Hydraulic Turbine

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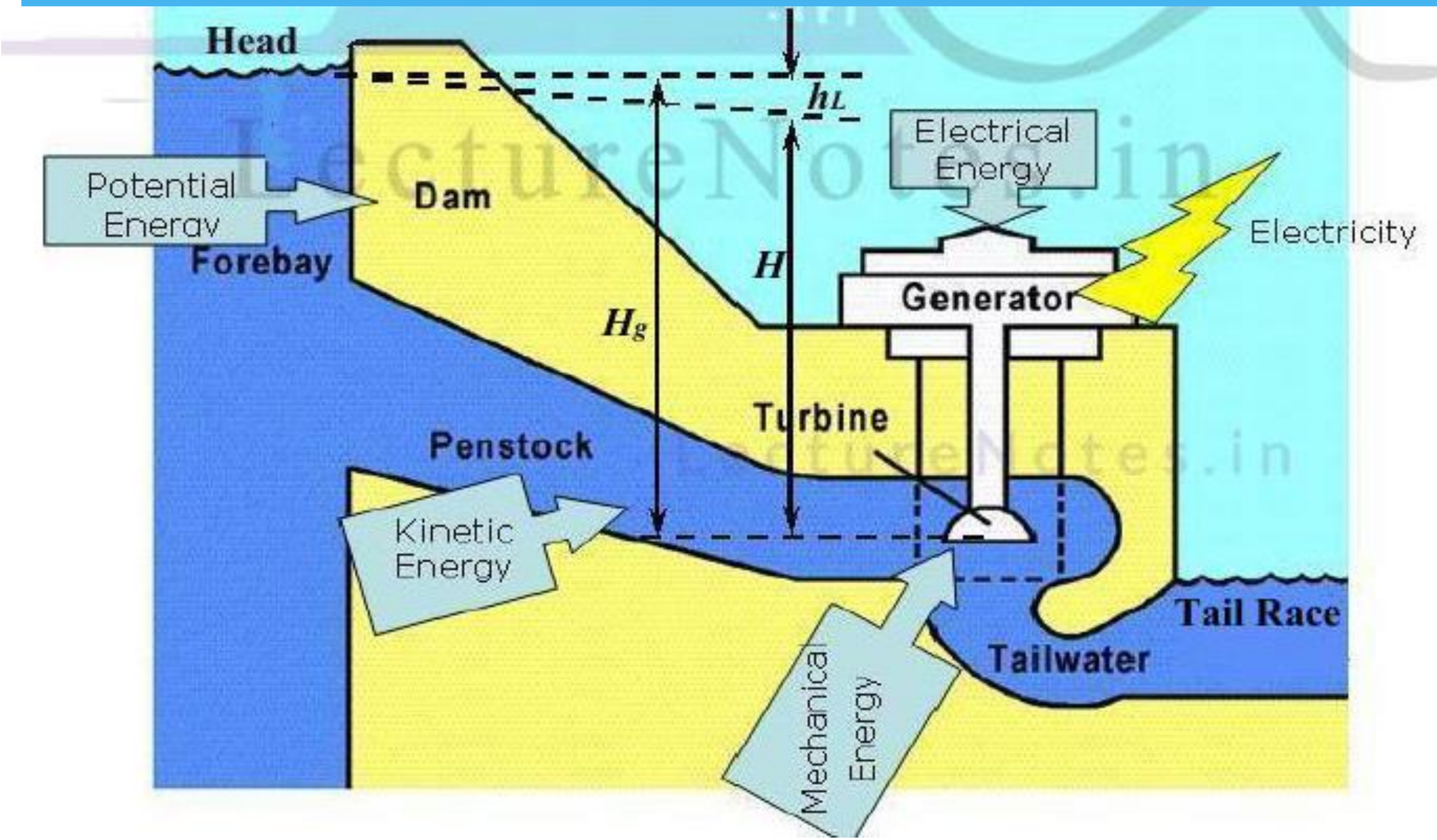
TURBINES

* The device which converts hydraulic energy into mechanical energy is known as Hydraulic Machines.
* The hydraulic machine which converts the hydraulic energy into mechanical energy is known as turbine.



Power plant



Head
hL
Electrical Energy
Potential Energy
Dam
Electricity
Forebay
H
Generator
Hg
Turbine
Penstock
Kinetic Energy
Mechanical Energy
Tail Race
Tailwater

Segments of a Power Plant

1.Dam

2.Headrace- the reservoir is known as Headrace.

3.Penstoke- pipe of larger diameter which carry the water under pressure .

4.Turbine-Converts the hydraulic energy into mechanical energy.

5.Tailrace- water surface level at down stream site is termed as tailrace.

Segments of a Power Plant

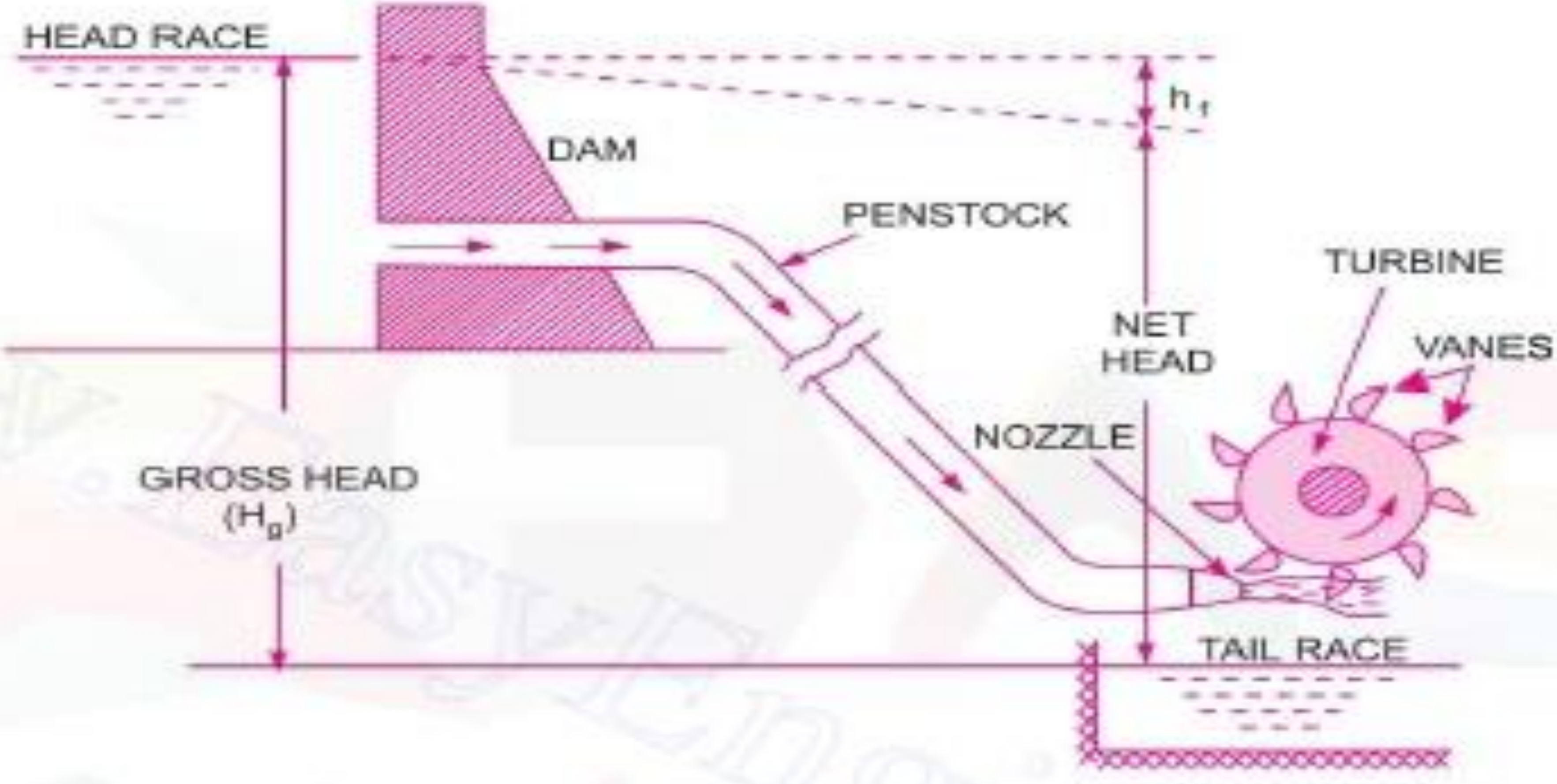


Fig. 18.1 *Layout of a hydroelectric power plant.*

Important Definitions

- **Gross head (Hg)** –It is the vertical difference between head race and tail race.

- **Net head (H)**-Net head or effective head is the actual head available at the inlet of a turbine.

$$H = H_g - h_f$$

H_g = Gross head, $h_f = \dfrac{4 \times f \times L \times V^2}{D \times 2g}$,

V = Velocity of flow in penstock,

L = Length of penstock,

D = Diameter of penstock.

3. Efficiencies of a Turbine. The following are the important efficiencies of a turbine.

(*a*) Hydraulic Efficiency, η_h (*b*) Mechanical Efficiency, η_m

(*c*) Volumetric Efficiency, η_v and (*d*) Overall Efficiency, η_o

(*a*) **Hydraulic Efficiency (η_h).** It is defined as the ratio of power given by water to the runner of a turbine (runner is a rotating part of a turbine and on the runner vanes are fixed) to the power supplied by the water at the inlet of the turbine. The power at the inlet of the turbine is more and this power goes on decreasing as the water flows over the vanes of the turbine due to hydraulic losses as the vanes are not smooth. Hence, the power delivered to the runner of the turbine will be less than the power available at the inlet of the turbine. Thus, mathematically, the hydraulic efficiency of a turbine is written as

$$\eta_h = \frac{\text{Power delivered to runner}}{\text{Power supplied at inlet}} = \frac{\text{R.P.}}{\text{W.P.}} \qquad \text{...(18.2)}$$

(*b*) **Mechanical Efficiency (η_m).** The power delivered by water to the runner of a turbine is transmitted to the shaft of the turbine. Due to mechanical losses, the power available at the shaft of the turbine is less than the power delivered to the runner of a turbine. The ratio of the power available at the shaft of the turbine (known as S.P. or B.P.) to the power delivered to the runner is defined as mechanical efficiency. Hence, mathematically, it is written as

$$\eta_m = \frac{\text{Power at the shaft of the turbine}}{\text{Power delivered by water to the runner}} = \frac{\text{S.P.}}{\text{R.P.}} \quad \text{...(18.4)}$$

(*c*) **Volumetric Efficiency (η_v).** The volume of the water striking the runner of a turbine is slightly less than the vloume of the water supplied to the turbine. Some of the volume of the water is discharged to the tail race without striking the runner of the turbine. Thus the ratio of the volume of the water actually striking the runner to the volume of water supplied to the turbine is defined as volumetric efficiency. It is written as

$$\eta_v = \frac{\text{Volume of water actually striking the runner}}{\text{Volume of water supplied to the turbine}} \quad \text{...(18.5)}$$

Classification of Turbines

The h ydraulic turbines can be classified based on t ype of energy at the inlet, direction of flow through the vanes, head available at the inlet, discharge through the vanes and specific speed . They can b e arranged as per the following table:

Turbine		Type of energy	Head	Discharge	Direction of flow	Specific Speed
Name	Type					
Pelton Wheel	Impulse	Kinetic	High Head > 250m to 1000m	Low	Tangential to runner	Low <35 Single jet 35 – 60 Multiple jet
Francis Turbine	Reaction Turbine	Kinetic + Pressure	Medium 60 m to 150 m	Medium	Radial flow Mixed Flow	Medium 60 to 300
Kaplan Turbine			Low < 30 m	High	Axial Flow	High 300 to 1000

CLASSIFICATION OF TURBINES

* If at the inlet of turbine the energy available is only kinetic energy, the
* turbine is known as **Impulse Turbine.**
* If at the inlet of turbine water possesses kinetic energy as well as
* pressure energy, the turbine is known as **Reaction Turbine.**
* If water flows along the tangent of runner,the turbine is known as **Tangential flow turbine.**

CLASSIFICATION OF TURBINES

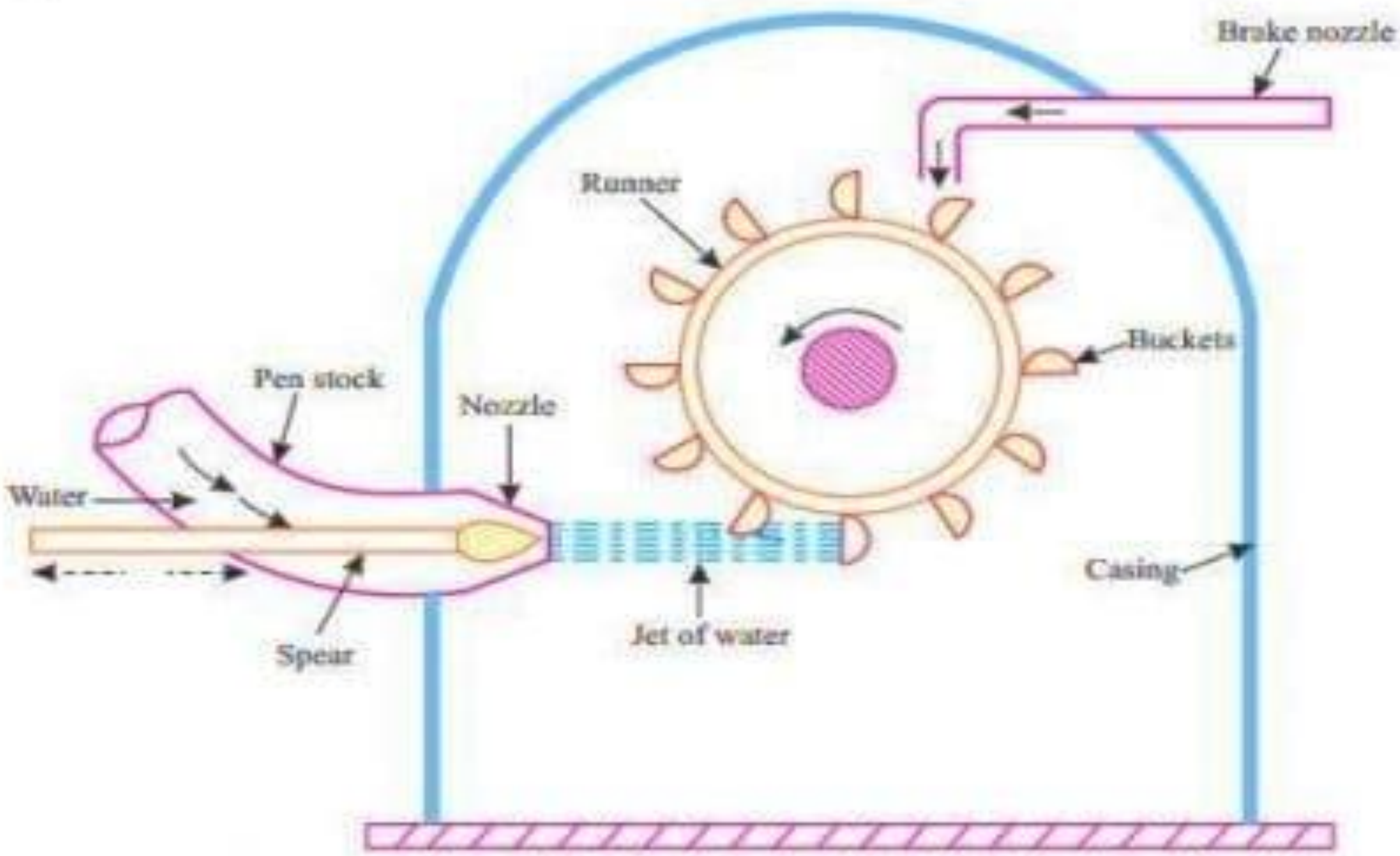
* If the water flows in radial direction through the runner,the turbine is known as **Radial flow turbine.**
* If the water flows from outward to inward radiially,the turbine is known as Inward radial flow turbine.
* If the water flows from inward to outward raidially,the turbine is known as Outward radial flow turbine.
* If water flows along the direction parallel to the axis of rotation of runner, the turbine is known as **Axial flow turbine.**
* If water flows in radial direction but leaves in the direction parallel to
* the axis of rotation, the turbine is known as **Mixed flow turbine**

Pelton Wheel Turbine

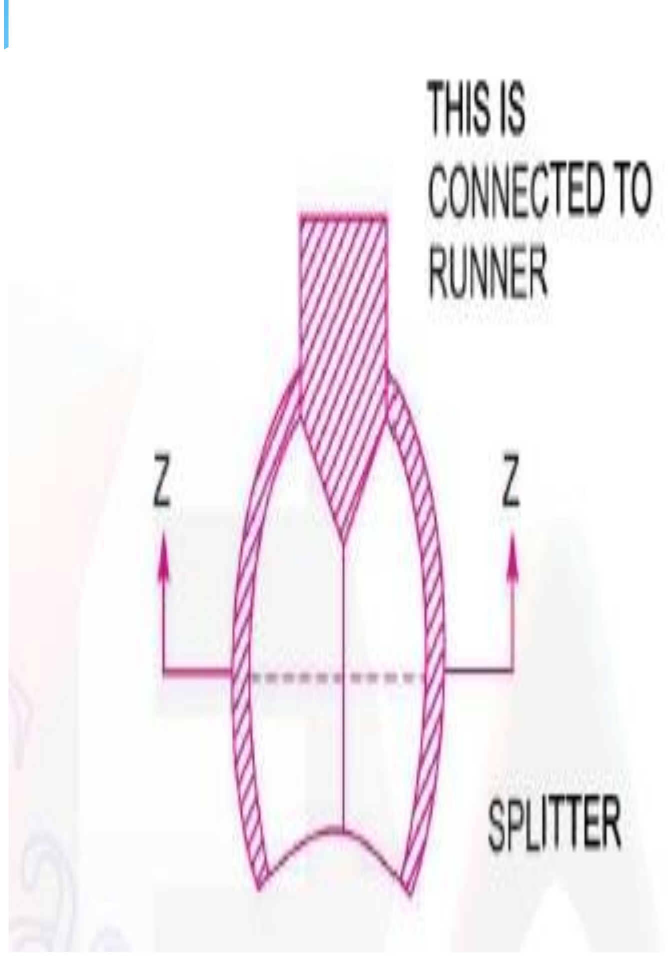
* Developed by An American Engineer L.A.Pelton.
* It is a tangential flow impulse turbine.
* In pelton wheel turbine energy is kinetic at the inlet of bucket .
* Pressure at the inlet & outlet is atmospheric.
* Pelton turbine is suitable for high head and low flow rate.

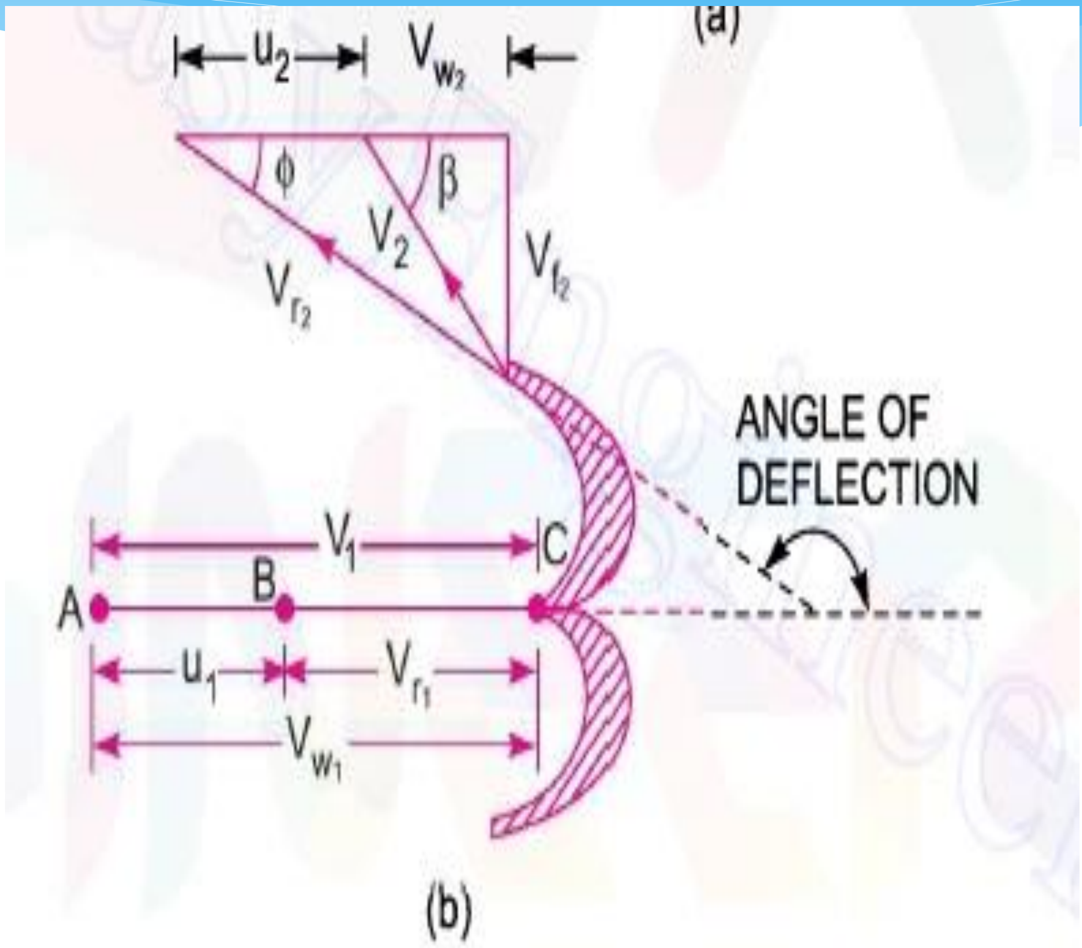
Pelton turbine

Pelton turbine



Velocity triangle of Pelton turbine





Velocity triangle of Pelton turbine

Let V_1 = Velocity of the jet at inlet.

u_1 = Velocity of the plate (vane) at inlet.

V_{r_1} = Relative velocity of jet and plate at inlet.

α = Angle between the direction of the jet and direction of motion of the plate, also called guide blade angle.

θ = Angle made by the relative velocity (V_{r_2}) with the direction of motion at inlet also called vane angle at inlet.

V_{w_1} and V_{f_1} = The components of the velocity of the jet V_1, in the direction of motion and perpendicular to the direction of motion of the vane respectively.

V_{w_1} = It is also known as velocity of whirl at inlet.

V_{f_1} = It is also known as velocity of flow at inlet.

V_2 = Velocity of the jet, leaving the vane or velocity of jet at outlet of the vane.

u_2 = Velocity of the vane at outlet.

V_{r_2} = Relative velocity of the jet with respect to the vane at outlet.

β = Angle made by the velocity V_2 with the direction of motion of the vane at outlet.

ϕ = Angle made by the relative velocity V_{r_2} with the direction of motion of the vane at outlet and also called vane angle at outlet.

V_{w_1} and V_{f_1} = Components of the velocity V_2, in the direction of motion of vane and perpendicular to the direction of motion of vane at outlet.

V_{w_2} = It is also called the velocity of whirl at outlet.

V_{f_2} = Velocity of flow at outlet.

From the velocity triangle at outlet, we have

$$V_{r_2} = V_{r_1} \text{ and } V_{w_2} = V_{r_2} \cos \phi - u_2.$$

The force exerted by the jet of water in the direction of motion is given by equation (17.19) as

$$F_x = \rho a V_1 [V_{w_1} + V_{w_2}] \qquad \text{...(18.8)}$$

As the angle β is an acute angle, +ve sign should be taken. Also this is the case of series of vanes, the mass of water striking is $\rho a V_1$ and not $\rho a V_{r_1}$. In equation (18.8), 'a' is the area of the jet which is given as

$$a = \text{Area of jet} = \frac{\pi}{4} d^2.$$

Now work done by the jet on the runner per second

$$= F_x \times u = \rho a V_1 [V_{w_1} + V_{w_2}] \times u \text{ Nm/s} \qquad \text{...(18.9)}$$

Power given to the runner by the jet

$$= \frac{\rho a V_1 \left[V_{w_1} + V_{w_2}\right] \times u}{1000} \text{ kW} \qquad \text{...(18.10)}$$

Work done/s per unit weight of water striking/s

$$= \frac{\rho a V_1 \left[V_{w_1} + V_{w_2}\right] \times u}{\text{Weight of water striking/s}}$$

$$= \frac{\rho a V_1 \left[V_{w_1} + V_{w_2}\right] \times u}{\rho a V_1 \times g} = \frac{1}{g} \left[V_{w_1} + V_{w_2}\right] \times u \qquad \text{...(18.11)}$$

The energy supplied to the jet at inlet is in the form of kinetic energy and is equal to $\frac{1}{2}mV^2$

$$\therefore \quad \text{K.E. of jet per second} = \frac{1}{2}(\rho a V_1) \times V_1^2$$

$$\therefore \quad \textbf{Hydraulic efficiency}, \quad \eta_h = \frac{\text{Work done per second}}{\text{K.E. of jet per second}}$$

$$= \frac{\rho a V_1\left[V_{w_1} + V_{w_2}\right] \times u}{\frac{1}{2}(\rho a V_1) \times V_1^2} = \frac{2\left[V_{w_1} + V_{w_2}\right] \times u}{V_1^2} \qquad \text{...(18.12)}$$

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

$\therefore \quad V_{r_2} = (V_1 - u)$

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

Substituting the values of V_{w_1} and V_{w_2} in equation (18.12),

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

$$= \frac{2\left[V_1 - u + (V_1 - u)\cos\phi\right] \times u}{V_1^2} = \frac{2(V_1 - u)\left[1 + \cos\phi\right]u}{V_1^2}. \qquad \text{...(18.13)}$$

Points to be Remembered for Pelton Wheel

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

where C_v = Co-efficient of velocity = 0.98 or 0.99

H = Net head on turbine

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

where ϕ = Speed ratio. The value of speed ratio varies from 0.43 to 0.48.

(*iii*) The angle of deflection of the jet through buckets is taken at 165° if no angle of deflection is given.

(*iv*) The mean diameter or the pitch diameter D of the Pelton wheel is given by

$$u = \frac{\pi DN}{60} \text{ or } D = \frac{60u}{\pi N}.$$

(*v*) **Jet Ratio.** It is defined as the ratio of the pitch diameter (D) of the Pelton wheel to the diameter of the jet (d). It is denoted by 'm' and is given as

$$m = \frac{D}{d} \text{ (= 12 for most cases)} \quad \text{...(18.16)}$$

(*vi*) Number of buckets on a runner is given by

$$Z = 15 + \frac{D}{2d} = 15 + 0.5\text{ m} \quad \text{...(18.17)}$$

where m = Jet ratio

(*vii*) **Number of Jets.** It is obtained by dividing the total rate of flow through the turbine by the rate of flow of water through a single jet.

Problem *A Pelton wheel has a mean bucket speed of 10 metres per second with a jet of water flowing at the rate of 700 litres/s under a head of 30 metres. The buckets deflect the jet through an angle of 160°. Calculate the power given by water to the runner and the hydraulic efficiency of the turbine. Assume co-efficient of velocity as 0.98.*

Solution. Given :

Speed of bucket, $u = u_1 = u_2 = 10$ m/s

Discharge, $Q = 700$ litres/s $= 0.7$ m^3/s, Head of water, $H = 30$ m

Angle of deflection $= 160°$

∴ Angle, $\phi = 180° - 160° = 20°$

Co-efficient of velocity, $C_v = 0.98$.

The velocity of jet, $V_1 = C_v\sqrt{2gH} = 0.98\sqrt{2 \times 9.81 \times 30} = 23.77$ m/s

$$\therefore \quad V_{r_1} = V_1 - u_1 = 23.77 - 10 = 13.77 \text{ m/s}$$

$$V_{w_1} = V_1 = 23.77 \text{ m/s}$$

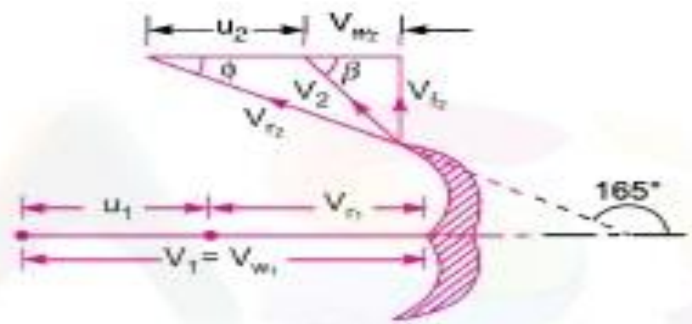


Fig. 18.6

From outlet velocity triangle,

$$V_{r_2} = V_{r_1} = 13.77 \text{ m/s}$$

$$V_{w_2} = V_{r_2}\cos\phi - u_2 = 13.77 \cos 20° - 10.0 = 2.94 \text{ m/s}$$

Work done by the jet per second on the runner is given by equation (18.9) as

$$= \rho a V_1 \left[V_{w_1} + V_{w_2}\right] \times u$$

$$= 1000 \times 0.7 \times [23.77 + 2.94] \times 10 \qquad (\because \quad aV_1 = Q = 0.7 \text{ m}^3/\text{s})$$

$$= 186970 \text{ Nm/s}$$

∴ Power given to turbine $= \dfrac{186970}{1000} =$ **186.97 kW. Ans.**

The hydraulic efficiency of the turbine is given by equation (18.12) as

$$\eta_h = \frac{2\left[V_{w_1} + V_{w_2}\right] \times u}{V_1^2} = \frac{2[23.77 + 2.94] \times 10}{23.77 \times 23.77}$$

$$= \mathbf{0.9454} \quad \text{or} \quad \mathbf{94.54\%}. \textbf{ Ans.}$$

Refrence

* Fluid Mechanics by Dr. R.K. Bansal.
* JNTU Heroes Lecturesnotes.in .
* www.learnengineering.org .