Turbines Study Materials

Turbines:

Hydraulic turbines are the machines which convert the energy of flowing water into mechanical energy. The mechanical energy developed by a turbine is used in running an electric generator which directly couples to the shaft of the turbine. Thus the mechanical energy is converted into electrical energy. This electrical power is known as hydroelectric power.

Classification of Turbines:

1. According to the action of the-water flowing.

a) Impulse turbine - Pelton wheel

b) Reaction turbine - Francis turbine, Kaplan turbine

2. According to the main direction of flow of water.

a) Tangential flow turbine - Pelton wheel.

b) Radial flow turbine - Old Francis turbine.

c) Axial flow turbine - Kaplan turbine

d) Mixed flow turbine - Modern Francis turbine

3. According to the head and quantity of water required:

a) High head (above 250 m) - Pelton wheel.

b) Medium head (60 m - 250 m) - Modern Francis turbine

c) Low head turbine (less than 60 m - Kaplan turbine)

4. According to the specific speed:

a) Low specific speed (10 to 35) - Pelton wheel

b) Medium specific speed (60 to 400) - Francis turbine

c) High specific speed (300 to 1000) - Kaplan turbine

Impulse turbine:

In an impulse turbine, all the energy available by water is converted into kinetic energy by passing it through a nozzle. The high velocity jet coming out of the nozzle then impinges on a series of buckets fixed around the aim of a wheel. Thus, the runner revolves freely in air.

Ex: Pelton wheel

Reaction turbine:

In a reaction turbine, the runner utilizes both potential and kinetic energies. Here only a portion of a potential energy is transformed into kinetic energy before the fluid enters the turbine runner. As the water flows through the runner, remaining part of potential energy goes on changing into kinetic energy.

Ex: Francis turbine and Kaplan turbine.

Head and Efficiencies of Pelton wheel:

1. **Gross head (H_g)**

The gross head is the difference between the water level at the reservoir and the level at the tailrace.

2. **Effective or Net Head (H):**

The head available at the inlet of the turbine is known as effective or net head.

$H = Hg - H_f - h$

where h_f = head loss due ,o friction in penstock.

$= \frac{4fLV^2}{2gD}$

h = height of the nozzle above the tailrace.

3. **Water and Bucket Power:**

The power supplied by the water jet is known as water power (wp) power supplied by the jet=WQH = ρgQH

where Q - Discharge supplied by the water jet m^3/s

H - Effective or net head.

The power developed by the bucket wheel is known as bucket or actual power, B P

4. **Hydraulic efficiency (η_b):**

It is defined as the ratio of power developed by the runner to the power supplied by the water jet

$$\eta_h = \frac{(V_{w_1} \pm V_{w_2})u}{gH} = \frac{H_r}{H}$$

The parameter, $H_r = \frac{1}{g}(V_{w_1} + V_{w_2}) \times u$ represents the energy transfer per unit weight of the water and is referred to the 'runner head' or Euler head.

Hydraulic loss within the turbine,

$\Delta H = H - H_r$

5. **Mechanical efficiency (h_m):**

$\eta_m = \frac{\text{Shaft power}}{\text{Water power}}$

$$\eta_m = \frac{P}{WQ_a H_r}$$

6. **Volume efficiency:**

$\eta_v = \frac{Q_a}{Q} = \frac{Q-q}{Q}$

7. **Overall efficiency (h_0)**

$\eta_0 = \frac{\text{Shaft power}}{\text{Water power}} = \frac{P}{W\,QH}$

$\eta_0 = \eta_v \times \eta_n \times \eta_m$

Design Aspects of Pelton wheel:

1. Velocity of jet

$V_1 = C_v\sqrt{2gH}$

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

H = Net head on turbine

2. Velocity of wheel

$u = K_u\sqrt{2gH}$

where K_u - speed ratio = 0.43 to 0.48

3. Mean diameter of wheel (D)

$u = \frac{\pi DN}{60} \Rightarrow D = \frac{60\,u}{\pi\,N}$

The mean diameter is also known as pitch diameter.

4. Jet ratio (m):

It is defined as the ratio of mean diameter (D) of the pelton wheel to the diameter of the jet (d).

$m = \frac{D}{d}$

m varies b/w 11 to 15. Normally, m = 12 is adopted.

5. Number of jets:

Normally, Pelton wheel has one nozzle or one jet. When more power is to be produced, No. of nozzles or jets may be employed with the same wheel. Theoretically six nozzles can be used with one Pelton wheel.

Number of jet is obtained by dividing the total rate of flow through the turbine by the rate of flow of water through a single jet.

Bucket dimensions:

Axial width, B = 4d to 5d

Radial length, L = 2d to 3d

Depth, T=0.8d to 1.2d

Angle, ϕ = 10° to 20°

Number of buckets (z):

The number of buckets is decided mainly on the following two principles.

1. The number of buckets should be as few as possible so that there is little loss due to friction.
2. No water escapes without striking the buckets.

The number of buckets is usually more than 15.

$Z = \frac{D}{2d} + 15 = 0.5m + 15$

Francis Turbine:

Francis turbine in an inward flow reaction turbine. It is developed by the American Engineer James B. Francis. In the earlier stages, Francis turbine had a purely radial flow runner. But the modern Francis turbine is a mixed flow reaction turbine in which the water enters the runner radially at its outer periphery and leaves axially at its centre. This arrangement provides a larger discharge area with the prescribed diameter of the runner.

Parts

1. Penstock

2. Scroll or spiral casing
3. Speed lins or stay ring
4. Guide vanes or wicket gates
5. Runner and runner blades
6. Draft tube

Workdone and Efficiencies of Francis turbine:

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

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

where Q = discharge through the runner

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

u_1 and u_2 = tangential velocity of wheel at inlet and outlet

Hydraulic efficiency (η_h):

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

Mechanical efficiency (η_m):

$\eta_m = \frac{p}{\frac{WQ}{g}(V_{w_1}u_1)}$

Overall efficiency (η_0):

$\eta_0 = \frac{p}{W\,Q_a H}$

Or $\eta_0 = \eta_m \times \eta_n$

Design Aspects of Francis Turbine:

1. Ratio of width to diameter $\left(\frac{B}{D}\right)$ is represented by $n = \frac{B}{D}$

2. **Flow ration (K_f):**

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

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

value of K_f varies from 0.15 to 0.3.

Speed ratio (K_u):

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

$K_u = \frac{u}{\sqrt{2gH}}$

Kaplan Turbine:

A Kaplan turbine is an axial flow reaction turbine which was developed by Austrian engineer V. Kaplan. It is suitable for relatively low heads. Hence it requires a large quality of water to develop large power.

Main components of a Kaplan turbine:

1. Scroll casing
2. Stay ring
3. Guide vanes
4. Runner
5. Draft tube

Working properties of Kaplan turbine:

1. In case of Kaplan turbine, the ratio $n = \frac{D_b}{D_o}$

   ` where D_b = Diameter of the hub or boss.

   D_o = outside diameter of the runner.

2. Discharge Q = Area of flow × Velocity of flow

   $Q = \frac{\pi}{4}D_0^2(1 - n^2) \times K_f\sqrt{2gH}$

3. The peripheral velocity u of the runner is dependent on the radius of the point under consideration and thus varies from section to section along the blade.
4. Velocity of flow (V_f) remains constant throughout.

Performance of Turbines:

Unit Speed (N_u)

Unit speed is the speed of a turbine when working under a unit head (i.e. 1m).

We know that u=wr=w $\frac{D}{2}$

$\therefore u \propto N$

Since the diameter D is constant for a given turbine.

Unit discharge (Q_u):

It is the theoretical discharge of a turbine when working under a unit head.

$Q_u = \frac{Q}{\sqrt{H}}$

Unit power:

It is the theoretical power of a turbine when working under a unit head.

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

Specific speed (N_s):

Specific speed is the speed of a geometrically similar turbine (i.e. a turbine identical in shape, dimensions, blade angles and gate openings etc.) which will develop unit power when working under a unit head.

The specific speed is used in comparing the different types of turbines as every type of turbine has different specific speed.

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

Note:

- Specific speed is proportional to the speed of rotation Evidently the high speed Kaplar turbines are expected to have high specific speed than Pelton wheel.
- Specific speed is inversely proportional to head obviously, the high head Pelton wheel has a low value of specific speed than Kaplar turbine which operates at low heads.

Turbine characteristics:

The curves which are plotted from the results of the tests performed on the turbine under different working conditions are known as characteristic curves. The purpose of these curves is to predict the behaviour and performance of a furbine under different working condtions.

1. **Main or constant head characteristic curves:**

These curves are obtained by maintaining a constant head and a constant gate opening. The speed of the turbine is varied by allowing a variable quantity of water to flow through the inlet.

2. **Operating or constant speed characteristic curves:**

These curves are obtained by keeping speed as constant for each gate opening. The dischange, Q and head H may vary according to their availability.