TURBO MACHINERY

Force Exerted by a Jet on a Moving Flat Plate

A moving Flat Plate held Normal to a Jet

$$Fx = \rho a(v - u)^2$$

Work done per second on the plate,

$$W = \rho a(v - u)^2 \times u$$

A Moving Flat Plate held Inclined to a Jet

$$Fx = \rho(v - u)^2 \sin\theta$$

$$W = \rho a(v - u)^2 \sin\theta \times u$$

Force Exerted on a Moving Curved Plate or Vane

Single Vane

$$Fx = \rho a(v - u)^2 (1 + \cos\theta)$$
$$W = \rho a(v - u)^2 (1 + \cos\theta)u$$

Efficiency,

$$\eta = \frac{2(v - u)^2 (1 + \cos\theta)\, u}{v^3}$$

Hydraulic Turbines

A hydraulic turbines is a hydraulic (or fluid machine) that converts hydraulic energy (energy possessed by water) into mechinical energy which can be further utilized to generate electric power.

In a hydraulic turbine, a wheel on which blades or buckets are mounted is directed against a flow of water to alter the momentum of the flowing water. As the momentum is changed with the passage of the water through the wheel, the resulting force rotates the shaft of the wheel performing work to generate power. Hydraulic turbines belong to the category of rotodynamic machines.

Classification of Hydraulic Turbines

Several criteria are used to classify hydraulic turbines, some of which are given below :

1. According to the action of water on the turbine blades
   (i) Impulse turbine : In an impulse turbine, e.g., Pelton wheel, at the supply nozzle the total head of the incoming fluid is converted into large velocity head in the form of a high velocity jet that strikes the buckets. This leads

to the rotation of the wheel. The pressure all over the wheel is constant and equal to atmospheric pressure so that energy transfer occurs due to purely impulse action. At the inlet of this type of turbine, only kinetic energy is available.

(ii) Recation turbines : Reaction turbines, e.g., Francis Kaplan and Propeller turbines always runs full where the water enters the turbine under pressure. The rotation of runner or rotor is partly due to impulse action and partly due to change in pressure over the runner blades. At the inlet of this type of turbine, water possesses both kinetic and pressure energy.

2. According to the head at inlet of turbine

(i) High-head turbine : In this type of turbine, net head varies from 150 m to 2000 m or more and they require a small quantity of water. For example, Petron wheel.

(ii) Medium-head turbine : The net head varies from 30 m to 150 m and the requirement is a moderate quantity of water for this type of turbines. For example, Francis turbine.

(iii) Low-head turbine : For this type of turbines, the net head is less than 30 m and the requirement is a large quantity of water. For example , Kaplan turbine.

3. According to the direction of How through the runner

(i) Tangential flow turbine : In this type of turbine, water flows tangentially to the runner. For example, Pelton turbine.

(ii) Radial flow turbine : In this type of turbine, water flows in the radial direction. It is further classified. It is further classified as

Inward radial flow turbine : Here water flows radially from outwards to inwards. For example, old Francis turbine.

Outward radial flow turbine : Here water flows radially from inwards to outwards. For example, Fourneyron turbine.

(iii) Axial flow turbine : In this type of turbine, water flows parallely to the axis of rotation of the runner. For example, kaplan turbine.

(iv) Mixed floe turbine : In this type of turbine, water flows through the runner and leaves axially, i.e., parallel to the axis of rotation of the runner. For example, modern Francis turbines.

4. According to specific speed

(i) Low specific speed turbine : In these turbines, the specific speed is less than 50 (varying from 10 to 35 for single jet and upto 50 for double jet). For example, Pelton wheel.

(ii) Medium specific speed turbines : the specific speed varies from 50 to 250 for these turbines. For example, Francis turbine.

Pelton Wheel

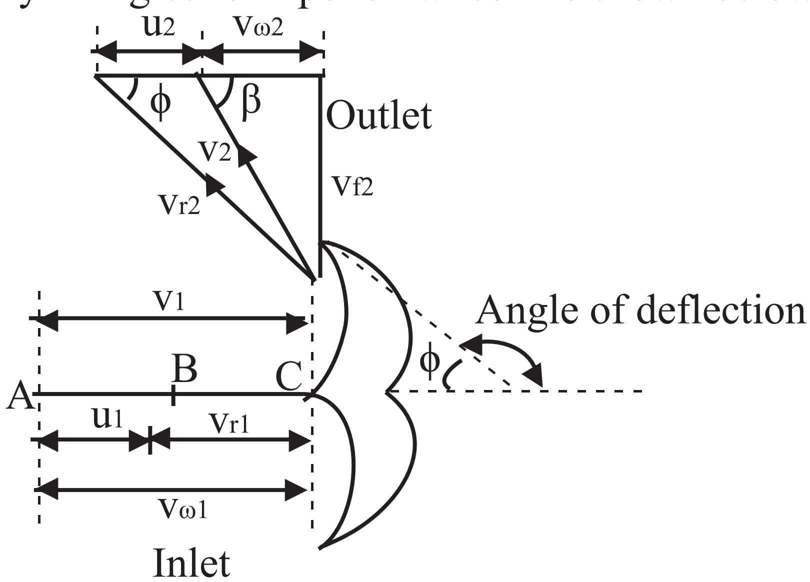
The pelton wheel (or pelton turbine) is a tangential flow impulse turbine. Water from a reservoir flows through penstocks at the outlet of which a nozzle is fitted. The nozzle increases the kinetic energy of the water flowing through the penstocks. At the outlet of the nozzle, water comes out in the form of a jet and strikes the buckets (or vanes) of the runner. This causes the rotation of the runner wherein the kinetic energy gets converted to mechanical energy.

The important parts of a pleton wheel other than the nozzle are :

1. Rotor : At the periphery of the rotor, equally spaced double hemispherical or double ellipsoidal buckets are mounted.
2. Needle spear : It is present in the nozzle and functions to control of the water flow through the nozzle and to provide a smooth flow with negligible losses.
3. Casing : If functions to prevent splashing of water and to discharge water to the tail race.
4. Brake nozzle : if functions to stop the runner in a short time by directing a jet of water, called the braking jet, on the back of the vanes.

Velocity Triangkes of a Pelton Wheel

A velocity triangle or velocity diagram is a triangle representing the various components of velocities of the working fluidin a turbo machine. The inlet and outlet velocity triangles for a pelton wheel are shown below :



$$u_1 = u_2 = u = \frac{\pi DN}{60}$$

Where N is the speed of the wheel in rpm and D is the diameter of the wheel.

Guide angle (α), the angle between the direction of the jet and direction of motion of the vane/ bucket is zero.

Efficiencies of a Turbine

Let P_i be the power supplied at the turbine inlet by the water jet water power, P_r be the power delivered to the runner by the water or power developed by the runner and P_s be the power available at the turbine shaft (Shaft power).

Hydraulic efficiency (η_h)

$$\eta_\eta = \frac{P_r}{P_i} = \frac{P_r}{\rho g Q H}$$

Where Q is the volume flow rate of the water supplied the jet to the turbine.

$$\eta_\eta = \frac{\text{Work done per second}}{\text{Kinetic energy of jet per second}}$$

$$= \frac{\rho Q g(v_{\omega 1} + v_{\omega 2}) \times u}{g \frac{1}{2} (\rho a v_1) v_1^2}$$

$$\eta_h = \frac{2(v_{\omega 1} + v_{\omega 2}) \times u}{v_1^2}$$

$$= \frac{2(v_1 - u)(1 + k\cos\phi)u}{v_1^2}$$

Euler head or runner head (Hr) It represents the energy transfer per unit weight of water.

$$H_r = \frac{1}{g}(v_{w1} + v_{w2})u$$

$$H - H_r = \Delta H$$

Where ΔH is the hydraulic losses within the turbine.

Reaction Turbines

In reaction turbines, as water flows through the stationary parts of the turbine, whole of its pressure energy is not transformed into kinetic energy.

Francis Turbine

The main parts of a Francis turbine are :

1. Spiral/ scroll casing : It constitutes a closed passage whose cross-sectional area gradually decreases along the direction of flow where the area is

maximum at inlet and minimum at exit.
2. Guide vanes/ wicket gates : The vane direct the water into the runner at the desired angle.
3. Runner and runner blades
4. Draft tube : It is gradually expanding tube which discharges water from the runner to the tail race.

Important Points for a Propeller or Kaplan Turbine

1. Expressions for work done, efficiency and power developed are identical to those of Francis turbine :

$$n = \frac{D_b}{D_o}$$

Where D_o is the outside diameter of the runner and D_b is the diameter of the hub or boss. The value of n varies from 0.55 to 0.6.

2. Inlet and outlet peripheral velocities are the same since the flow is axial i.e.,

$$u_1 = u_2 = u = \frac{\pi D_o N}{60}$$

3. Velocity of flow at inlet and outlet are equal i.e.,

$$v_{f1} = v_{f2} = v_f$$

4. Area of flow at inlet - area of flow at outlet

$$= \frac{\pi}{4} (D_o^2 - D_b^2)$$

5. The discharge Q flowing through the runner is given by

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

6. The flow ratio

$$k_f = \frac{V_f}{\sqrt{2gH}}$$

Where the value of k_f is around 0.7 for a Kaplan turbine.

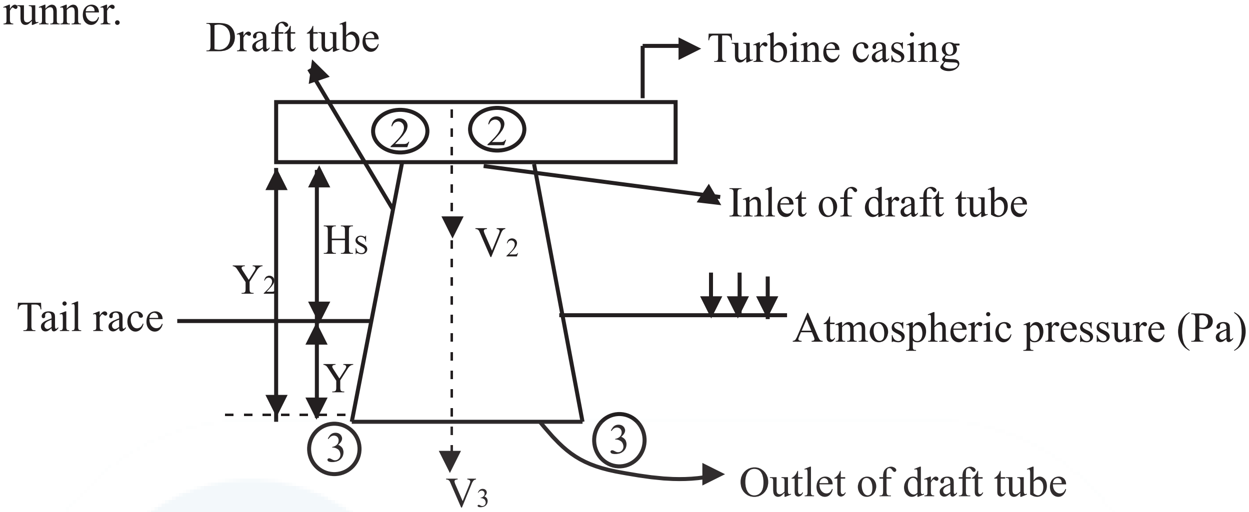
7. Peripheral velocity of the runner blade is dependent upon the diameter under consideration and varies from section to section along the blade.

Draft Tube

In the case of mixed and axial flow turbines, a large portion of the available energy still remains with the water as it leaves the runner. As this energy cannot be used in the runner, it is necessary to extract the unused energy. This can be done using a draft tube.

Draft tube is an integral part of mixed and axial flow turbines. The draft tube helps to make it possible to have the pressure at the runner outlet much below the atmospheric pressure. A draft tube serves the following two purposes :

1. It allows the turbine to be set above the tail-water level, without loss of head and thus can be easily maintained.
2. If regains a major portion of the kinetic energy delivered to it from the runner.



$$\frac{P_2}{\rho g} = \frac{P_a}{\rho g} + (y - y_2) - \left(\frac{v_2^2 - v_3^2}{2g} - h_L\right)$$

The above equation is valid for the straight conical draft tune shown above. The term $(y - y_2)$ is called as the suction head of the drafy tube. (H_S). The term $\left(\frac{v_2^2 - v_3^2}{2g}\right)$ is called dynamic head.

$$\frac{P_2}{\rho g} = \frac{P_a}{\rho g} + H_S - \left[\frac{v_2^2 - v_3^2}{2g} - h_L\right]$$

The term $\frac{P_2}{\rho g}$ is less than atmospheric pressure

Efficiency of a draft tube (η_d)

$$\eta_d = \frac{\text{Net gain in pressure head}}{\text{Velocity head at entrance of draft tube}}$$

$$\eta_d = \frac{\left[\frac{v_2^2 - v_3^2}{2g} - h_L\right]}{\frac{v_2^2}{2g}}$$

Note that v_2 is the velocity of water at the inlet of the draft tube while v_3 is the velocity of water at the outlet of the draft tube.

The most commonly used draft tube types are

1. Straight conical or concentric tube and
2. He elbow type

Specific Speed

The specific speed of a turbine is defined as the speed of a geometrically similar turbine that would develop unit power (1 kw) under unit head (1m).

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

Where N_s is the specific speed (in rpm) of the turbine, N is the speed (in rpm) of the actual turbine, P is the shaft power in kw and H is the head, in metres, under which the turbine is working.

Governing of Hydraulic Turbines

Governing of a hydraulic turbine, i.e., speed regulation, is necessary as it required to run the electric generator that is directly coupled to the turbine at a constant speed under all fluctuating load conditions. In an impulse turbine, governing is achieved by spear regulation, deflector regulation or by combined spear and deflector regulation. In reaction turbines, the governing (discharge) is achieved by varying area of flow between adjacent guide vanes.

Cavitation

In a flow field, when the pressure at any point equals the vapour pressure of the liquid at that temperature vapour cavities (bubbles of vapour) begin to appear. The cavities formed, due to liquid motion are carried to higher pressure regions where the vapour condenses and they suddenly collapse. This formation, growth and collapse of vapour filled cavities or bubbles in a liquid flow due to decrease in liquid pressure is called cavitation.

Cavitation produces erosion of material (called pitting), noise and vibration which lead to a drop in the output and efficiency.

In reaction turbines, cavitation may occur at the runner exit or the draft tube inlet where the pressure is negative

Net positive section head (NPSH)

ENTRI

$$NPSH = \frac{P_e}{\rho g} + \frac{V_e^2}{2g} - \frac{P_v}{\rho g}$$

Where p_e , v_e are the static pressure and velocity of the liquid at the outlet of the runner (or at the inlet of the draft tube) and p_v is the vapour pressure of the liquid at the working temperature.

If the frictional losses in the draft tube and the velocity of the discharge from the draft tube are considered to be negligibly small, then

$$NPSH = \frac{P_{atm}}{\rho g} - \frac{P_v}{\rho g} - H_s$$

Thomas's cavitation parameter (of factor) is defined as

$$\sigma = \frac{NPSH}{H} = \frac{\frac{P_{atm}}{\rho g} - \frac{P_v}{\rho g} - H_s}{H}$$

The critical value of the cavitation parameter (or factor) is defined as

$$\sigma_c = \frac{\frac{P_{atm}}{\rho g} - \frac{P_v}{\rho g} - H_s}{H}$$

For cavitation to not occur, $\sigma > \sigma_c$ (since $p_e > p_v$)

The critical cavitation factor depends on the specific speed of the turbine.

Surge Tanks

A surge tanks is a small reservoir or tank in which the water level changes to reduce the pressure swings so that they are not transmitted in full to a closed circuit. A surge tank serves generally the following two purposes.

1. To prevent water hammer effect and to protect the upstream tunnel from high pressure rises.
2. To serve as a supply or storage tank under respectively increased or reduced load conditions.