic efficiency ($\eta_{hyd.}$) = $\frac{P_r}{wQH}$

(6)

$$\Rightarrow \frac{391.2 \times 10^3}{9810 \times 1\cancel{0^3} \times 42} = 0.949.$$

$\Rightarrow$ 94.9%.

Que:2. A pelton wheel is to be design for a shaft power of 9560 kW under a head of 350 m, the overall efficiency is 85%. the jet diameter (d) is $\frac{1}{6}^{th}$ of wheel diameter (D) the speed is 750 rpm, c_v is 0.985 blade speed ratio (U/V_1) 0.45 Find

(1) Wheel diameter

(2) Jet diameter

(3) No. of Jets.

$$V_1 = c_v\sqrt{2gH} = 0.985 \times \sqrt{2 \times 9.81 \times 350} = 81.62 \text{ m/s}$$

$$U = 0.45 V_1 = 36.73 \text{ m/s}$$

$$U = \frac{\pi D N}{60} \qquad D = \frac{U \times 60}{\pi N} = \frac{36.73 \times 60}{\pi \times 0.750} = 0.935 \text{ m}$$

Jet diameter = $D/6$

$d = 0.155$ m.

S.P = 9560.

$$\eta_{hyd} = \frac{P_r}{wQH}$$

$$\eta_o = 0.85 = \frac{P_s}{wQH}$$

$$wQH = \frac{9560}{0.85} = 11247.05 \text{ kW.}$$

$$\text{discharge} = \frac{\pi}{4} d_1^2 \times V_1 = \frac{\pi}{4}(0.155)^2 \times 81.62$$

$\Rightarrow$ 1.54 m3/sec.

$$Q = \frac{11247.05 \times 10^3}{9810 \times 350} = 3.2756 \ m^3/sec.$$

$$\text{No. of Jet} = \frac{\text{total discharge}}{\text{discharge from a single Nozzle/jet}}$$

$$= \frac{3.2756}{1.54} = 2.127. \simeq \underline{\underline{2}} \ \underline{Ans.}$$

Q.3. Water having a density of 1000 kg/m3 comes out from Nozzle with a velocity of 10 m/s [V_1] and jet strikes the bucket mounted on pelton wheel the wheel rotates at 10 rad/sec. the wheel diameter is 1 m [D] the deflection angle (θ) is 120° if the mass flow rate 1 kg/sec. then find the torque exerted on the wheel.

Solution:

$\rho = 1000 \ kg/m3$

$V_1 = 10 \ m/s$

$\omega = 10 \ rad/sec \qquad \omega = \frac{2\pi N}{60} \qquad N = \frac{\omega \times 60}{2\pi} = 95.49 \ rpm$

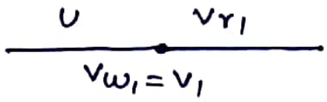
$D = 1 m$

$\theta = 120° \qquad \beta_2 = 60°$

$V_1 = 10 m/s.$

$\dot m = 1 \ kg/s$

$\tau = ?$



$\cancel{P_r = \dot m [V_{w_1}}$

$$U = \frac{\pi D N}{60} = \frac{\pi \times 1 \times 95.49}{60} = 5 \ m/s \qquad P = \text{Torque} \times \omega$$

$V_{r_1} = V_1 - U = 10 - 5 = 5 \ m/s$

$P_r = \dot m [V_{w_1} + V_{w_2}] U$

$V_{r_1} = V_{r_2} \Rightarrow 5 \ m/s$

$V_{r_2} \cos\beta_2 = 5 \times \cos 60$

$= 2.5 < U$

$V_{w_2} = U - V_{r_2} \cos\beta_2$

$= U - 2.5$

$= 2.5 \ m/s$

$\underline{V_{r_2} \cos\beta_2 < U}$ (3rd case triangle)

$P_r = 1 [10 + \cancel{5}^{\,2.5}] \times 5$

$P_r = 37.5 \ W$

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power = F × V

$\cancel{F = \frac{75}{10}} = \cancel{7.5}$ N

Torque = F × r = $\cancel{7.5 \times 0.5}$ = $\cancel{3.75}$ N-m. Ans.

power = Torque × ω

Torque = $\frac{37.5}{10}$ = 3.75 N-m. Ans.

Que:3. A single jet pelton wheel is required to drive a generator of 10 MW power. the available head is 760 m, Mechanical efficiency is 0.95, hydraulic efficiency is 0.87, coefficient of velocity is 0.97 the bucket speed is 0.46 times the jet speed. the relative velocity of water ~~at inlet~~ leaving the bucket is 0.85 times the relative velocity at inlet Find.

(1) Discharge.

(2) tangential force exerted on the wheel.

(3) Best synchronus speed for generation at 50 Hz frequency. & the corresponding wheel diameter if the ratio of wheel dia. to jet diameter is not to be less than 10.

Solution:

Given that

$P_s = 10$ MW

$H = 760$ m

$\eta_m = 0.95$; $\eta_{hyd.} = 0.87$, $C_v = 0.97$

$U = 0.46\, V_1$

$V_{r_2} = 0.85\, V_{r_1}$

$\frac{D}{d} \geq 10$

$f = 50$ Hz.

$V_1 = C_v \sqrt{2gH} \Rightarrow 0.97 \times \sqrt{2 \times 9.81 \times 760} = 118.45$ m/s

$u = 0.46\, V_1 = 0.46 \times 118.45 \Rightarrow 54.48$ m/s

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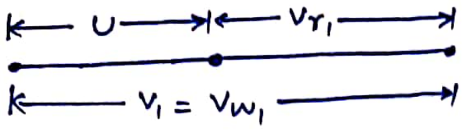


$$V_{r_1} = V_1 - U = 118.45 - 54.48 \Rightarrow 63.97 \text{ m/s}$$

$$V_{r_2} = 0.85\, V_{r_1} = 0.85 \times 63.97 = 54.37 \text{ m/s.}$$

(1)

$$\eta_o = \frac{P_s}{WQH} \qquad \eta_o = \eta_m \times \eta_h$$

$$\downarrow$$

$$= 0.95 \times 0.87 = \frac{10 \times 10^6}{9810 \times Q \times 760}$$

$$Q = 1.62283 \text{ m}^3/\text{sec.}$$

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

$$= 1.622 = \frac{\pi}{4}(d^2) \times 118.45$$

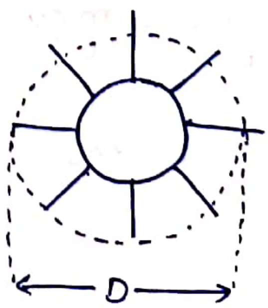
$$d = 0.13207 \text{ m}$$

$$\frac{D}{d} \geq 10 \Rightarrow \frac{D}{d} = 10$$

$$D = 10d$$

$$\boxed{D = 1.3207 \text{ m}}$$

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



$$N = \frac{U \times 60}{\pi D} = \frac{54.48 \times 60}{\pi \times 1.3207}$$

$$N = 788.25 \text{ rpm.}$$

$$N = \frac{120f}{P} \rightarrow \text{always even.}$$

8

$$788.25 = \frac{120 \times 50}{P}$$

$$P = 7.6 \quad = \quad \underline{P = 8}$$

Synchronous Speed $(N) = \frac{120 \times 50}{8} = 750$ rpm.

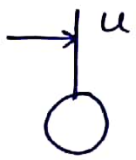
$$U = \frac{\pi D N}{60}$$

$$= \frac{54.48 \times 60}{\pi \times 750} = D \quad \Rightarrow \quad D = 1.387\text{ m.}$$

$$\frac{D}{d} = \frac{1.387}{0.132} = 10.51 > 10$$

(3) tangential force:

$$\eta_m = \frac{P_s}{P_r} \qquad P_r = \frac{10}{0.95} = 10.51 \text{ MW}$$



$$P_r = F_t \times u$$

$$F_t = \frac{10.51 \times 10^6}{54.48}$$

$$\boxed{F_t = 193.214 \text{ KN}}$$

IInd Method

$$F = m\left(\frac{v-u}{t}\right) = \frac{\dot{m}}{t}(v-u)$$

$$\underline{F_t = \dot{m}(V_{w_1} - V_{w_2})}$$

Reactions turbine

Francis turbine:

In reaction turbines the fluid enters the turbine at high pressure & high velocity. as it flows through runner vanes, pressure decreases and relative velocity increases. becouse of this rotation is possible therefore in reaction turbine as the fluid flows through runner vanes both pressure and k.E decreases and hence power is obtained.

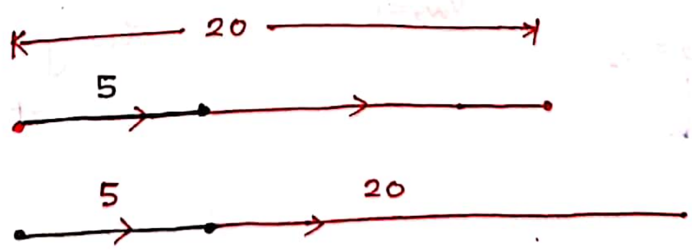
[In reaction turbine ($V_{r_2} > V_{r_1}$)

"It is a mixed flow, Medium head, Medium discharge, Medium specific speed reaction turbine.

$$\boxed{V_{r_2} > V_{r_1}}$$

In Francis turbine the fluid from penstocks enter the spiral casing (logarithmic), from casing it entires stay vanes with which resist load and transmit to the foundation. From stay vanes the fluid enters guide vanes, the purpose of guide vanes is to allow the fluid on the runner blades at correct angle, from guide vanes the fluid enters the runner vanes from runner exit, the fluid then enters draft tube, Draft tube is used in reaction turbines.

Velocity triangles for Francis turbine :



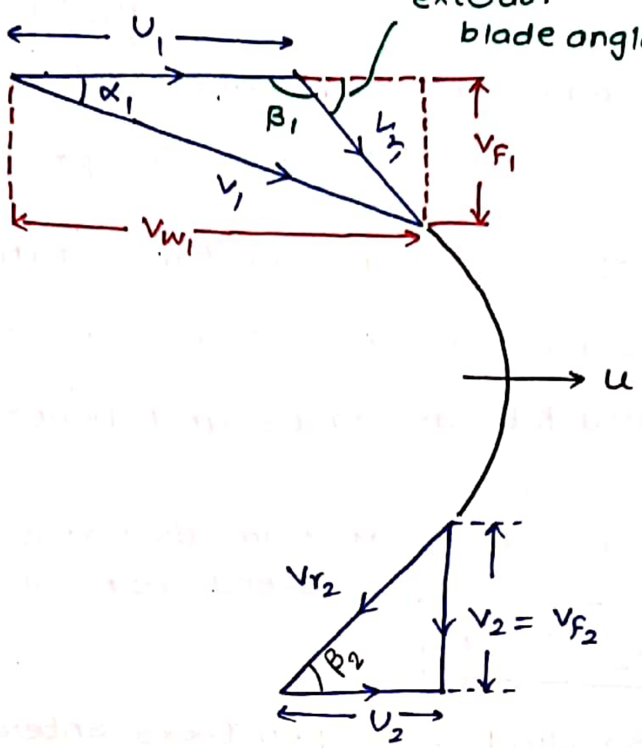
Relative = 5+20 = 25

(1)

$\left.\begin{array}{l} D_1 > D_2 \\ U_1 > U_2 \\ V_{r_2} > V_{r_1} \end{array}\right]^{*}$

$\beta_1 > 90$

exterior blade angle

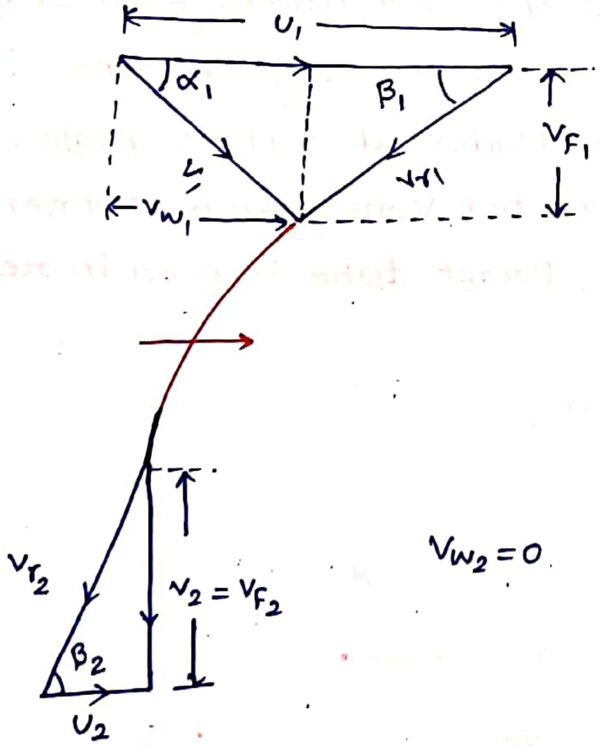


β_1 = interior blade angle.

$\underline{V_{w_2} = 0}$ (b/c axial exit)

(2)

$\beta_1 < 90$



$V_{w_2} = 0$

β_1 & β_2 → Blade angles at inlet & outlet respectively

α_1 = guide vane angle at inlet.

P_r (runner power) $= \dot{m}[V_{w_1}U_1 - V_{w_2}U_2]$

$$P_r = \dot{m}[V_{w_1}U_1] \qquad \because V_{w_2} = 0$$

axial exit

$$\eta_h = \frac{P_r}{\rho g Q H}$$

$$\eta_h = \frac{\dot{m} V_{w_1} U_1}{\rho g Q H}$$

$$\rho = \frac{m}{Vol.}$$

$$\frac{m}{t} = \rho \times \frac{Vol.}{t}$$

$$\dot{m} = \rho Q$$

$$\boxed{\eta_h = \frac{V_{w_1} U_1}{g H}}$$

(very important eq. in Francis turbine)

$$\eta_{mech.} = \frac{P_s}{P_r}$$

$$\eta_o = \frac{P_s}{w Q H}$$

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

Speed ratio: (k_u).

$$k_u = \frac{U_1}{\sqrt{2gH}}$$

$$k_u = 0.70 \text{ to } 0.85$$

Flow ratio (ψ) :

$$\psi = \frac{V_{F_1}}{\sqrt{2gH}}$$

$$\psi = 0.15 \text{ to } 0.35.$$

Discharge of Francis turbine:

No. of ~~runner~~ blades in Runner → 16 to 24.

(10)

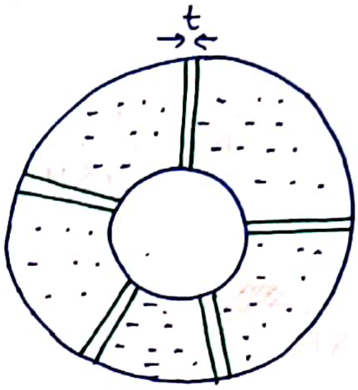
Area.

$A = (\pi D - zt) B$

$Q = A_1 V_{f_1} = A_2 V_{f_2}$

$Q = (\pi D - zt) B V_f$

$\boxed{Q = k \pi D B V_f}$



Z = No. of vanes

t = thickness of vanes

k = Factor which accounts for thickness of vanes as the flow is steady $\pi D_1 B_1 V_{f_1} = \pi D_2 B_2 V_{f_2}$

B_1 & B_2 are width of runner at inlet & outlet respectively.

Q. An inward flow reaction turbine works under a head of 110 m. the outer diameter 1.5 m and the inner diameter is 1 m. the width of the runner is constant throughout is equal to 150 mm. outlet blade angle is 15°; $\eta_h = 90\%$, the axial discharge velocity at the exit is 6 m/s. Find speed of the turbine in rpm., blade angles and runner power.

Given that

$H = 110\,m$

$D_1 = 1.5\,m$

$D_2 = 1\,m$

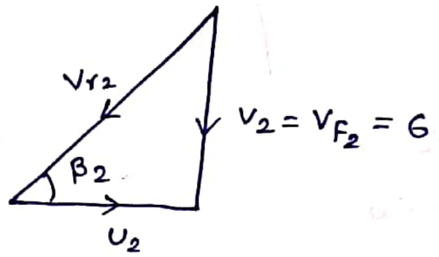
$B_1 = B_2 = 0.15\,m$

$\beta_2 = 15°$

$\eta_h = 90\%$

$V_2 = V_{f_2} = 6\,m/s$

outlet velocity Δ (b/c Max. information given for that)



$$\tan\beta_2 = \frac{V_2}{U_2}$$

$$U_2 = \frac{6}{\tan 15} \qquad U_2 = 22.39\,m/s$$

$$U_2 = \frac{\pi D_2 N}{60}$$

$$22.39 = \frac{\pi \times 1 \times N}{60} \Rightarrow N = 427.87\ rpm.$$

$$U_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 1.5 \times 427.87}{60} = 33.59\,m/s$$

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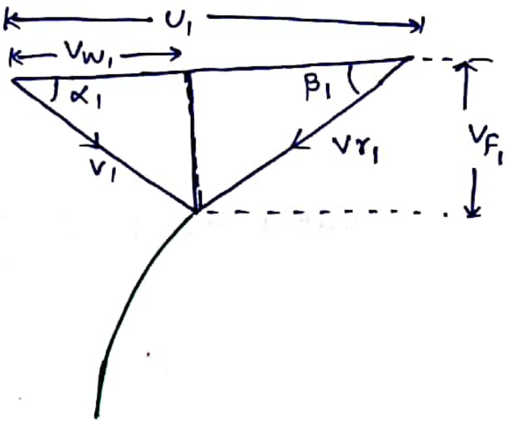
$$\eta_h = \frac{V_{w_1} U_1}{gH}$$

$$\Rightarrow 0.9 = \frac{V_{w_1} \times 33.59}{9.81 \times 110} \quad ; \quad V_{w_1} = 28.9 \text{ m/s.}$$

$\underline{V_{w_1} < U_1}$ so 2^{nd} velocity triangle.



$$\cancel{\pi} D_1 \cancel{B_1} V_{f_1} = \cancel{\pi} D_2 \cancel{B_2} V_{f_2}$$

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

$$V_{f_1} = \frac{6}{1.5} = 4 \text{ m/s}$$

$$\tan\beta_1 = \frac{V_{f_1}}{U_1 - V_{w_1}}$$

$$\tan\beta_1 = \frac{4}{33.59 - 28.9} \Rightarrow \boxed{\beta_1 = 40.52^\circ}$$

$$\tan\alpha_1 = \frac{V_{f_1}}{V_{w_1}} = \frac{4}{28.9}$$

$$\boxed{\alpha_1 = 7.88^\circ}$$

$$\frac{P_r}{wQH} = \eta_h$$

$$\eta_h \times wQH = P_r \Rightarrow 0.9 \times 9810 \times \pi \times 1.5 \times 0.15 \times 4 \times 110$$
$$= 2.745 \text{ MW.}$$

or $P_r = \dot{m} V_{w_1} U_1 = \rho \underline{Q} V_{w_1} U_1$
$$= \rho \times \pi D_1 B_1 V_{f_1} \times V_{w_1} U_1$$

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Que: 2. Estimate the main dimensions of a Francis turbine to suit the following conditions.

Head = 100 m, power = 2.5 MW, speed (N) = 500 rpm, $\eta_h = 0.9$, $\eta_o = 0.85$

Flow ratio (ψ) = 0.15, the ratio of width of the wheel to the diameter at inlet (B_1/D_1) = 0.1, the outer diameter of the runner is twice the inner dia. ($D_1 = 2D_2$), the flow velocity is constant throughout.

Solution:

Given that

$H = 100\text{ m}$

$P_s = 2.5\text{ MW}$

$N = 500\text{ rpm}$; $\eta_h = 0.9$, $\eta_o = 0.85$, $\psi = 0.15$, $B_1/D_1 = 0.1$

$\cancel{H} = V_{f_1} = V_{f_2}$

$\cancel{\pi} D_1 B_1 \cancel{V_{f_1}} = \cancel{\pi} D_2 B_2 \cancel{V_{f_2}}$

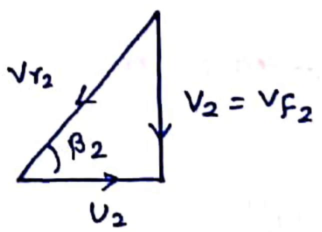
$\Rightarrow \cancel{2D_2} \quad D_1 \times 0.1 D_1 = \frac{D_1}{2} \times B_2$

$\Rightarrow$

$V_{f_1} = \psi\sqrt{2gH} = 0.15\sqrt{2\times 9.81\times 100} = 6.64\text{ m/s}$

$\eta_o = \frac{S.P.}{\omega Q H}$

$= 0.85 = \frac{2.5\times 10^6\text{ W}}{9810\times Q\times 100}$



$Q = 2.9981\text{ m/s}$

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

$= 2.99 = \pi \times D_1 \times 0.1 D_1 \times 6.64$

$D_1 = 1.1988\text{ m}.$

$B_1 = 0.1 D_1$

$\boxed{B_1 = 0.1198\text{ m}}$

$D_1 = 2D_2$

$\Rightarrow D_2 = \frac{D_1}{2} = 0.599 \text{ m}$

$Q = \pi D_2 B_2 V_{f_2}$

$= 2.99 = \pi \times 0.599 \times B_2 \times 6.64$

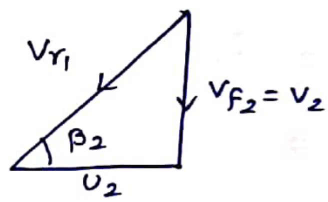
$\boxed{B_2 = 0.239 \text{ m}}$

Blade angles:

$U_1 = \frac{\pi D_1 N_1}{60} = \frac{\pi \times 1.198 \times 500}{60} = 31.38 \text{ m/s}$

$U_2 = \frac{\pi D_2 N_2}{60} = \frac{\pi \times 0.599 \times 500}{60} = 15.68 \text{ m/s}$

$\tan\beta_2 = \frac{V_2 = V_{f_2}}{U_2}$



$\tan\beta_2 = \frac{6.64}{15.68}$

$\boxed{\beta_2 = 22.94^\circ}$

$\cancel{P_r = m V_{w_1} U_1}$

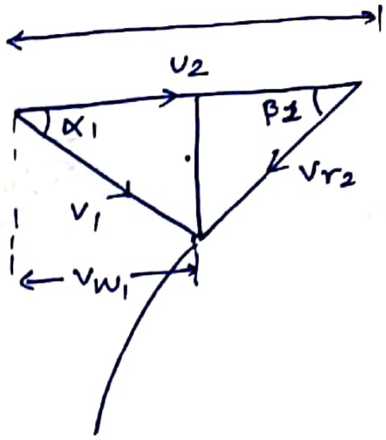
$\frac{P_s}{P_r} = \eta_m$

$\eta_h = \frac{V_{w_1} U_1}{gH}$

$= 0.9 = \frac{V_{w_1} \times 31.38}{9.81 \times 100}$

$V_{w_1} = 28.13 \text{ m/s}$

$V_{w_1} < U_1$



$$\tan\beta_1 = \frac{V_{f2}}{U_2 - V_{w1}}$$

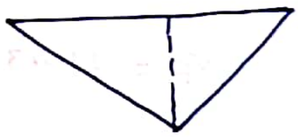
$$\tan\beta_1 = \frac{6.64}{31.38 - 28.13}$$

$$\boxed{\beta_1 = 63.96}$$

$$\tan\alpha_1 = \frac{V_{f1}}{V_{w1}} = \frac{6.64}{28.13}$$

$$\boxed{\alpha_1 = 13.28^\circ}$$

Q. An inward flow reaction turbine of francis type has a runner diameter of 60 cm and width 5 cm at the outer ring, the inner diameter of the outlet is 39 cm the blade inlet angle is 85° (interior) and the outlet blade angle is 14°, the velocity of flow is uniform throughout and 8% of circumferential area is occupied by blade thickness, Head = 54 m, $\eta_h = 0.88$. $\eta_o = 0.81$ for axial exit calculate speed in rpm and shaft power.



Solution:

Given that

$D_1 = 0.6m$

$B_1 = 0.05 m$

$D_2 = 0.39 m$

$\beta_1 = 85^\circ$ (interior)

$\beta_2 = 14^\circ$

$V_{f1} = V_{f2}$

$K = 0.92$

$H = 54m$

$\eta_h = 0.88$ $\eta_o = 0.81$

$\eta_h =$

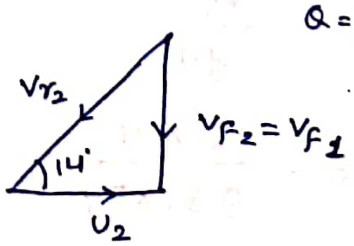
$$U_1 = \frac{\pi D_1 N_1}{60} \qquad U_2 = \frac{\pi D_2 N_2}{60}$$

$V_{w1}U_1$

$Q = A \times V_{f1}$

$$= \frac{19.58 \times 60}{\pi \times 0.6}$$

623 rpm



$V_{f1} = 4\sqrt{}$

$$\eta_h = \frac{V_{w1}U_1}{gH}$$

$Q = K\pi D_1 B_1 V_f = \pi \times 0.6$

$\eta_o =$

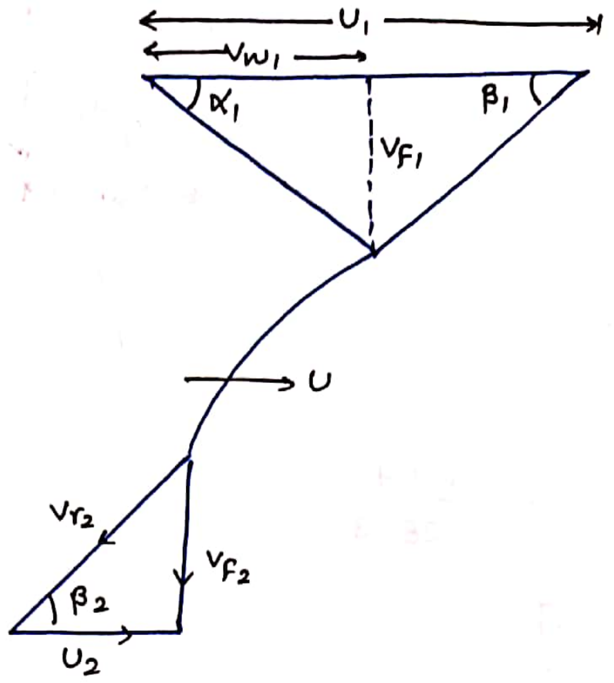
$V_{f1} = 0.15\sqrt{2 \times g \times 54} = 4.88.$

$$\tan 14 = \frac{V_{f1}}{U_2}$$

13

$\underline{\beta_1 < 90}$

so we draw this



$$\tan\beta_2 = \frac{V_{f_2}}{U_2}$$

$$V_{f_2} = U_2 \tan 14 \Rightarrow 0.249\,U_2 \quad \text{——— (1)}$$

$$\tan\beta_1 = \frac{V_{f_1}}{U_1 - V_{w_1}}$$

$$V_{f_1} = 11.43\,(U_1 - V_{w_1}) \quad \text{——— (2)}$$

From (equ 1 & 2 $\quad V_{f_1} = V_{f_2}$

$$= 0.249\,U_2 = 11.43\,(U_1 - V_{w_1})$$

$$\Rightarrow \eta_h = \frac{V_{w_1} U_1}{gH}$$

$$0.88 = \frac{V_{w_1} \times U_1}{9.81 \times 54} \Rightarrow V_{w_1} U_1 = 466.17 \,.\quad \left[V_{w_1} = \frac{466.17}{U_1}\right]$$

$$\Rightarrow \frac{0.249 \cdot \pi\,(0.\overset{39}{6})\,N}{60} = 11.43\left[\frac{\pi \times 0.6\,N}{60} - \frac{466.17 \times 60}{\pi\,(0.6)\,N}\right]$$

$$\Rightarrow 5.82 \times 10^{-3} N = 11.43\left[\frac{0.0204 N}{0.0314 N} - \frac{14838.65}{N}\right]$$

$$= 7.82 \times 10^{-3} N = 11.43 \times 0.0204 N - \frac{169605.7}{N}$$

$$N = 692.3 \text{ rpm.}$$

$$\eta_o = \frac{P_s}{wQH} = \qquad Q = K\pi D_1 B_1 V_{f1}$$

$$U_2 = \frac{\pi D_2 N}{60} = 14.15 \text{ m/s}$$

$$Q = 0.92 \times \pi \times 0.6 \times 0.05 \times 3.52$$

$$= 0.305 \text{ m}^3/\text{sec}$$

$$U_2 \times \tan\beta_2 = V_{f2}$$

$$V_{f1} = V_{f2} = 3.5247 \text{ m/s}$$

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

$$P_s = 131.3 \text{ kW.}$$

Assignment-

A Francis turbine has to be design to develop 367.5 kW. under a head of 70 m, while running at 750 rpm the ratio of width of the runner to the diameter at inlet is 0.1 the inner diameter is 1/2 the outer diameter the flow ratio is 0.15, $\eta_h = 0.95$ $\eta_{Mech.} = 0.84$, 4% of circumferential area is occupied by thickness of vanes, the velocity of flow is constant and fluid leaves axially at the exit, calculate

[1] Diameter of the wheel (D_1 & D_2) [$D_1 = 0.6325$ m ; $D_2 = 0.31625$ m]

[2] Quantity of water supplied. [0.67063 m³/sec]

[3] Guide vane angle at inlet ($B_1 = 104.35°$ (interior))

[4] Runner vane angle at inlet and exit. ($\alpha_1 = 11.95°$)

Specific Speed : (N_s)

It is the speed of Geometrically similiar turbine working under unit head (1m) and developing unit power (1 kW).

$Q = K\pi D B V_f$

$Q \propto D B V_f$ —— (I)

$\psi = \frac{V_{f_1}}{\sqrt{2gH}}$ $\quad V_{f_1} = \psi\sqrt{2gH}$ $\Rightarrow$ $V_{f_1} \propto \sqrt{H}$ —— (1)

$k_u = \frac{U}{\sqrt{2gH}}$ $\quad U = k_u\sqrt{2gH}$ $\Rightarrow$ $\frac{\pi D N}{60} = k_u\sqrt{2gH}$

$D \propto \frac{\sqrt{H}}{N}$ —— (2)

$D/B = 0.1$

$D \propto B$

$B \propto \frac{\sqrt{H}}{N}$ —— (3)

put the value from (1) (2) (3) into (I)

$Q \propto \frac{\sqrt{H}}{N} \cdot \frac{\sqrt{H}}{N} \cdot \sqrt{H}$

$Q \propto \frac{H^{3/2}}{N^2}$ —— (II) $\quad Q = C\frac{H^{3/2}}{N^2}$

if $H = 1$ m $\quad Q = 1\ m^3/s$ then $N = N_s$

$\Rightarrow 1 = \frac{C\ (1)}{N_s^2}$ $\quad \Rightarrow N_s^2 = C$

$$\Rightarrow \quad Q = N_s^2 \cdot \frac{H^{3/2}}{N^2}$$

$$N_s^2 = \frac{N^2 Q}{H^{3/2}}$$

Imp.

$$\boxed{N_s = \frac{N\sqrt{Q}}{H^{3/4}}}$$

Specific Speed for pump.

From equation (II)

$$Q \propto \frac{H^{3/2}}{N^2}$$

$$P = \omega Q H$$

$$P \propto Q H$$

$$P \propto \frac{H^{3/2} \cdot H}{N^2}$$

$$P \propto \frac{H^{5/2}}{N^2} \Rightarrow P = c_1 \frac{H^{5/2}}{N^2}$$

$N = N_s$ if $H = 1\,m$; $P = 1\,kW$

$$\Rightarrow \quad 1 = \frac{c_1(1)}{N_s^2} \qquad c_1 = N_s^2$$

$$\Rightarrow \quad P = N_s^2 \cdot \frac{H^{5/2}}{N^2}$$

Imp.

$$\Rightarrow \boxed{N_s = \frac{N\sqrt{P}}{H^{5/4}}}$$

Specific speed for turbine
(Dimensional specific speed)

P = shaft power in kW

H = head in meter

Note: All Geometrically Similiar turbines have Same Specific speed.

Specific Speed of Various Turbines:

S. No.	Type of turbine	Specific speed (Dimensional)	Dimensionless Specific Speed
1	Pelton wheel with single Jet	10-30	0·03 - 0·3
2	pelton wheel with Multi Jet	30-60	
3	Francis turbine	60-300	0·3 - 2
4	Kaplan turbine	300-600	2 - 5
5	propeller turbine	600-1000	

Similitude & Modelling of turbine:

From dimensional analysis three Number i.e. Head Number, discharge Number and power number can be obtained as-

Head Number = $\frac{gH}{N^2D^2}$ (all three dimensionless)

Discharge Number = $\frac{Q}{ND^3}$

power Number = $\frac{P}{\rho N^3 D^5}$

Unit Quantities: unit Quantities are those Quantities when the same turbine is allow to operate under unit head (1m)

Turbine

$H \longrightarrow 1\,m$

$D \longrightarrow D$ (same turbine)

$N \longrightarrow N_U$

$Q \longrightarrow Q_U$

$P \longrightarrow P_U$

Unit speed (N_U)

$$\frac{gH}{N^2 \cancel{D^2}} = \frac{g(1)}{N_U^2 \cancel{D^2}}$$

$$\boxed{N_U = \frac{N}{\sqrt{H}}}$$

Unit discharge (Q_U):

$$\frac{Q}{N\cancel{D^3}} = \frac{Q_U}{N_U(\cancel{D^3})}$$

$$Q_U = Q\cdot\left(\frac{N_U}{N}\right) \Rightarrow \boxed{Q_U = \frac{Q}{\sqrt{H}}}$$

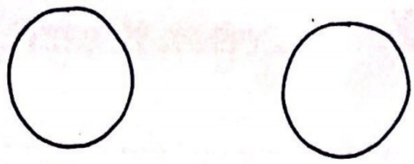
Unit power (P_U):

$$\frac{P}{\cancel{\rho} N^3 \cancel{D^5}} = \frac{P_U}{\cancel{\rho} N_U^3 \cancel{D^5}}$$

$$P_U = P\left(\frac{N_U}{N}\right)^3$$

$$\boxed{P_U = \frac{P}{H^{3/2}}}$$

Note:



H_1 $\quad\quad\quad$ H_2

N_1 $\quad\quad\quad$ N_2

D $\quad\quad\quad$ D

$$\left(\frac{gH}{N^2D^2}\right)_1 = \left(\frac{gH}{N^2D^2}\right)_2$$

$$\frac{H_1}{N_1^2} = \frac{H_2}{N_2^2}$$

$$\frac{N_1}{\sqrt{H_1}} = \frac{N_2}{\sqrt{H_2}} = N_{u_1} = N_{u_2}$$

When the Same turbine is operating under different conditions, unit quantities are equated. therefore

$N \propto H^{1/2}$
$Q \propto H^{1/2}$
$P \propto H^{3/2}$

Q. A turbine develops 8000 kW when running at 1000 rpm the Head on the turbine is 30 m, if the head is reduced to 18 m Determine the Speed and power.

Solution. turbine is same so we equate Unit quantities.

$$\frac{N_1}{\sqrt{H_1}} = \frac{N_2}{\sqrt{H_2}}$$

$$= \frac{1000}{\sqrt{30}} = \frac{N_2}{\sqrt{18}} \quad\quad N_2 = 774.6 \text{ rpm}$$

$$\frac{P_1}{H_1^{3/2}} = \frac{P_2}{H_2^{3/2}}$$

$$\Rightarrow \frac{8000}{(30)^{3/2}} = \frac{P_2}{(18)^{3/2}} \Rightarrow P_2 = 3718\,kW$$

Q. At a hydroelectric power plant the available head is 24.5m and the Flowrate is 10.1 m3/sec, if the speed is 4 rps (240 rpm) and ~~ov~~ η_0 is 90%. based on specific speed what type of turbine is this.

Solution.

$$N_S = \frac{N\sqrt{P}}{H^{5/4}}$$

$N \to 4\,rps = 240\,rpm$

$P =$ shaft power

$$\eta_0 = \frac{P_s}{\omega Q H}$$

$$P_s = 0.90 \times 9810 \times 10.1 \times 24.5$$

$$= 2184.736\,kW$$

$$\Rightarrow N_S = \frac{240\sqrt{2184.736}}{(24.5)^{5/4}} = \frac{11217.87}{54.50} = 205.83$$

So [redacted] N_S is lies b/w 60 & 300, it is Francis turbine.

Q. A hydraulic turbine develops 100 kW power under a head of 40 m. if the head is reduced to 20 m then the power developed in kW.

Ans:

$P_1 = 100\,kW$

$H_1 = 40\,m$

$H_2 = 20\,m$

$$= \frac{100}{(40)^{3/2}} = \frac{P_2}{(20)^{3/2}} \qquad \underline{P_2 = 35.35\,kW}$$

Q. A large hydraulic turbine is to generate 300 kW. at 100 rpm Under a head of 40 m. For initial testing of 1/4 scale Model operating under a head of 10 m, power develop by the Model _ in kW

Solution:

$$\left(\frac{P}{\rho N^3 D^5}\right)_m = \left(\frac{P}{\rho N^3 D^5}\right)_p$$

$$N_S = \left(\frac{N\sqrt{P}}{H^{5/4}}\right)_m = \left(\frac{N\sqrt{P}}{H^{5/4}}\right)_p$$

$$D_m = D/4$$

$$\Rightarrow \frac{100\sqrt{300}}{(40)^{5/4}} = 17.2181$$

$$\left[= \frac{P}{\left(\frac{306.1862}{\sqrt{P}}\right)^3 \cdot \frac{\cancel{D^5}}{4^5}}\right]_m = \left[\frac{300}{100^3 \times \cancel{D^5}}\right]_p$$

$$\Rightarrow N_m\sqrt{P_m} = 306.1862$$

$$N = \frac{306.1862}{\sqrt{P}}$$

$$\Rightarrow \frac{P_m \times P_m^{3/2}}{28032.18} = \frac{300}{100^3}$$

$$P_m^{5/2} = 8.409$$

$$\boxed{P_m = 2.34 \text{ kW}}$$ Ans.

Tomorrow:
- Kaplan
- cavitation
- principle of draft tube.

Q. A model of a hydraulic turbine is tested at a head of 1/4th of prototype head, the diameter of the model of 1/2' of that of prototype if N is the speed of full scale turbine than what is the speed of prototype.

Sol. ~~H_m~~ = model = 1, prototype = 2

$$h_1 = \frac{h_2}{4}$$

$$D_1 = \frac{D_2}{2}$$

$$\left(\frac{gH}{N^2D^2}\right)_1 = \left(\frac{gH}{N^2D^2}\right)_2$$

$$= \frac{\frac{H_2}{\cancel{4}}}{N_1^2 \frac{D_2^2}{\cancel{4}}} = \frac{H_2}{N^2 D_2^2}$$

$$N_1^2 = N^2$$

$$\boxed{N_1 = N}$$

Q. A radial flow hydraulic turbine is required to be design to produce 20 MW power under a head of 16 m at a speed of 90 rpm a geometrically similar model with an output of 30 KW and a head of 4 m is to be tested under similiar conditions at What speed the model must be run and what is the required diameter ratio between model & prototype & what is the volume flow rate through the model if the ~~moe~~ efficiency is 90%.

Solution:

Turbine-1

$P_1 = 20 MW$

$H_1 = 16 m$

$N_1 = 90 rpm$

Model-2

$P_2 = 30 KW$

$H_2 = 4 m$

$$\frac{D_m}{D_p} = \frac{D_2}{D_1} = ?$$

$Q_m = Q_2 = ?$, $\eta_h = 90\%$

(1) $$\left(\frac{P}{\rho N^3 D^5}\right)_1 = \left(\frac{P}{\rho N^3 D^5}\right)_2$$

(ii) $$\left(\frac{gH}{N^2 D^2}\right)_1 = \left(\frac{gH}{N^2 D^2}\right)_2$$

⇒ if Geometrically similar specific speed is same.

$$\left(\frac{N\sqrt{P}}{H^{5/4}}\right)_1 = \left(\frac{N\sqrt{P}}{H^{5/4}}\right)_2$$

$$= \frac{90\sqrt{20 \times 10^3}}{(16)^{5/4}} = \frac{N_2\sqrt{30}}{(4)^{5/4}} \Rightarrow N_2 = 410.79 \text{ rpm}$$

(2) $$\eta_o = \frac{P_m}{\omega Q H}$$

$$= Q = \frac{30 \times 10^3}{9810 \times 4 \times 0.9} = 0.849 \ m^3/s$$

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Q. A francis turbine of 3m diameter develops 6750 kW at 300rpm under a head of 45 m, a similar Model of Scale ratio 1/8 is to be tested at a head of 9 m, estimate the diameter, speed, discharge and power developed by the model, assume overall efficiency of both model & prototype to be 82%.

Solution:

Turbine-1, Model-2

$D_1 = 3m$ $\quad D_2 = D_1/8$

$P_1 = 6750kW$ $\quad H_2 = 9m$

$N_1 = 300rpm$

$H_1 = 45m$

(i)
$$\left(\frac{\cancel{g}H}{N^2D^2}\right)_1 = \left(\frac{\cancel{g}H}{N^2D^2}\right)_2$$

$$\frac{H_1}{N_1^2 D_1^2} = \frac{H_2}{N_2^2 D_2^2}$$

$$\Rightarrow \frac{45}{300^2 \times \cancel{D_1^2}} = \frac{9}{N_2^2 \cdot \frac{\cancel{D_1^2}}{8^2}} = \frac{45}{300^2} = \frac{72\times 8}{N_2^2} = 1073.31 \text{ rpm.}$$

(ii) $D_2 = \frac{D_1}{8} = 0.375\ m$

(iii)
$$\left(\frac{P}{\cancel{\rho}N^3D^5}\right)_1 = \left(\frac{P}{\cancel{\rho}N^3D^5}\right)_2$$

$$\Rightarrow \frac{6750}{300^3 \times 3^5} = \frac{P}{1073.31^3 \times 0.375^5} \quad \Rightarrow P_2 = 9.43\text{ kW.}$$

(iv) $\eta_o = \frac{9.43\times10^3}{\omega Q H}$ $\Rightarrow$ $Q = \frac{9.43\times10^3}{9810\times9\times0.82}$

$\Rightarrow 0.13\ m^3/s$

(3)

$$\frac{H_1}{N_1^2 D_1^2} = \frac{H_2}{N_2^2 D_2^2}$$

$$\Rightarrow \frac{16}{90^2 \times D_1^2} = \frac{4}{410.79^2 D_2^2}$$

$$= \frac{D_2^2}{D_1^2} = \frac{90^2 \times 4}{16 \times 410.79^2}$$

$$\Rightarrow \boxed{\frac{D_2}{D_1} = 0.109}$$

Kaplan turbine:

It is an axial flow, Low head, high discharge, high specific speed reaction turbine.

$\Rightarrow$ $Q = (\pi D - Zt) B V_f$ Q can be ↑ by ↑ D, | ↓ Z | or ↑ V_f

if D↑, size is large, so we don't prefer

V_f ↑ - flow velocity is more, losses is more at exit.

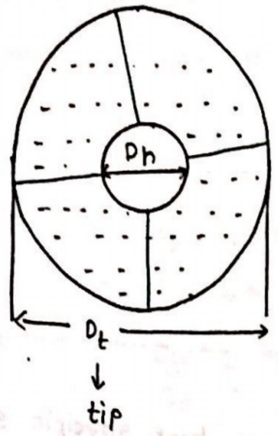
So ↓ Z (No. of blade) is best option to ↑ the discharge.

there are some places where the availability of head is low and at these places to develop a given power ($P = WQH$), $QH = \text{constant}$ and under low heads, discharge showd be high We know that

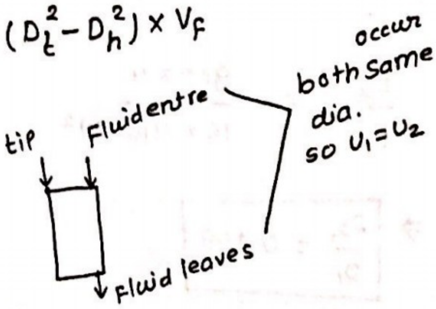
$$Q = (\pi D - Zt) B V_f$$

. Discharge can be increased by increasing the flow velocity but this results in higher exit losses. there the suitable option is to decrease the number of vanes, the runner of a kaplan turbine consist of 4-6 blades.

In kaplan turbine fluids enters axially and leaves axilly if, D_h / D_b is hub or boss diameter and D_t is tip diameter, then the discharge of a kaplan turbine is



$$Q = \frac{\pi}{4}(D_t^2 - D_h^2) \times V_f$$



Note: As the fluid enters and leaves at the same diameter therefore $U_1 = U_2$ in kaplan turbine,

(2) Generally in kaplan turbine $V_{f_1} = V_{f_2}$

Q. A kaplan turbine produces 25 MW power under a head of 40 m the blade tip diameter is 2.5 times hub diameter the overall efficiency is 90%, Speed ratio is 2, flow ratio is 0.6 calculate tip dia., hub meter, speed of the runner.

Solution.

Given that

$P = 25\,MW$

$H = 40\,m$

$D_t = 2.5 D_h$

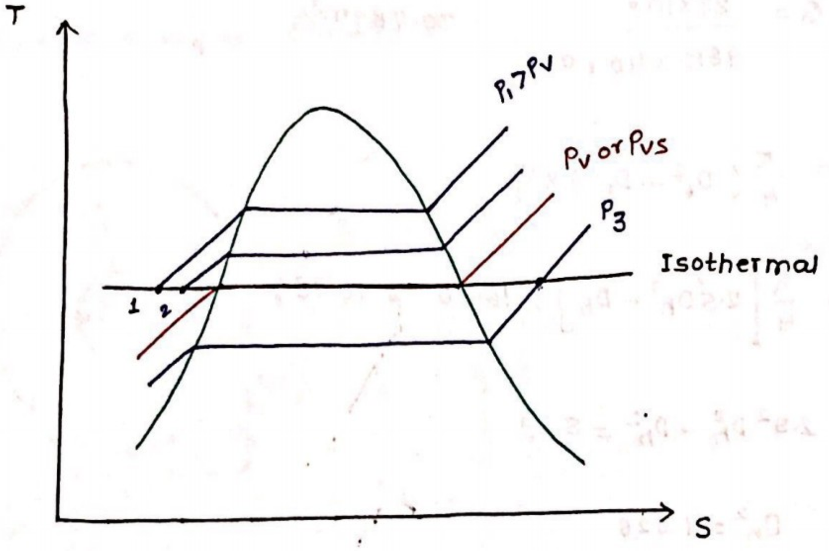
$\eta_o = 0.9$

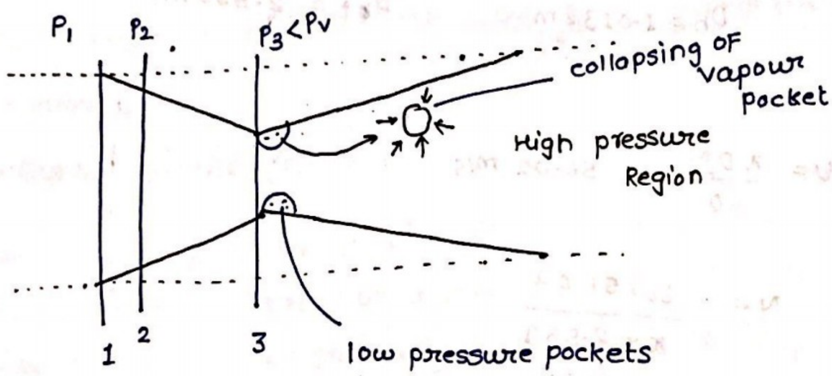
$K_u = 2$ $\qquad K_u = \frac{U_1}{\sqrt{2gH}}$ $\qquad U_1 = K_u\sqrt{2gH}$

$= 2\sqrt{2 \times 9.81 \times 40} = 56.02\,m/s$

$\psi = 2$ $\qquad \psi = \frac{V_f}{\sqrt{2gh}}$ $\qquad V_f = 0.6\sqrt{2 \times 9.81 \times 40} = 16.80\,m/s$

Cavitation





$a_1 v_1 = a_2 v_2$

$a_1 > a_2$

so $V_2 \uparrow$

$a \downarrow$ $v \uparrow$, $P \downarrow$. at point 3 $P_3 < P_v$.

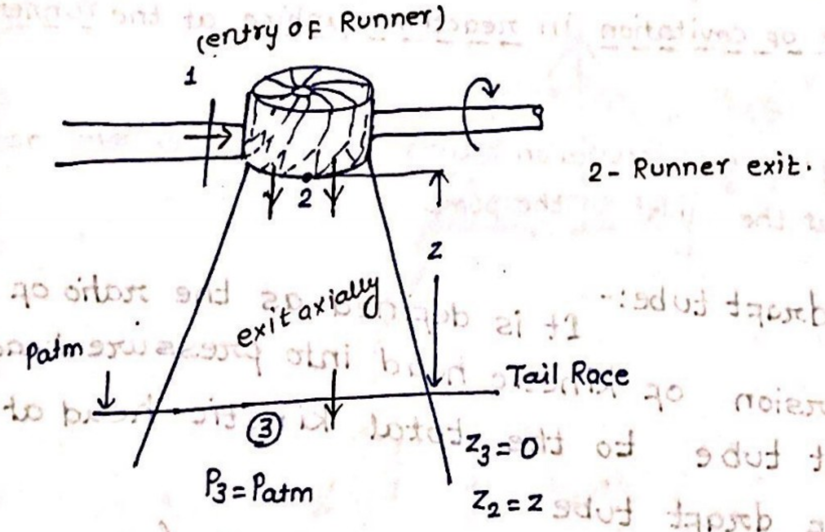
consider ~~the~~ a liquid flowing through a converging and diverging passage under isothermal conditions. When the liquid flows through a converging passage pressure decrease, if the reduction in area is more, then the reduction in pressure is high it may so happen that at some section the pressure is less than vapour pressure. When the pressure is less than vapour pressure, vapour pockets are formed, when these vapour pockets are carried to region of high pressure they collapse. and the surrounding high pressure liquid rushes suddenly in this region (as shown in figure) this results in huge noise and Mechanical demage this phenomenon is known as cavitation.

"Cavitation is a low pressure phenomenon." In order to avoid cavitation the liquid pressure must be greater than vapour pressure'.

The thoma's cavitation factor is given by $(\sigma) = \dfrac{P - P_v}{\frac{\rho v^2}{2}}$

P = local pressure & P_v is vapour pressure.

Draft tube:



Apply bernoulli's equation b/w 2 & 3

$$\frac{P_2}{w} + \frac{V_2^2}{2g} + Z_2 = \frac{P_3}{w} + \frac{V_3^2}{2g} + Z_3$$

$$\frac{P_2}{w} + \frac{V_2^2}{2g} + z = \frac{P_{atm}}{w} + \frac{V_3^2}{2g} + 0$$

$$\frac{P_2}{w} = \frac{P_{atm}}{w} - \left[z + \frac{V_2^2 - V_3^2}{2g}\right] \qquad V_2 > V_3$$

$$\boxed{P_2 < P_{atm}}$$

- Draft tube enables to Install the turbine above the tail race without sacrificing head.
- With the Installation of draft tube, pressure at the runner exit is low, thus it improves the efficiency.
- Draft tube is used in Reaction turbine, in reaction turbine the pressure decreases from more than atmospheric to less than atmospheric.
- As the pressure at the runner exit is low it may so happen that this pressure may fall below vapour pressure and hence there is a chance of cavitation in reaction turbine at the runner exit.

Note: In centrifugal pumps cavitation occurs at the ~~inlet of~~ eye of the impeller or at the inlet to the pump.

efficiency of draft tube:- It is defined as the ratio of actual conversion of kinetic head into pressure head in the draft tube to the total kinetic head at the inlet of draft tube.

$$\eta_{d.T.} = \frac{\left(\frac{V_2^2}{2g} - \frac{V_3^2}{2g}\right)}{V_2^2/2g} = 1 - \frac{V_3^2}{V_2^2} \quad \left\{ h_f \text{ - Neglected)} \right.$$

$$\simeq 60 \text{ to } 85\%$$