ME 221
ELEMENTS OF FLUID MECHANICS & MACHINERY

TURBINES

LECTURE 7

MD. Rakib Hossain
Lecturer
Department of Mechanical Engineering, BUET.

TURBINES

- Turbines or Hydraulic turbines are the machines which convert the hydraulic energy into mechanical energy.
- The mechanical energy produced by a hydraulic turbine can be converted into electrical energy by coupling the turbine to an electric generator.

CLASSIFICATION OF TURBINES

Turbines can be classified according to the following criteria

1. Hydraulic Action

   a) Impulse Turbine: Here the available head is converted into Kinetic Energy by passing the water through the nozzle.

      Example: Pelton wheel, Girard Turbine, Banki Turbine etc.

   b) Reaction Turbine: A part of the total head is converted into Kinetic Energy and the rest remains in the form of pressure energy.

      Example: Francis Turbine, Kaplan Turbine, Propeller Turbine etc.

CLASSIFICATION OF TURBINES

2. Direction of Flow of Water

   a) Tangential Flow Machine: The water strikes the runner in the direction of tangent to the wheel.

      Example: Pelton Turbine.

   b) Radial Flow Turbine: Francis Turbine

   c) Axial Flow Turbine: Kaplan Turbine

   d) Mixed Flow Turbine: Francis Turbine

CLASSIFICATION OF TURBINES

3. Direction of the Shaft

   a) Horizontal: Shaft is horizontal and the runner is vertical.

   Example: Pelton wheel.

   b) Vertical: Shaft is vertical and the runner is horizontal.

   Example: Francis Turbine.

CLASSIFICATION OF TURBINES

4. Head

   a) High Head Turbine: Net Head 150-2000m or more.

      Example: Pelton wheel.

   b) Medium Head Turbine: Head from 30-150m.

      Example: Francis Turbine.

   c) Low Head Turbine: Head<30m

      Example: Kaplan Turbine.

CLASSIFICATION OF TURBINES

5. Specific Speed

   a) Low Specific Speed: Speed<60 rpm.

      Example: Pelton wheel.

   b) Medium Specific Speed: 400>speed>60 rpm

      Example: Francis Turbine.

   c) High Specific Speed: speed>400 rpm

      Example: Kaplan Turbine.

PELTON WHEEL

Major Components:

a) Buckets and Runner:

A pelton wheel is fitted with buckets having the shape of double hemispherical cup. The angle at the outlet tip varies from 10-20^0 and the jet deflects 170-160^0. The advantage of double cup shaped bucket is that because of symmetry the axial thrust on the shaft is zero.

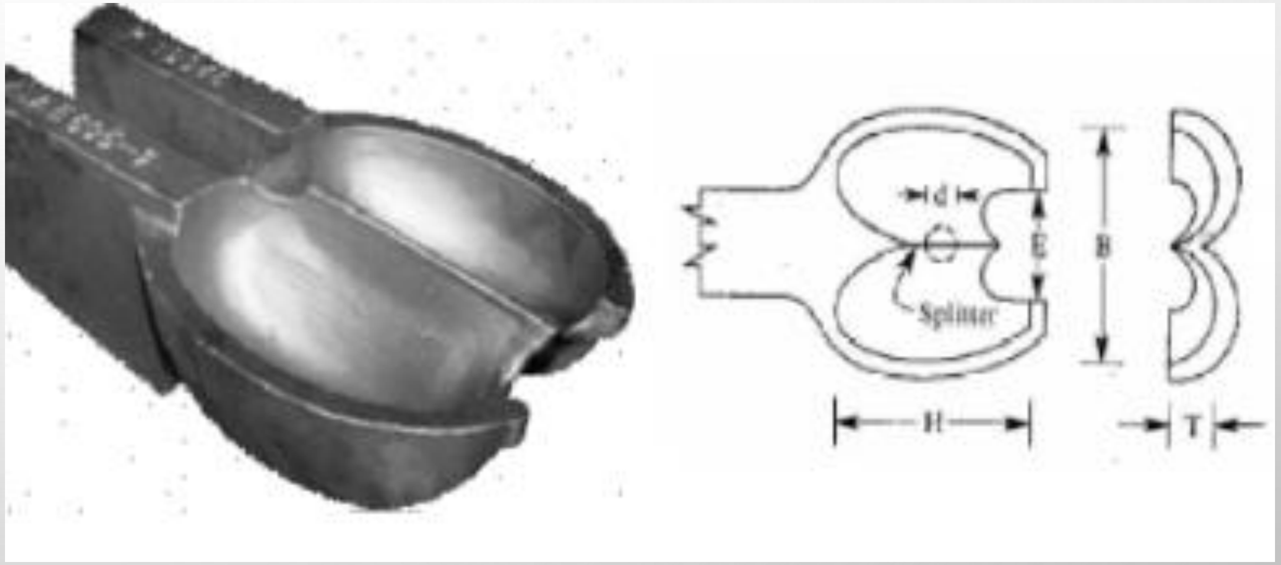


Fig: Double Hemispherical cup bucket

PELTON WHEEL

b) Nozzle with Control Mechanism:

jet velocity remains the same and only the discharge changes.

c) Casing:

I. To prevent splashing of water

II. To lead water to tail race

III. To act as a safeguard against accident

PELTON WHEEL

d) Hydraulic Brake:

The hydraulic brake consists of a small nozzle which directs a jet on the back of the buckets in opposite direction which causes braking.

e) Deflector:

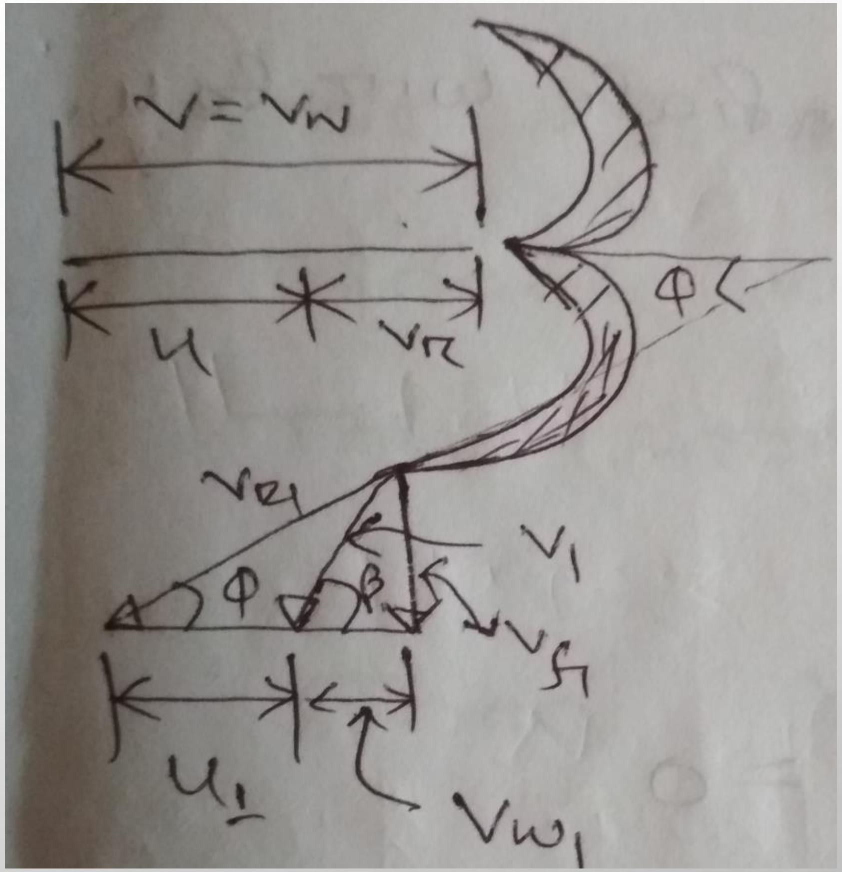
The sudden closing of the nozzle may cause excessive water hammer. To avoid water hammer, the nozzle is closed slowly by a movable steel plate known as deflector.

WORKDONE BY PELTON WHEEL

Let, the Effective/Net Head, H = Gross Head- h_f

Where, h_f= Net loss of head in penstock

(line from reservoir to turbine)



WORKDONE BY PELTON WHEEL

Torque, $T = \rho a v[v_w R - (-v_{w1} R_1)]$

Where, a= area of jet; v=velocity of jet; R, R_1=inside and outside radius

$$T = \rho a v(v_w R + v_{w1} R_1)$$

Work done per second, $\mathrm{P} = T \times w$

$$\Rightarrow P = \rho a v(v_w R + v_{w1} R_1) \times w$$

$$\Rightarrow P = \rho a v(v_w u + v_{w1} u_1)$$

Let, $u = u_1$, then

WORKDONE BY PELTON WHEEL

$$P = \rho a v(v_w + v_{w1})u$$

$$\Rightarrow P = \rho a v[v + (v_{r1} cos\varphi - u)]u$$

$$\Rightarrow P = \rho a v[(v - u\ ) + v_{r1} cos\varphi]u$$

Assuming, $v_{r1} = k v_r$

$$P = \rho a v[(v - u\ ) + k v_r cos\varphi]u$$

$$\Rightarrow P = \rho a v[(v - u\ ) + k(v - u) cos\varphi]u$$

$$\Rightarrow P = \rho a v(v - u\ )(1 + k cos\varphi)u$$

WORKDONE BY PELTON WHEEL

Neglecting losses in the nozzle,

Input energy$= \frac{1}{2}mv^2 = \frac{1}{2}(\rho av)v^2$

So, Hydraulic efficiency, $\eta_h = \frac{\rho av(v-u)(1+k\cos\varphi)u}{\frac{1}{2}(\rho av)v^2}$

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

As v is fixed, it can't be changed because it depends on height.

WORKDONE BY PELTON WHEEL

So differentiating with respect to u

η_h will be maximum if

$$\frac{d\eta_h}{du} = 0$$

$$\Rightarrow \frac{d}{du}\left[\frac{2u(v-u)(1+k\cos\varphi)}{v^2}\right] = 0$$

$$\Rightarrow \frac{(1+k\cos\varphi)}{v^2}\frac{d}{du}(2uv-2u^2) = 0$$

WORKDONE BY PELTON WHEEL

$$2v - 4u = 0$$

$$\Rightarrow u = \frac{v}{2}$$

Therefore, the maximum hydraulic/wheel efficiency

$$\eta_h = \frac{2 \times \frac{v}{2} \times (v - \frac{v}{2}) \times (1 + kcos\varphi)}{v^2} = \frac{1}{2}(1 + kcos\varphi)$$

If k=1 i.e. the vanes are very smooth, then, $\eta_h = \frac{1}{2}(1 + cos\varphi)$

WORKDONE BY PELTON WHEEL

- φ can't be zero otherwise it strikes the bucket from backward.
- The hydraulic efficiency is less than unity because k is always less than unity and $\varphi \neq 0$.
- Mechanical Efficiency η_m is defined as the ratio of the power obtained at the shaft to the power developed by the runner.

$$\eta_m = \frac{S.H.P}{P}$$

WORKDONE BY PELTON WHEEL

- The overall efficiency

$$\eta_o = \frac{S.H.P}{Power\ supplied\ at\ the\ turbine}$$

$$= \frac{S.H.P}{P} \times \frac{P}{P_T}$$

$$= \eta_m \times \eta_h$$

Problem 1:

A Pelton wheel is rotating at a speed of 600 rpm. The diameter of jet is 80 mm and the jet velocity is 110 m/s. The ratio of jet to bucket speed is 2.2. The bucket deflects the jet through an angle of 165^0. Find the

a) Wheel diameter, b) Power developed, c) Loss of energy at the exit of water.

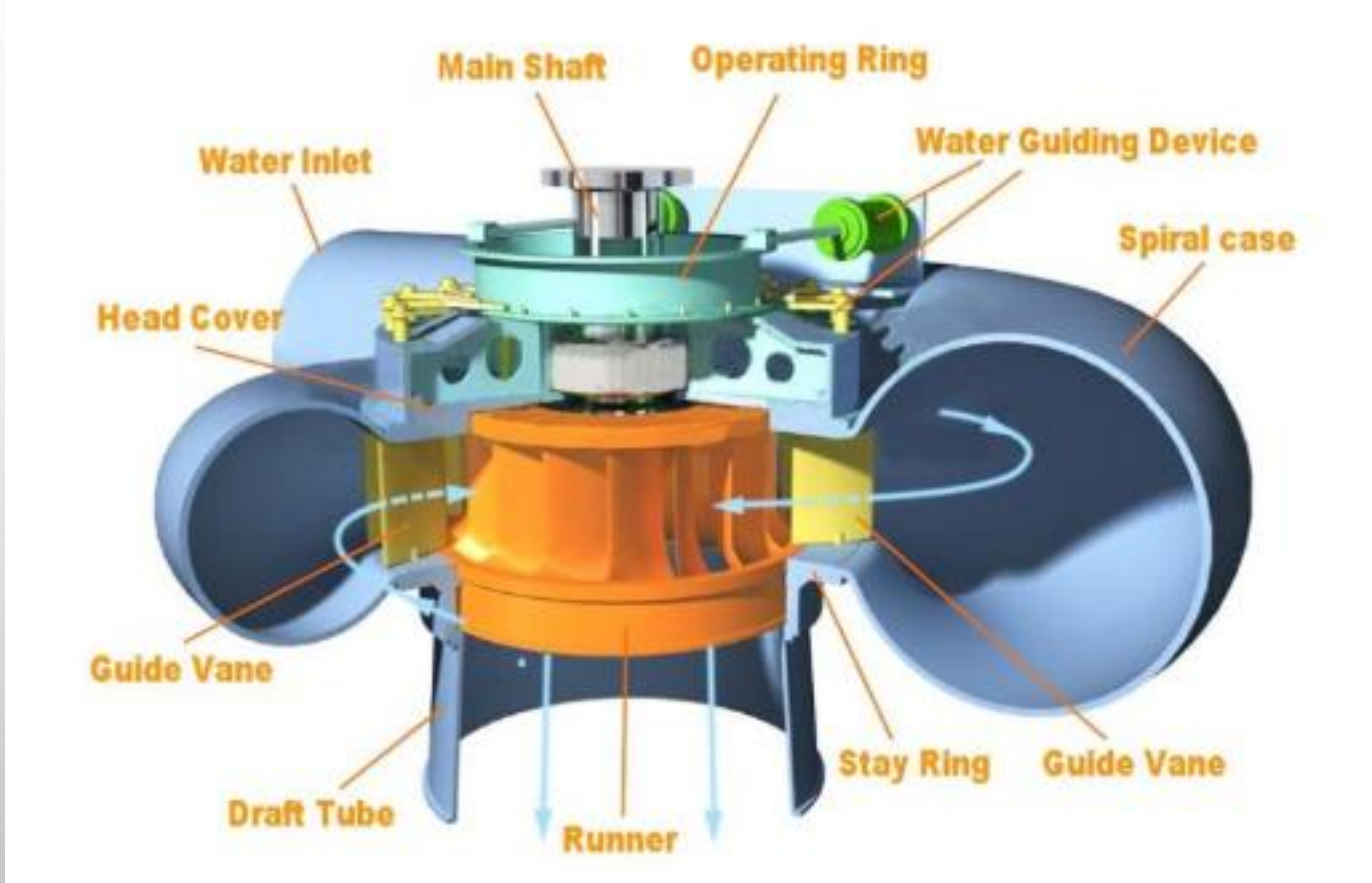
Problem 2:

The diameter of a double jet Pelton wheel is 2m and it is working with a head of 340m. The diameter of each jet is 160mm. The buckets deflect the jet through an angle of 165^0. After the flow over the buckets 15% of the relative velocity is reduced. The coefficient of the velocity of nozzle is 0.98. Considering maximum efficiency, find the speed of the turbine and the energy lost with the exit water.

FRANCIS TURBINE

- In a Francis Turbine, only a part of the net head is transformed into kinetic energy at inlet and the rest of head remains in the form of pressure energy. There is a difference of pressure between the entrance and the exit of runner. The difference is known as reaction pressure. This pressure is responsible for running of the reaction turbine.

MAIN COMPONENTS OF FRANCIS TURBINE



MAIN COMPONENTS OF FRANCIS TURBINE

- **Spiral Casing:**

The area of the casing decreased along the circumference. The purpose of casing is to distribute the water over the guide vanes and to prevent the formation of eddies. For small head, it is made of Concrete and for high head, it is made of Steel/Cast iron.

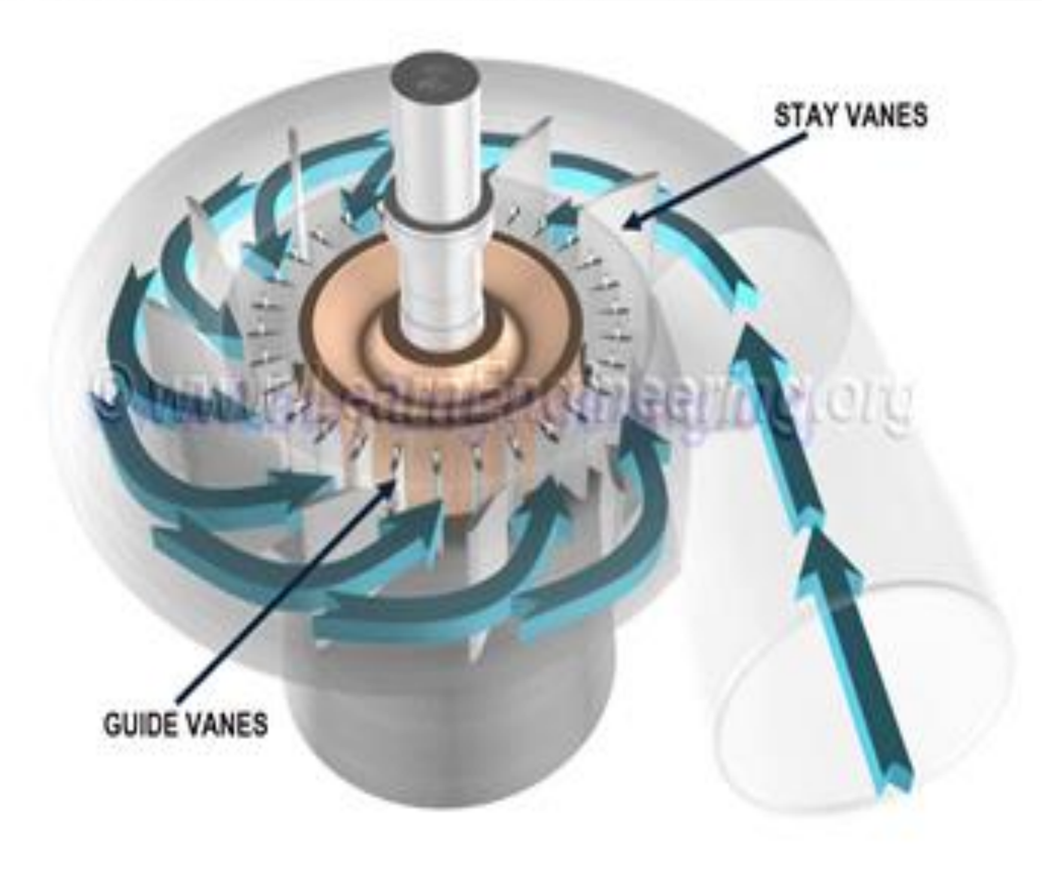
- **Stay Vanes:**

Stay vanes and guide vanes guides the water to the runner blades. Stay vanes remain stationary at their position and reduces the swirling of water due to radial flow, as it enters the runner blades. Thus making turbine more efficient.

MAIN COMPONENTS OF FRANCIS TURBINE

- **Guide Vanes:**

Water after passing through stay vanes, glides through guide vanes to enter the runner blades. Guide vanes can change their angle thus can control the angle of attack of water to the runner blades, making them work more efficiently. Moreover they also regulate the flow rate of water into the runner blades thus controlling the power output of a turbine according to the load on the turbine.



MAIN COMPONENTS OF FRANCIS TURBINE

❖ Runner Blades:

Design of the runner blades decides how well a turbine is going to perform. So runner blades of mixed flow turbine can be divided into two parts, the upper part of the blades use the reaction force of water flowing through it and the lower half is in the shape of a small bucket using the impulse action of water flowing through it. These two forces together makes the runner to rotate.

❖ Draft Tube:

Draft tube connects the runner exit to the tail race. Its cross-section area increases along its length, as the water coming out of runner blades is at considerably low pressure, so its expanding cross-section area help it to recover the pressure as it flows towards tail race.

FRANCIS TURBINE WORKING PRINCIPLE

Water enters the turbine through spiral casing, and starts entering the runner blades, passing through stay vanes and guide vanes, as it moves along the length of casing the decreasing cross-section area of the spiral casing makes sure that the pressure energy of water would remain uniform along its length, as a portion of water is also entering the runner blades, which would reduce its flow rate along the length of the casing. The stay vanes being stationary at their place, removes the swirls from the water, which are generated due to flow through spiral casing and tries it to make the flow of water more linear to be deflected by adjustable guide vanes. The angle of guide vanes decides the angle of attack of water at the runner blades thus make sure the output of the turbine.

FRANCIS TURBINE WORKING PRINCIPLE

Guide vanes also controls the flow rate of water in-to the runner blades thus acting according the load on the turbine. The runner blades are stationary and can-not pitch or change their angle so it's all about the guide vanes which controls the power output of a turbine.

Further-more the upper part of runner blades are designed in such a way that they use the pressure difference between the opposite faces of a blade created by water flowing through it, same as the air-foil uses the pressure difference to generate lift force. And the remaining part of the blade is designed like a small bucket, which makes use of water's kinetic energy. Thus runner blades make use of both pressure energy and kinetic energy of water and rotates the runner in most efficient way.

FRANCIS TURBINE WORKING PRINCIPLE

The water coming out of runner blades would lack both the kinetic energy and pressure energy, so we use the draft tube to recover the pressure as it advances towards tail race, but still we cannot recover the pressure to that extent that we can stop air to enter into the runner housing thus causing cavitation.

Problem 3:

Water enters into an inward flow reaction turbine at an angle of 22^0 to the tangent to the outer rim and leaves the turbine radially. The speed of the wheel is 300 rpm and the velocity of flow is constant at 3 m/s. Find the necessary angle of blades when the inner and outer diameters of the turbine are 30 cm and 60 cm respectively. If width at the inlet is 15 cm, calculate horsepower developed. Thickness of blade may be neglected.

Problem 4:

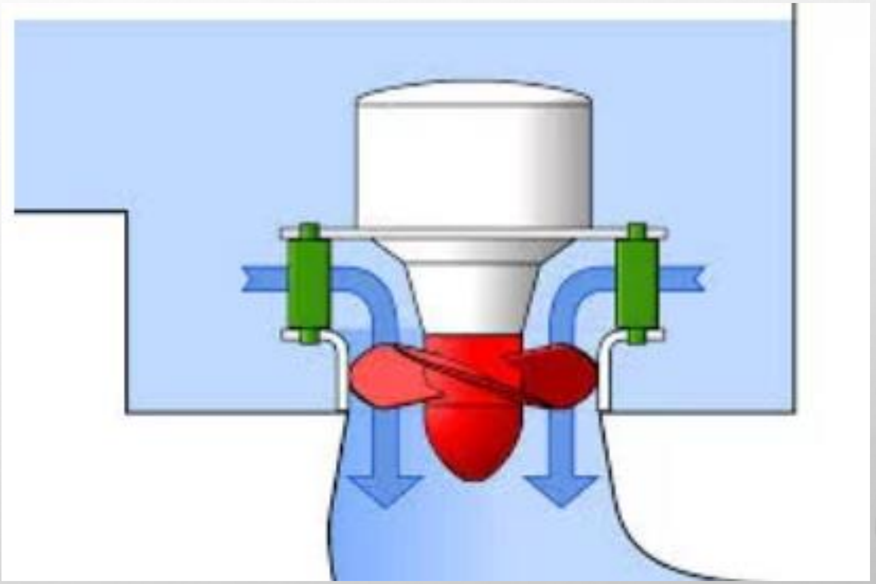
An inward flow reaction turbine develops 220 KW and 300 rpm under a head of 20m. The inlet and outlet diameter of turbine are 2m and 1m respectively. The width of the wheel at inlet is 0.2m and the flow rate of water is 1.6 m^3/s. The velocity of flow at outlet is 3 m/s and the discharge is radial. Find the hydraulic efficiency, overall efficiency, vane angles and guide vane angle at inlet.

KAPLAN TURBINE

The Kaplan Turbine was developed in the year 1913 by Viktor Kaplan, who was a Austrian Professor. This turbine is fitted with adjustable blades. The blade angle changes automatically by an oil-pressure servo-motor as the load changes. The Kaplan turbine is purely axial. There are usually 4 to 6 blades. The blades are made of stainless steel.

WORKING PRINCIPLE OF KAPLAN TURBINE

- Kaplan turbine works on the principle of axial flow reaction. In axial flow turbines, the water flows through the runner along the direction parallel to the axis of rotation of the runner. The water at the inlet of the turbine possesses both kinetic energy as well as pressure energy for effective rotation of the blades in a hydro-power station.



WORKING PRINCIPLE OF KAPLAN TURBINE

- The water coming from the pen-stock is made to enter the scroll casing. The scroll casing is made in the required shape that the flow pressure is not lost. The guide vanes direct the water to the runner blades. The vanes are adjustable and can adjust itself according to the requirement of flow rate. The water takes a 90 degree turn, so the direction of the water is axial to that of runner blades.
- The runner blades start to rotate as the water strikes due to reaction force of the water. The runner blades has twist along its length in order to have always optimum angle of attack for all cross section of blades to achieve greater efficiency.

WORKING PRINCIPLE OF KAPLAN TURBINE

- From the runner blades, the water enters into the draft tube where its pressure energy and kinetic energy decreases. Kinetic energy gets converted into pressure energy results in increased pressure of the water.
- The rotation of the turbine is used to rotate the shaft of generator for electricity production.

APPLICATION OF KAPLAN TURBINE

- Kaplan turbines are widely used throughout the world for electrical power production.
- It can work more efficiently at low water head and high flow rates as compared with other types of turbines.
- It is smaller in size and easy to construct.
- The efficiency of kaplan turbine is very high as compares with other hydraulic turbine.

DISADVANTAGE OF KAPLAN TURBINE

- The only disadvantage of kaplan turbine is cavitation, which occurs due to pressure drop in draft tube. Use of draft tube and proper material generally stainless steel for the runner blades may reduce the cavitation problem to a greater extent.

SPECIFIC TURBINE

- For Comparing the turbines of different types, the concept of specific turbine is quite useful.
- A specific turbine is an imaginary turbine which is identical in shape, geometrical properties, blade angles etc. with the actual turbine but reduced to such a size that it develops one horsepower under a unit head.
- In other words, a specific turbine is a small scale model of the actual turbine, the dimensions of the model are such that it produces one horsepower under a unit head.

SPECIFIC TURBINE

- The equation of specific speed is

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

- Specific speed is independent of the dimension or size of the actual turbine and the specific turbine. All turbines of the same geometrical shape and having the same efficiency will have the same specific speed.

PERFORMANCE CHARACTERISTIC CURVES OF TURBINES

- Hydraulic turbines gives their best performance when they are operated at certain conditions of head, discharge, speed and output power.
- Model turbines are tested under different conditions of head, discharge, speed, power, efficiency. Results are plotted in the form of curves and are known as performance characteristic curves.

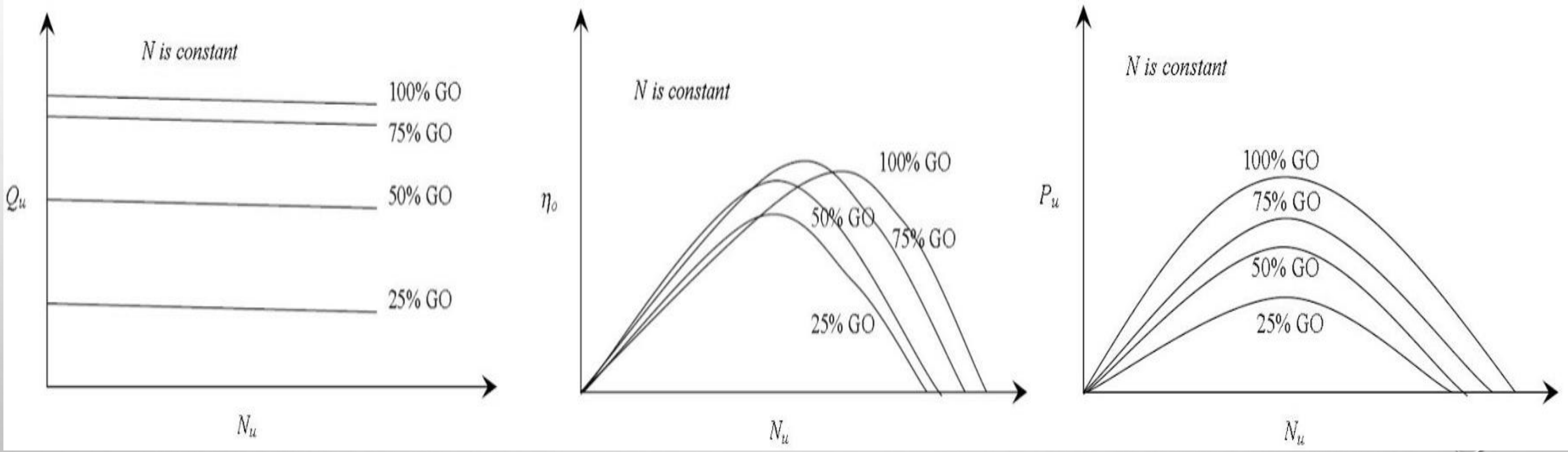
PERFORMANCE CHARACTERISTIC CURVES OF TURBINES

- There are three types of characteristics curves
  - Main characteristic curves / constant head curves
  - Operating characteristic curves / constant speed curves
  - Constant efficiency curves (Muschel curves)

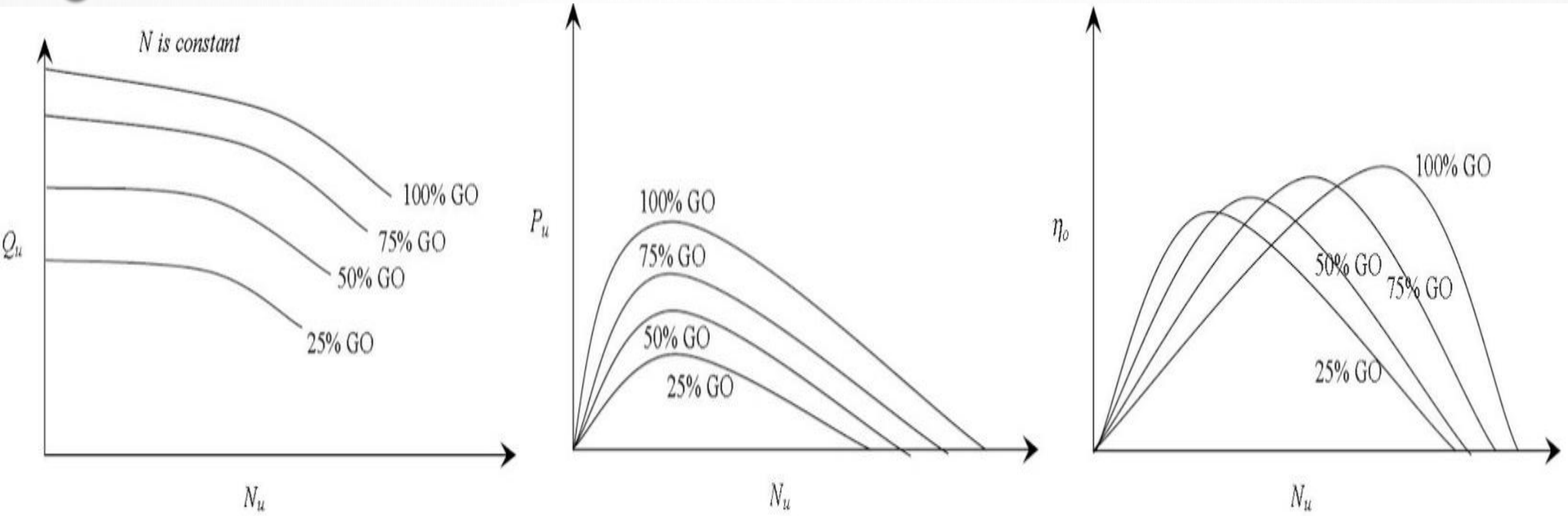
MAIN CHARACTERISTIC CURVES/ CONSTANT HEAD CURVES

- Curves are drawn by conducting experiment at constant head.
- Head and gate openings are kept constant and speed is varied by varying load on the turbine.
- For each value of speed, corresponding values of power and discharge are obtained.

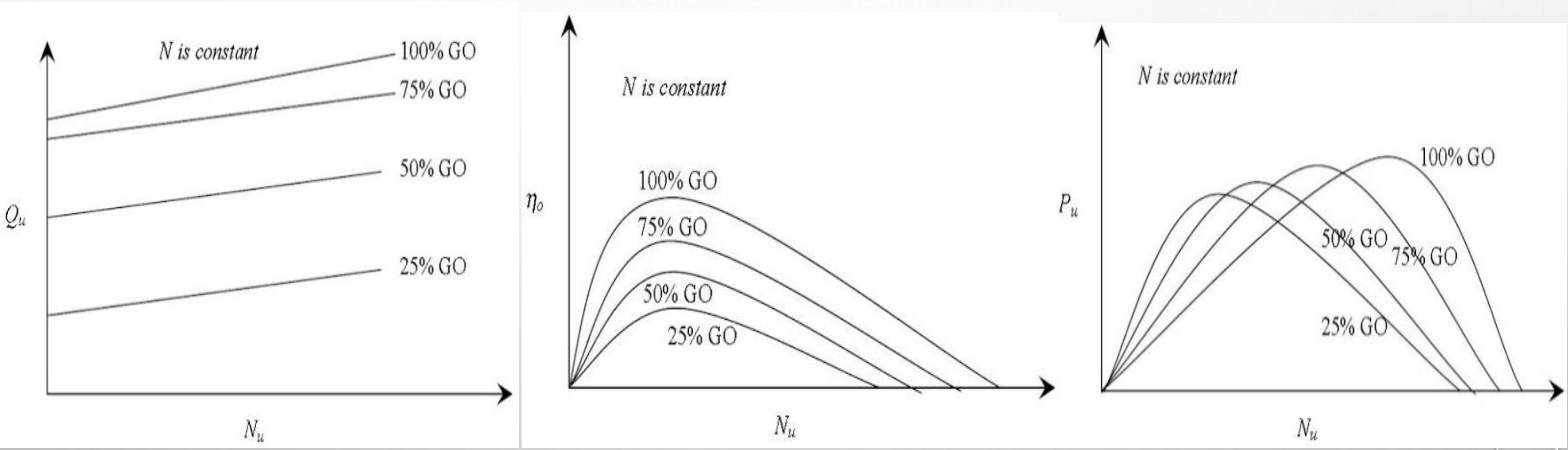
PELTON TURBINE



FRANCIS TURBINE



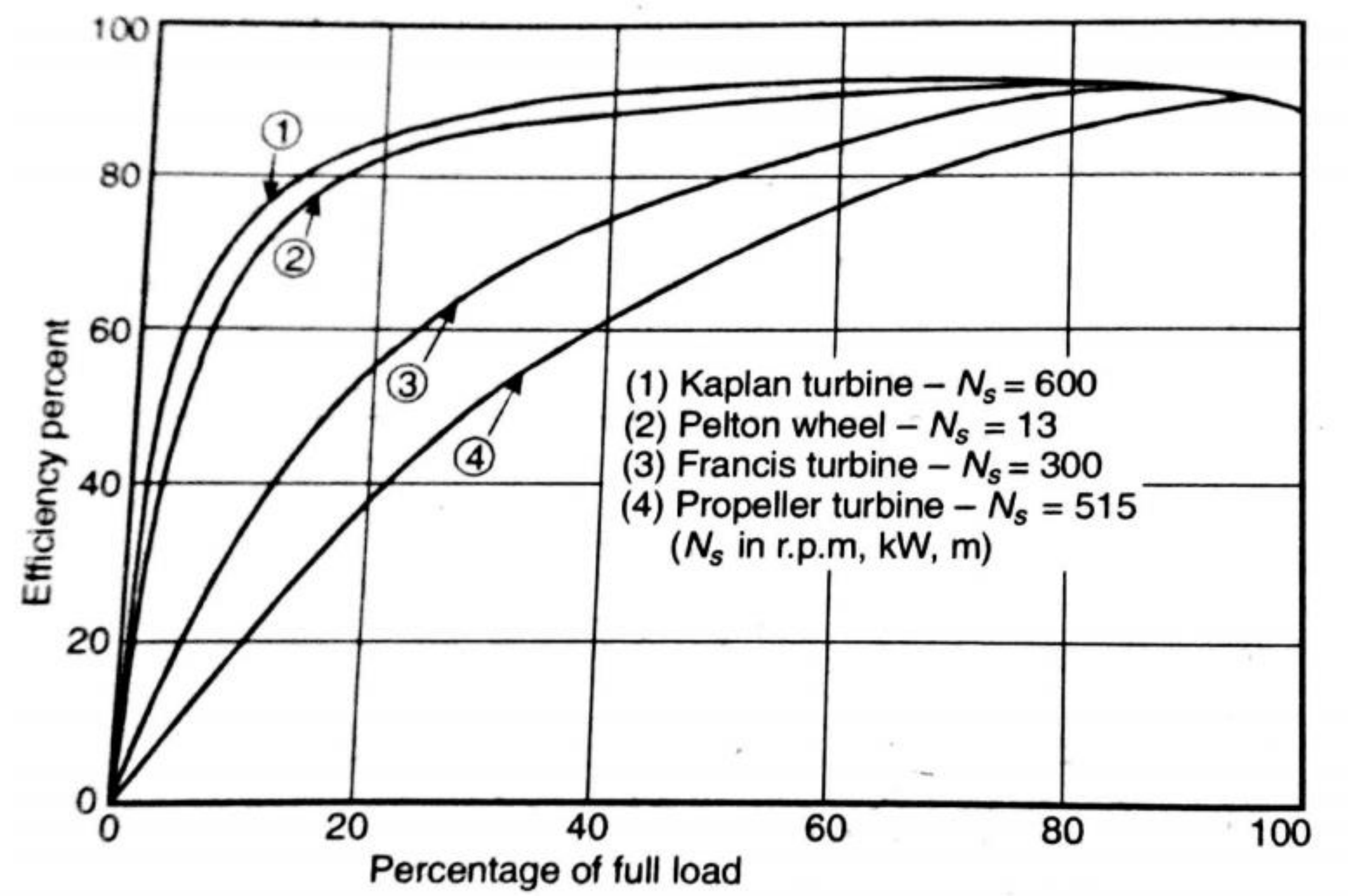
KAPLAN TURBINE



SIGNIFICANCES OF MAIN CHARACTERISTICS CURVE

- Discharge of pelton wheel depends only on gate opening.
- Discharge decreases and increases respectively for Francis and kaplan turbines with increase in speed.
- Power is maximum at a particular speed and so is efficiency.
- Maximum efficiency of pelton wheel occurs at same speed irrespective of %of GO.

OPERATING CHARACTERISTIC CURVES / CONST. SPEED CURVES



OPERATING CHARACTERISTIC CURVES / CONST. SPEED CURVES

- Kaplan turbine gives the best performance. This is because of adjusting the vane angles and a high efficiency can be obtained.
- The Propeller Turbine gives the worst performance.
- Maximum efficiency is 85%.


Appreciate those
who love you.
Help those
who need you.
Forgive those
who hurt you.
Forget those
who leave you.
BLESS
everyone
and you will be blessed.