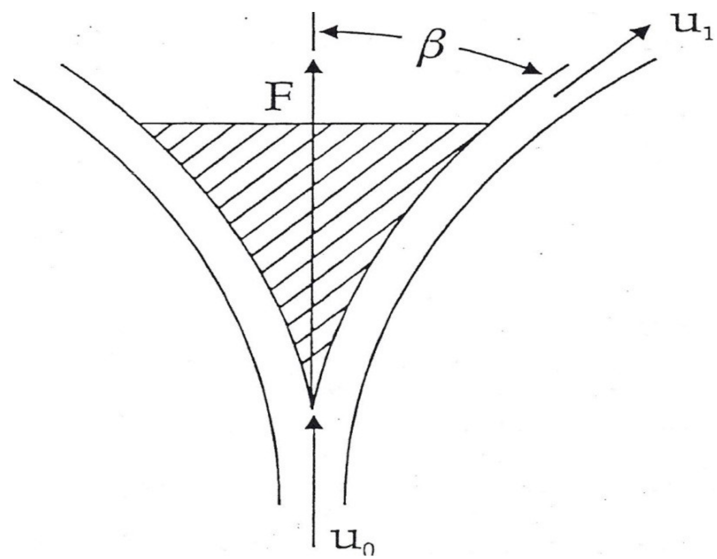
THERMAL AND HYDRAULIC MACHINES

UNIT 4



- Consider a vane symmetrical about the x-axis as shown in Figure 2.0. A jet of fluid flowing at the rate of (m dot) kg/s along the x-axis with the velocity u_0 m/s strikes the vane and is deflected by it through angle β, so that the fluid leaves the vane with the velocity u_0 m/s inclined at an angle β to the x-axis.

5.1 Theory

Momentum enters the system in the x direction at a rate of:

$$\dot{m}u_0 (kgm/s^2)$$

Momentum leaves the system in the same direction at the rate of:

$$\dot{m}u_1 \cos\beta \ (kgm/s^2)$$

The force on the vane In the x direction is equal to the rate of change of momentum change. Therefore:

$$F \approx \dot{m}(u_0 - u_1 \cos\beta) \qquad \text{(Newton's)}$$

Ideally, jets are "isotachtic", or constant velocity so that $\mu_0 = \mu_1$. Therefore:

$$F \approx \dot{m}u_0(1 - \cos\beta) \qquad \text{(Newton's)}$$

Theory

SHAPE	β	F
→|	90^0	$\dot{m}u_0$
→>	120^0	$1.5\ \dot{m}u_0$
→)	180^0	$2\ \dot{m}u_0$
→\	30^0	$0.87\ \dot{m}u_0$

Hydraulic machinery

- Turbine is a device that extracts energy from a fluid (converts the energy held by the fluid to mechanical energy)

- Pumps are devices that add energy to the fluid (e.g. pumps, fans, blowers and compressors).

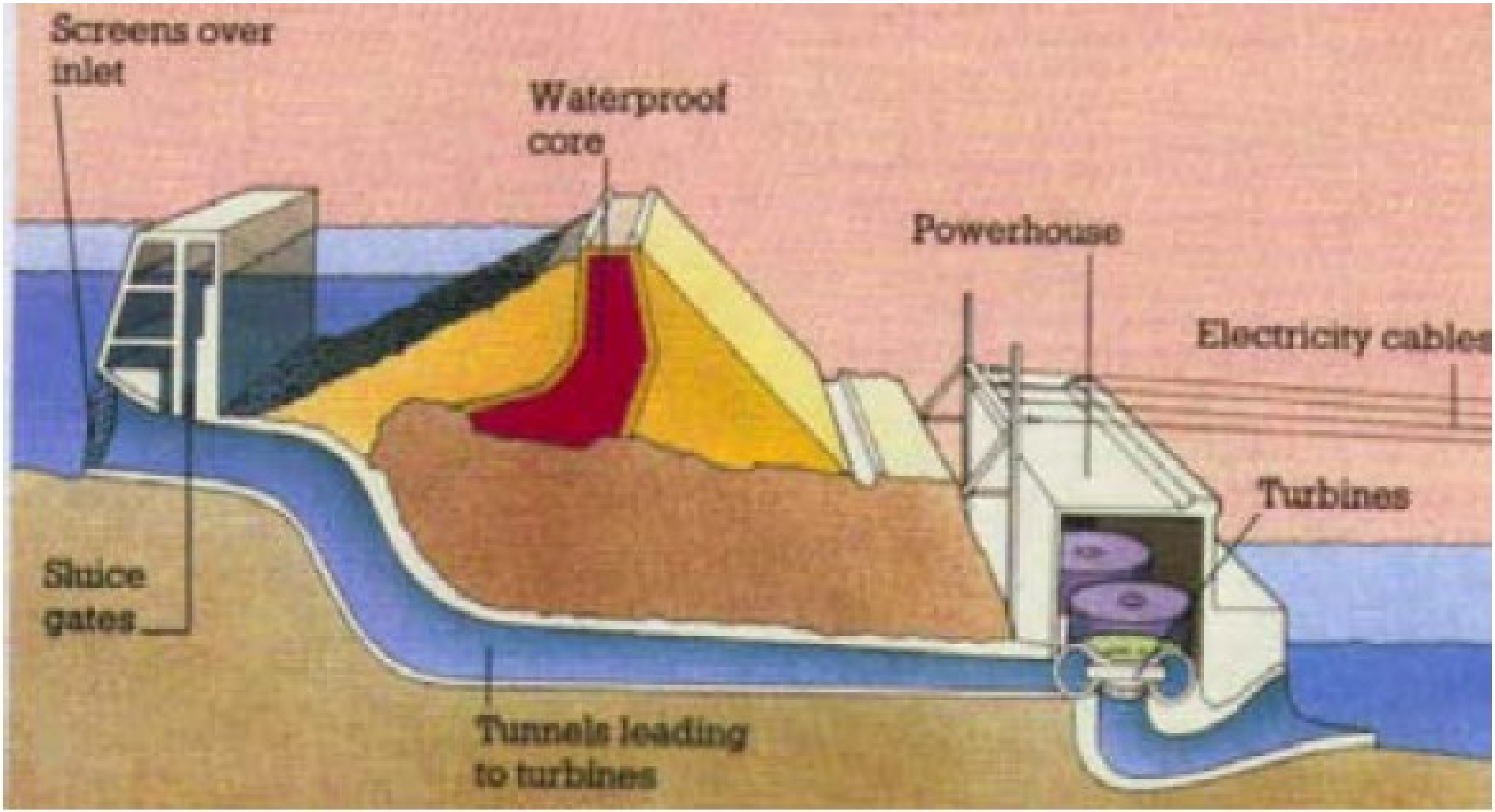
Turbines

- Hydro electric power is the most remarkable development pertaining to the exploitation of water resources throughout the world
- Hydroelectric power is developed by hydraulic turbines which are hydraulic machines.
- Turbines convert hydraulic energy or hydro-potential into mechanical energy.
- Mechanical energy developed by turbines is used to run electric generators coupled to the shaft of turbines
- Hydro electric power is the most cheapest source of power generation.

Turbines

- J.V. Poncelet first introduced the idea of the development of mechanical energy through hydraulic energy
- Modern hydraulic turbines have been developed by L.A. Pelton (impulse), G. Coriolis and J.B. Francis (reaction) and V Kaplan (propeller)

Turbines



Screens over inlet
Waterproof core
Powerhouse
Electricity cables
Turbines
Sluice gates
Tunnels leading to turbines

Types of turbines

Turbines can be classified on the basis of:

- Head and quantity of water available
- Hydraulic action of water
- Direction of flow of water in the runner
- Specific speed of turbines
- Disposition of the shaft of the runner

Classification of turbines

- Based on head and quantity of water

  According to head and quantity of water available, the turbines can be classified into

  a) High head turbines

  b) Medium head turbines

  c) Low head turbines

  a) High head turbines

  High head turbines are the turbines which work under heads more than 250m. The quantity of water needed in case of high head turbines is usually small. The Pelton turbines are the usual choice for high heads.

Classification of turbines

- Based on head and quantity of water

  b) Medium head turbines

  The turbines that work under a head of 45m to 250m are called medium head turbines. It requires medium flow of water. Francis turbines are used for medium heads.

  c) Low head turbines

  Turbines which work under a head of less than 45m are called low head turbines. Owing to low head, large quantity of water is required. Kaplan turbines are used for low heads.

Classification of turbines

- Based on hydraulic action of water

According to hydraulic action of water, turbines can be classified into

a) Impulse turbines

b) Reaction turbines

a) Impulse turbines

If the runner of a turbine rotates by the impact or impulse action of water, it is an impulse turbine.

b) Reaction turbines

These turbines work due to reaction of the pressure difference between the inlet and the outlet of the runner.

Classification of turbines

- Based on direction of flow of water in the runner

  Depending upon the direction of flow through the runner, following types of turbines are there

  a) Tangential flow turbines

  b) Radial flow turbines

  c) Axial flow turbines

  d) Mixed flow turbines

  a) Tangential flow turbines

  When the flow is tangential to the wheel circle, it is a tangential flow turbine. A Pelton turbine is a Tangential flow turbine.

Classification of turbines

- Based on direction of flow of water in the runner

  b) Radial flow turbines

  In a radial flow, the path of the flow of water remains in the radial direction and in a plane normal to the runner shaft. No pure radial flow turbine is in use these days.

  c) Axial flow turbines

  When the path of flow water remains parallel to the axis of the shaft, it is an axial flow turbine. The Kaplan turbine is axial flow turbine

  d) Mixed flow turbines

  When there is gradual change of flow from radial to axial in the runner, the flow is called mixed flow. The Francis turbine is a mixed flow turbine.

Classification of turbines

- Based on specific speed of turbines

  Specific speed of a turbine is defined as the speed of a geometrically similar turbine which produces a unit power when working under a unit head.

  The specific speed of Pelton turbine ranges between 8-30, Francis turbines have specific speed between 50-250, Specific speed of Kaplan lies between 250-850.

- Based on disposition of shaft of runner

  Usually, Pelton turbines are setup with horizontal shafts, where as other types have vertical shafts.

Heads, Losses and Efficiencies of Hydraulic Turbines

- Heads

These are defined as below:

(a) Gross Head: Gross or total head is the difference between the headrace level and the tail race level when there is no flow.

(b) Net Head: Net head or the effective head is the head available at the turbine inlet. This is less than the gross head, by an amount, equal to the friction losses occurring in the flow passage, from the reservoir to the turbine inlet.

Heads, Losses and Efficiencies of Hydraulic Turbines

- Losses

Various types of losses that occur in a power plant are given below:

(a) Head loss in the penstock: This is the friction loss in the pipe of a penstock.

(b) Head loss in the nozzle: In case of impulse turbines, there is head loss due to nozzle friction.

(c) Hydraulic losses: In case of impulse turbines, these losses occur due to blade friction, eddy formation and kinetic energy of the leaving water. In a reaction turbine, apart from above losses, losses due to friction in the draft tube and disc friction also occur.

Heads, Losses and Efficiencies of Hydraulic Turbines

(d) Leakage losses: In case of impulse turbines, whole of the water may not be striking the buckets and therefore some of the water power may go waste. In a reaction turbine, some of the water may be passing through the clearance between the casing and the runner without striking the blades and thus not doing any work. These losses are called leakage losses.

(e) Mechanical losses: The power produced by the runner is not available as useful work of the shaft because some power may be lost in bearing friction as mechanical losses.

f) Generator losses: Due to generator loss, power produced by the generator is still lesser than the power obtained at the shaft output.

Heads, Losses and Efficiencies of Hydraulic Turbines

- Efficiencies

Various types of efficiencies are defined as under:

(a) Hydraulic efficiency: It is the ratio of the power developed by the runner to the actual power supplied by water to the runner. It takes into account the hydraulic losses occurring in the turbine

η_h = Runner output / Actual power supplied to runner

= Runner output / (ρQgH)

Where, Q = Quantity of water actually striking the runner blades

H = Net head available at the turbine inlet

Heads, Losses and Efficiencies of Hydraulic Turbines

- Efficiencies

(b) Volumetric efficiency: It is the ratio of the actual quantity of water striking the runner blades to the quantity supplied to the turbine. It takes into account the volumetric losses.

Let ΔQ = Quantity of water leaking or not striking the runner blades

$$\eta_v = Q / (Q + \Delta Q)$$

(c) Mechanical efficiency: The ratio of the shaft output to the runner output is called the mechanical efficiency and it accounts for the mechanical losses.

$$\eta_m = \text{Shaft output} / \text{Runner output}$$

Heads, Losses and Efficiencies of Hydraulic Turbines

- Efficiencies

(d) Overall efficiency: Ratio of shaft output to the net power available at the turbine inlet gives overall efficiency of the turbine

η_m = Shaft output / Net power available

$$\eta_o = \frac{Shaft.output}{\rho(Q + \Delta Q)gH}$$

$$\eta_o = \frac{Shaft.output}{Runner.output} \times \frac{Runner.output}{\rho QgH} \times \frac{Q}{(Q + \Delta Q)}$$

$$\eta_o = \eta_m \times \eta_h \times \eta_v$$

Thus all the three types of losses, mechanical, hydraulic and volumetric have been taken into account.