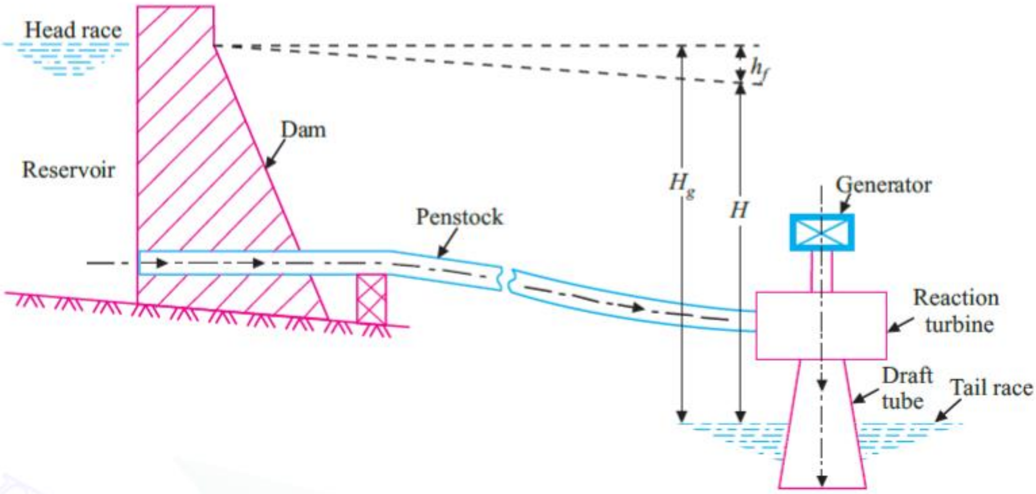
FRANCIS TURBINE

The modern francis turbine is an inward flow rwaction turbine, i.e water under pressure enters the runner from the guide vanes towards the centre in radial direction and discharges out of the runner axially. In the francis turbine the pressure at inlet is more than that at the outlet. Francis turbine runner is always full of water. The moment of runner is affected by the change of both the potential and kinetic energies of water. After doing the work the water is discharged to the tail race through a closed tube of gradually enlarging section. This is known as draft tube.



2.4.1.1. Work done and efficiency of Francis turbine

Net head at the turbine runner : In the Fig. 2.12,

H_g = Gross head = Difference of water levels between head race and tail race;

h_f = Loss of head in the penstock;

H = Net head = $(H_g - h_f)$. The net head is also called *available* or *working* or *operation head*.

Also, $$H = \begin{bmatrix} \text{Total energy available at exit} \\ \text{from the penstock} \end{bmatrix} - \begin{bmatrix} \text{total energy available at exit} \\ \text{from the draft tube} \end{bmatrix}$$

$$= \left(\frac{p}{w} + \frac{V^2}{2g} + z\right)_{\text{penstock}} - \left(\frac{p}{w} + \frac{V^2}{2g} + z\right)_{\text{draft tube}}$$

If the draft tube exit is at tail race level, and the datum is also taken at that level, then,

$$H = \left(\frac{p}{w} + \frac{V^2}{2g} + z\right)_{\text{penstock}} - \frac{V_d^2}{2g}$$

(where, V_d = velocity at the exit of the draft tube)

Neglecting the velocity at the draft tube exit (V_d), we have:

$$H = \left(\frac{p}{w} + \frac{V^2}{2g} + z\right) \qquad ...(2.16)$$

The velocity triangle at inlet and outlet of the Francis turbine are drawn in the same way as in case of inward flow reaction turbine. As in case of Francis turbine, the discharge is radial at outlet, the velocity of whirl at outlet (*i.e.*, V_{w_2}) will be zero. Hence the work done by water on the runner per second will be

$$= \rho Q[V_{w_1} u_1]$$

And work done per second per unit weight of water striking/s $= \frac{1}{g}\left[V_{w_1} u_1\right]$

Hydraulic efficiency will be given by, $\eta_h = \frac{V_{w_1} u_1}{gH}$.

18.8.1 Important Relations for Francis Turbines. The following are the important relations for Francis Turbines :

1. The ratio of width of the wheel to its diameter is given as $n = \frac{B_1}{D_1}$. The value of n varies from 0.10 to .40.

2. The flow ratio is given as,

Flow ratio $= \frac{V_{f_1}}{\sqrt{2gH}}$ and varies from 0.15 to 0.30.

3. The speed ratio $= \frac{u_1}{\sqrt{2gH}}$ varies from 0.6 to 0.9.

Problem 18.23 *A Francis turbine with an overall efficiency of 75% is required to produce 148.25 kW power. It is working under a head of 7.62 m. The peripheral velocity = 0.26 $\sqrt{2gH}$ and the radial velocity of flow at inlet is 0.96$\sqrt{2gH}$. The wheel runs at 150 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) Diameter of the wheel at inlet, and *(iv) Width of the wheel at inlet.*

Solution. Given :

Overall efficiency $\eta_o = 75\% = 0.75$

Power produced, S.P. = 148.25 kW

Head, $H = 7.62$ m

Peripheral velocity, $u_1 = 0.26\sqrt{2gH} = 0.26 \times \sqrt{2 \times 9.81 \times 7.62} = 3.179$ m/s

Velocity of flow at inlet, $V_{f_1} = 0.96\sqrt{2gH} = 0.96 \times \sqrt{2 \times 9.81 \times 7.62} = 11.738$ m/s.

Speed, $N = 150$ r.p.m.

Hydraulic losses = 22% of available energy

Discharge at outlet = Radial

$$V_{w_2} = 0 \text{ and } V_{f_2} = V_2$$

Hydraulic efficiency is given as

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

$$= \frac{H - .22\,H}{H} = \frac{0.78\,H}{H} = 0.78$$

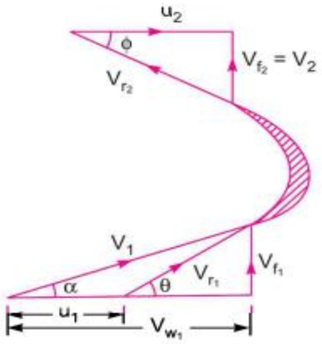


Fig. 18.21

But $\eta_h = \dfrac{V_{w_1} u_1}{gH}$

$\therefore$ $\dfrac{V_{w_1} u_1}{gH} = 0.78$

$\therefore$ $V_{w_1} = \dfrac{0.78 \times g \times H}{u_1}$

$$= \frac{0.78 \times 9.81 \times 7.62}{3.179} = 18.34 \text{ m/s.}$$

(i) The guide blade angle, i.e., α. From inlet velocity triangle,

$$\tan\alpha = \frac{V_{f_1}}{V_{w_1}} = \frac{11.738}{18.34} = 0.64$$

$\therefore$ $\alpha = \tan^{-1} 0.64 = \mathbf{32.619°}$ or **32° 37′. Ans.**

(ii) The wheel vane angle at inlet, i.e., θ

$$\tan\theta = \frac{V_{f_1}}{V_{w_1} - u_1} = \frac{11.738}{18.34 - 3.179} = 0.774$$

$\therefore$ $\theta = \tan^{-1} .774 = \mathbf{37.74}$ or **37° 44.4′. Ans.**

(iii) Diameter of wheel at inlet (D_1).

Using the relation, $u_1 = \dfrac{\pi D_1 N}{60}$

$$D_1 = \frac{60 \times u_1}{\pi \times N} = \frac{60 \times 3.179}{\pi \times 50} = \mathbf{0.4047 \text{ m. Ans.}}$$

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

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

But $\text{W.P.} = \dfrac{\text{WH}}{1000} = \dfrac{\rho \times g \times Q \times H}{1000} = \dfrac{1000 \times 9.81 \times Q \times 7.62}{1000}$

$\therefore$ $\eta_o = \dfrac{148.25}{\dfrac{1000 \times 9.81 \times Q \times 7.62}{1000}} = \dfrac{148.25 \times 1000}{1000 \times 9.81 \times Q \times 7.62}$

or $Q = \dfrac{148.25 \times 1000}{1000 \times 9.81 \times 7.62 \times \eta_o} = \dfrac{148.25 \times 1000}{1000 \times 9.81 \times 7.62 \times 0.75} = 2.644 \text{ m}^3/\text{s}$

Using equation (18.21), $Q = \pi D_1 \times B_1 \times V_{f_1}$

$\therefore$ $2.644 = \pi \times .4047 \times B_1 \times 11.738$

$\therefore$ $B_1 = \dfrac{2.644}{\pi \times .4047 \times 11.738} = \mathbf{0.177 \text{ m. Ans.}}$

Example 2.17. *A reaction turbine works at 450 r.p.m. under a head of 120 m. Its diameter at inlet is 1.2 m and the flow area is 0.4 m^2. The angles made by absolute and relative velocities at inlet are 20° and 60° respectively with the tangential velocity. Determine :*

(i) The volume flow rate,

(ii) The power developed, and

(iii) The hydraulic efficiency. **[PTU]**

Solution.

Speed of turbine, N = 450 r.p.m

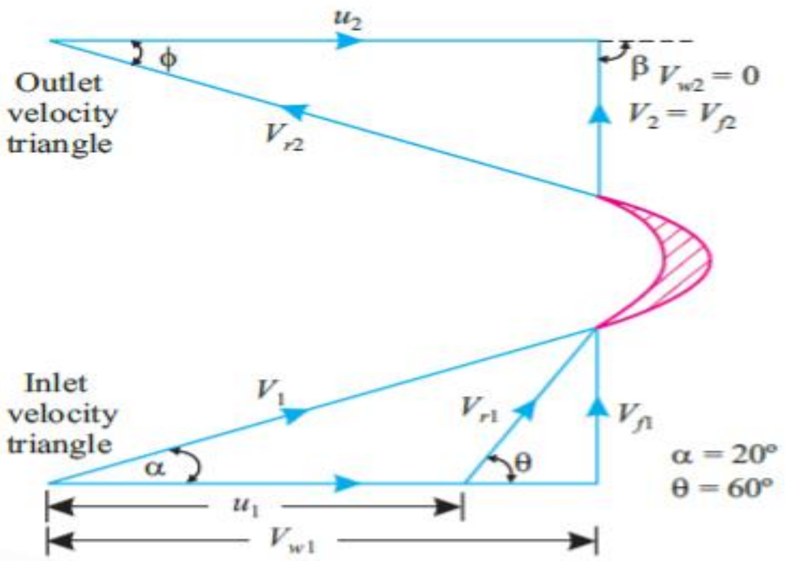
Head, H = 120 m

Diameter at inlet, D_1 = 1.2 m

Flow area, $\pi D_1 B_1$ = 0.4 m^2

Angle made by absolute velocity, α = 20°

Angle made by the relative velocity at inlet, θ = 60°



(i) The volume flow rate, Q :

Tangential velocity of the turbine,

$$u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 1.2 \times 450}{60} = 28.27 \text{ m/s}$$

From inlet velocity triangle, we have:

$$\tan \alpha = \frac{V_{f1}}{V_{w1}}, \quad \text{or,} \quad \tan 20° = \frac{V_{f1}}{V_{w1}}$$

$$\therefore \quad V_{f1} = V_{w1} \tan 20° = 0.364\, V_{w1} \qquad \ldots(i)$$

Also, $$\tan \theta = \frac{V_{f1}}{V_{w1} - u_1} = \frac{0.364\, V_{w1}}{V_{w1} - 28.27} \qquad (\because V_{f1} = 0.364\, V_{w1})$$

or, $$\tan 60° = \frac{0.364\, V_{w1}}{V_{w1} - 28.27}, \text{ or, } 1.732 = \frac{0.364\, V_{w1}}{V_{w1} - 28.27}$$

or, $1.732\,(V_{w1} - 28.27) = 0.364\, V_{w1}$, or, $1.732\, V_{w1} - 48.96 = 0.364\, V_{w1}$

$$\therefore \quad V_{w1} = \frac{48.96}{(1.732 - 0.364)} = 35.79 \text{ m/s}$$

From eqn. (*i*), we have:

$$V_{f1} = 0.364 \times 35.79 = 13.027 \text{ m/s}$$

$\therefore$ Volume flow rate, $Q = \pi D_1 B_1 \times V_{f1}$

But, $\pi D_1 B_1 = 0.4 \text{ m}^2$ ...(*Given*)

$$\therefore \quad Q = 0.4 \times 13.027 = \mathbf{5.211\ m^3/s} \text{ (Ans.)}$$

(ii) Power developed :

Work done per second $= \rho Q (V_{w1} u_1)$ $\quad [\because V_{w2} = 0 \text{ ...Given}]$

$= 1000 \times 5.211 \times 35.79 \times 28.27 = 5272402$ Nm/s or J/s

$\therefore$ Power developed $= 5272402$ J/s, or, $W =$ **5272.4 kW** **(Ans.)**

(iii) The hydraulic efficiency, η_h :

$$\eta_h = \frac{V_{w1} u_1}{gH} \quad \text{...[Eqn (2.19)]}$$

$$= \frac{35.79 \times 28.27}{9.81 \times 120} = 0.8595 = \mathbf{85.95\%} \text{ (Ans.)}$$