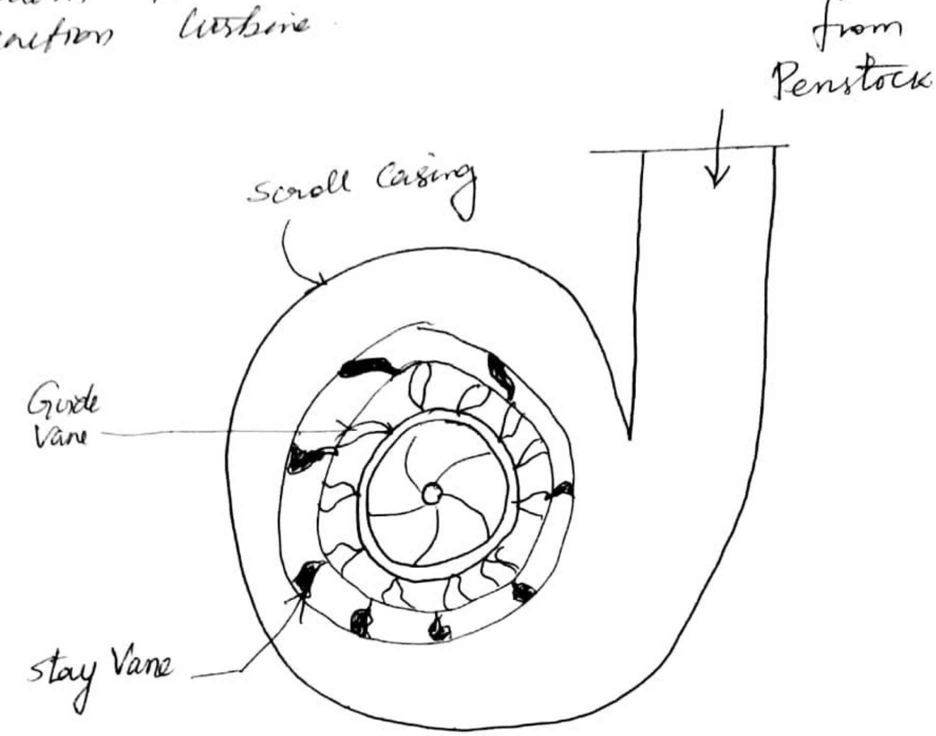
A.

Francis Turbine

* It is an inward flow reaction turbine.
* Modern Francis Turbine is a mixed flow reaction turbine.



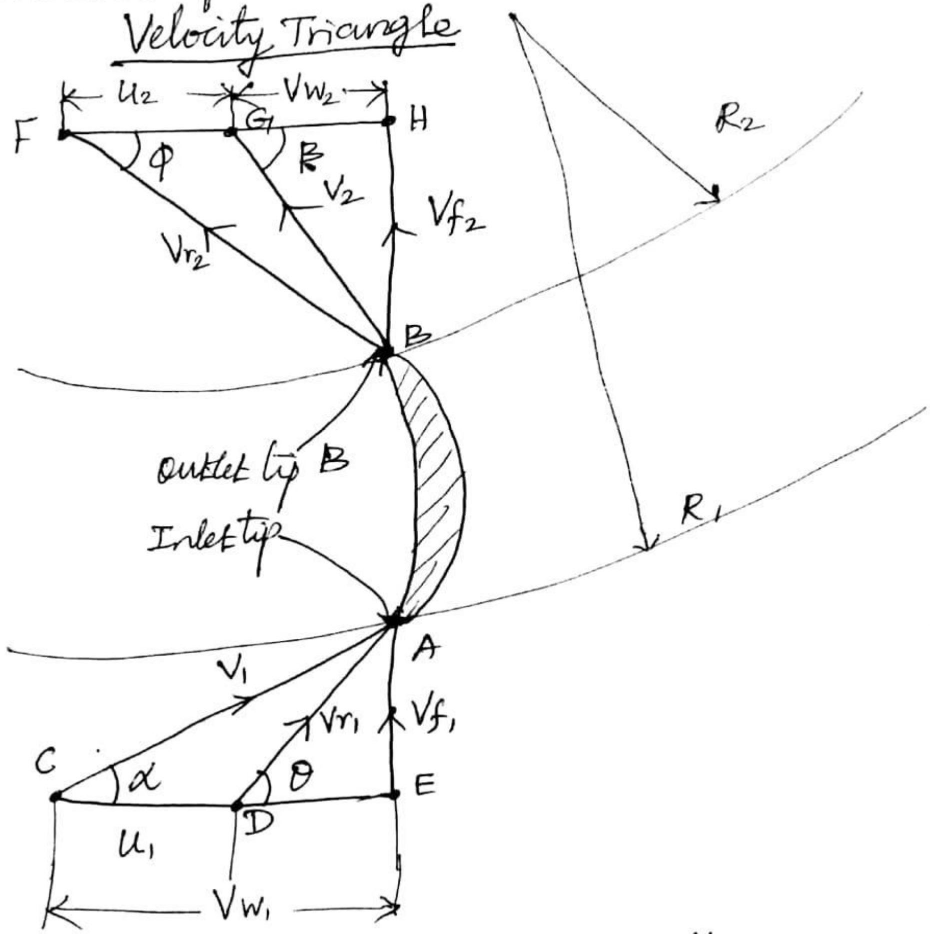
Parts involving

1. Penstock
2. Scroll or Spiral Casing
3. Speed ring or stay ring
4. Guide vanes or wicket gates
5. Runner and runner blades
6. Draft tube

WORK DONE AND EFFICIENCIES OF FRANCIS TURBINE

Illustrates the runner and the velocity diagram for an inward flow reaction i.e Francis turbine

Velocity Triangle



General expression for work done follows from the euler momentum equation with usual notation.

$$\text{Work done} = \rho Q \left(V_{w_1} u_1 \pm V_{w_2} u_2\right)$$

$$= \frac{WQ}{g}\left(V_{w_1} u_1 \pm V_{w_2} u_2\right)$$

$$= \frac{WQ}{g} (V_{w_1} u_1 \pm V_{w_2} u_2)$$

where Q = discharge through the runner

V_{w_1} and V_{w_2} = velocity of whirl at inlet and outlet

u_1 and u_2 = Tangential velocity of wheel at inlet and outlet.

For Maximum output, the runner is so designed that $V_{w_2} = 0$. Therefore

$$\text{Work done} = \frac{WQ}{g} (V_{w_1} u_1)$$

$$W.D = \rho Q V_{w_1} u_1$$

Hydraulic input to the turbine = WQH
where H - net head

(i) Hydraulic efficiency (η_h)

$$\eta_h = \frac{\text{Power developed by the runner}}{\text{Hydraulic input}}$$

$$= \frac{\frac{WQ}{g}(V_{w_1} \times u_1)}{WQH}$$

$$\boxed{\eta_h = \frac{V_{w_1} \times u_1}{gH}}$$

If $V_{w2} \neq 0$ then

$$\eta_h = \frac{V_{f1}}{V_{f2}} = \frac{K_{t2}}{K_{t1}} \frac{\pi D_2 B_2}{\pi D_1 B_1}$$

The value of η_h ranges from 85 to 95%.

2) Mechanical efficiency (η_m)

$$\eta_m = \frac{\text{Power available at the runner shaft}}{\text{Power developed by the runner}}$$

$$\eta_m = \frac{P}{\frac{WQ}{g}(V_{w1} u_1)}$$

If $V_{w2} \neq 0$ then

$$\eta_m = \frac{P}{\frac{WQ}{g}(V_{w1} u_1 - V_{w2} u_2)}$$

3) Overall efficiency (η_o)

$$\eta_o = \frac{\text{Shaft Power}}{\text{Water Power}}$$

$$\eta_o = \frac{P}{WQH}$$

otherwise $\eta_o = \eta_m \times \eta_h$

its value ranges from 80 to 90%.

Design Aspects of Francis Turbine

Ratio of width of diameter $\left(\frac{B}{D}\right)$

The ratio of width B to wheel diameter D is represented by n.

$$\text{i.e } n = \left(\frac{B}{D}\right)$$

(1) Flow ratio (K_f)

The ratio of the velocity of flow at inlet V_{f_1} to the theoretical velocity ($\sqrt{2gh}$) is known as flow ratio.

$$K_f = \frac{V_{f_1}}{\sqrt{2gH}}$$

The value of K_f varies from 0.15 to 0.3

(2) Speed Ratio (K_u)

It is the ratio of the peripheral speed at inlet to the theoretical jet velocity

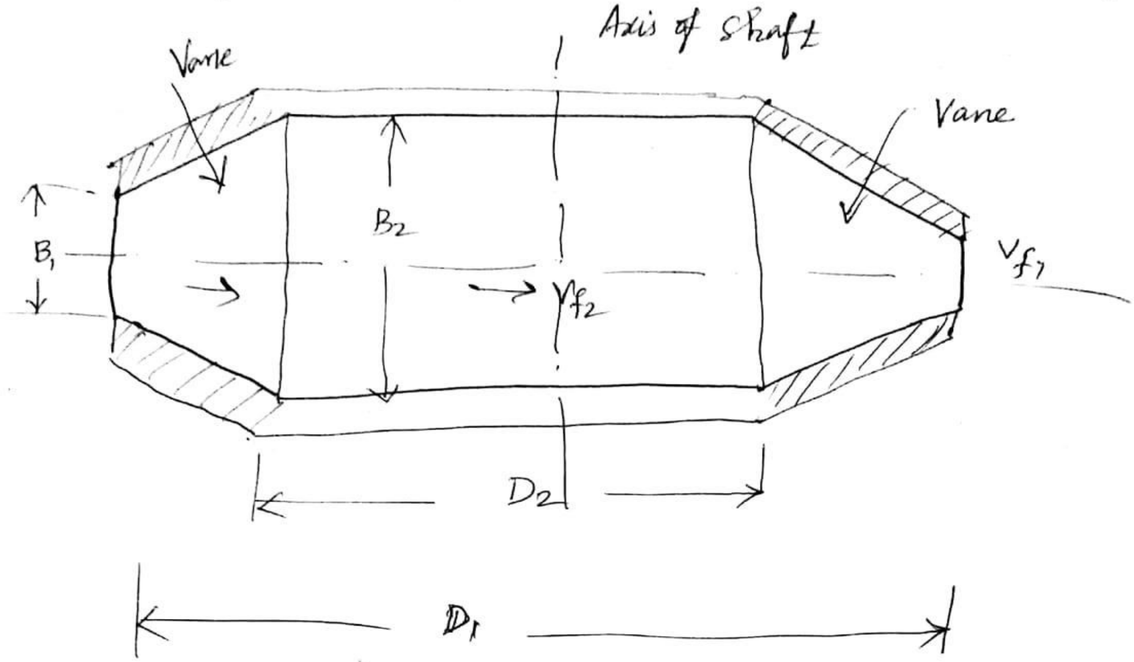
$$K_u = \frac{u}{\sqrt{2gH}}$$ it ranges from 0.6 to 0.9

(3) Design Procedure

Given data: Power to be developed P
Speed N and Head H
Assume suitable values for η_h, η_o, n and K_f

Required: Size of the runner and its vane angle.

· The design procedure involves the following steps



Step 1

The required discharge Q is determined from the relation

$$\eta_0 = \frac{P}{WQH}$$

Step 2

The flow velocity is obtained from the discharge and flow area. Let B_1, D_1 and t_1 respectively be the width, diameter and thickness of the runner vane at inlet. Then total area at the outer periphery.

$$A = (\pi D_1 - Z t_1) B_1$$

$= K_t \; \pi \; D_1 \; B_1$

where Z – Number of Vanes

K_t – Vane thickness Co-efficient

$= 0.95$

Flow velocity $V_{f1} = \dfrac{Q}{K_t \; \pi \; D_1 \; B_1}$

$$V_{f1} = \frac{Q}{K_t \; \pi n \; D_1^2}$$

$$n = \frac{B_1}{D_1}$$

Also

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

Equating the above two equations for V_{f1}

$$K_f \sqrt{2gH} = \frac{Q}{K_t \; \pi n \; D_1^2}$$

$$D_1 = \left[\frac{Q}{K_f \; K_t \; \pi \; n \sqrt{2gH}} \right]^{1/2}$$

From D_1, width $B_1 = n D_1$

Step 3:

The tangential velocity (u_1) is Calculated from the relation

$$u_1 = \frac{\pi D_1 N}{60}$$

Step 4:

The whirl velocity (V_{w1}) is Calculated from the equation.

$$\eta_h = \frac{V_{w1}\, u_1}{gH}$$

$$V_{w1} = \frac{\eta_h\, g H}{u_1}$$

Step 5

By using inlet velocity triangle, the angle of guide blade (α) and the runner blade (θ) at the inlet are obtained.

$$\tan\alpha = \frac{V_{f1}}{V_{w1}}$$

$$\tan\theta = \frac{V_{f1}}{V_{w1} - u_1}$$

Step 6

Assume runner diameter D_2 at the outlet is assumed to be approximately one-half of the diameter at inlet

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

$$u_2 = \frac{u_1}{2}$$

Step 7

By using continuity equation, the flow velocity of exit (V_{f2}) is found as

$$Q = K_{t1}\,\pi D_1 B_1 V_{f1}$$

$$= K_{t2}\,\pi D_2 B_2 V_{f2}$$

$$\boxed{\frac{V_{f1}}{V_{f2}} = \frac{K_{t2}\,\pi D_2 B_2}{K_{t1}\,\pi D_1 B_1}}$$

Generally it is assumed that $V_{f1} = V_{f2}$ and $K_{t1} = K_{t2}$ that gives $B_2 = 2B_1$

Step 8

The radial discharge at the runner exit $\beta = 90^\circ$ is assumed and the runner blade angle ϕ is obtained from the outlet velocity triangle.

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

Step 9

The number of runner vanes should be either one more or one less than the number of guide vanes in order to avoid setting up of periodic impulse

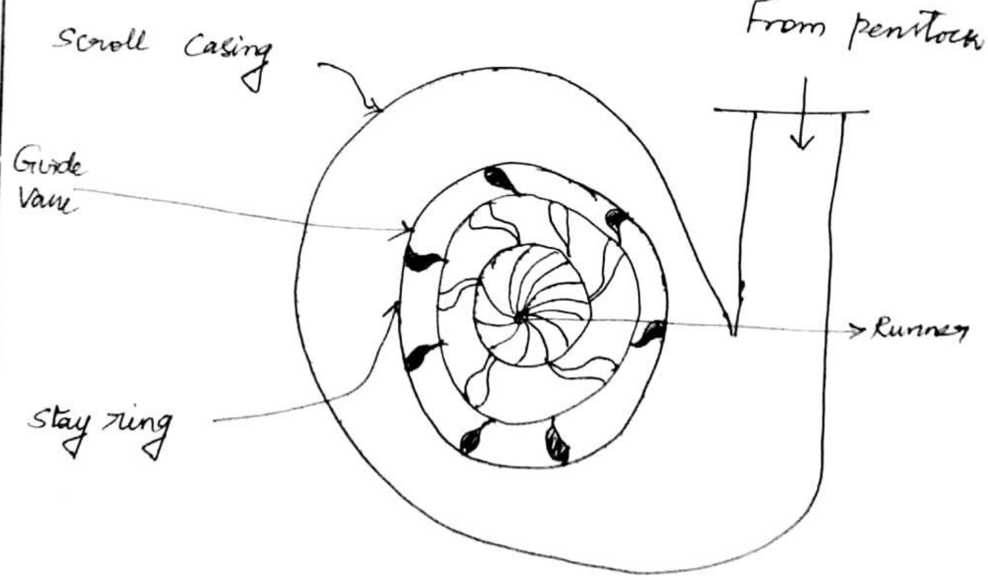
PROPELLER TURBINE:

The Propeller turbine is an axial flow reaction turbine which is mainly suitable for low head (upto 30m) and high flow rate installations such as barrages in rivers.

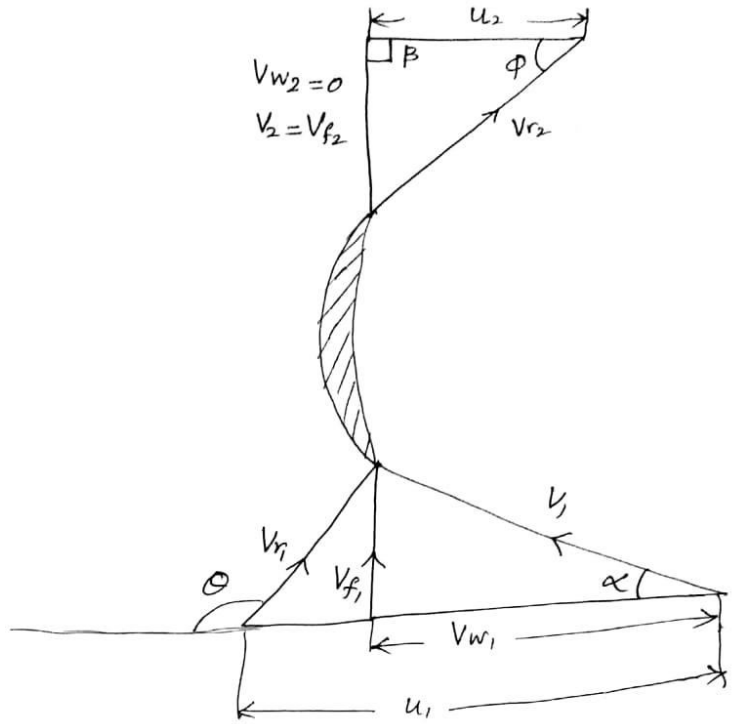
Kaplan Turbine:

+ Axial Flow reaction turbine – suitable for relatively low heads.
- It requires Large quantity of water to develop Large power.

Consists of a hub fixed to the shaft. on the hub, the adjustable Vanes are fixed.



It is drawn Similar to francis Turbine.



Working Properties of kaplan Turbine:

W.D, η, P } by kaplan Turbine = francis Turbine

Deviations are

(i) In case of kaplan turbine the ratio $n = \frac{D_b}{D_o}$

D_b – diameter of the Hub or boss

D_o – outside Diameter of the runner.

The value of n usually varies from 0.35 to 0.6

(ii) Discharge Q = Area of flow × velocity of flow

$$Q = \frac{\pi}{4}\left(D_o^2 - D_b^2\right) \times V_f$$

$$Q = \frac{\pi}{4}\left(D_o^2 - D_b^2\right) \times K_f\sqrt{2gH}$$

$$Q = \frac{\pi}{4} D_o^2\left(1 - n^2\right) \times K_f\sqrt{2gH}$$

$$\left(\because\ n = \frac{D_b}{D_o}\right)$$

The value of flow ratio K_f for a Kaplan turbine is around 0.70

(iii) The peripheral velocity u of the runner is dependent on the radius of the point under consideration and thus, it varies from section to section along the blade.

In order to have shock free entry and exit of water, the blade angles vary from section to section.

The blade angles are greater at the outer tip than the hub and thus the runner blades of a Kaplan turbine are wrapped or twisted.

(iv) The velocity of flow V_f remains constant throught

$$(\text{i.e } V_{f_1} = V_{f_2} = V_f)$$

Difference between Francis and Kaplan Turbine:

	Francis Turbine	Kaplan Turbine
1.	Mixed flow reaction turbine	Axial flow reaction Turbine
2.	Runner Vanes are not adjustable	Runner vanes are adjustable.
3.	Large No. of vanes (16 to 24)	Less no of vanes (3 to 8)
4.	Medium head Turbines (60m to 250m)	Low head Turbine (upto 30m)
5.	Medium Speific Speed (50 to 250)	High Speific Speed (250 to 850)

Discussion:

Differentiate between Francis and Kaplan turbine.

Ans.

Francis turbine	Kaplan turbine
1. Radially inward, mixed flow.	Purely axial flow turbine.
2. Position of shaft can be horizontal or vertical.	Only vertical shaft disposition.
3. Runner vanes are not adjustable.	Runner vanes are adjustable.
4. Large no. of vanes, (16–24) blades.	Small no. of vanes, (3–8) blades.
5. Medium head, medium flow.	Low head, large volume flow.
6. Specific speed from 50–250.	Specific speed from 250–850.