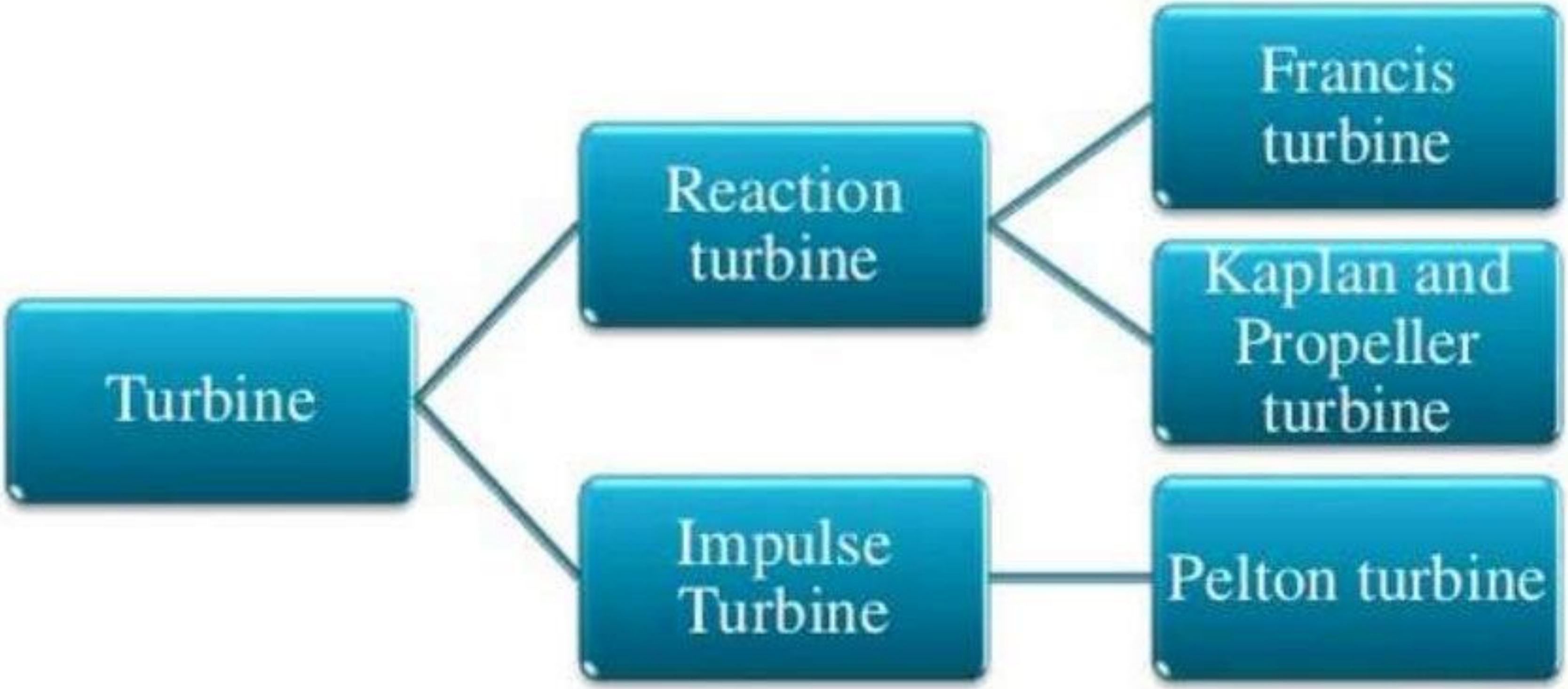
Topics

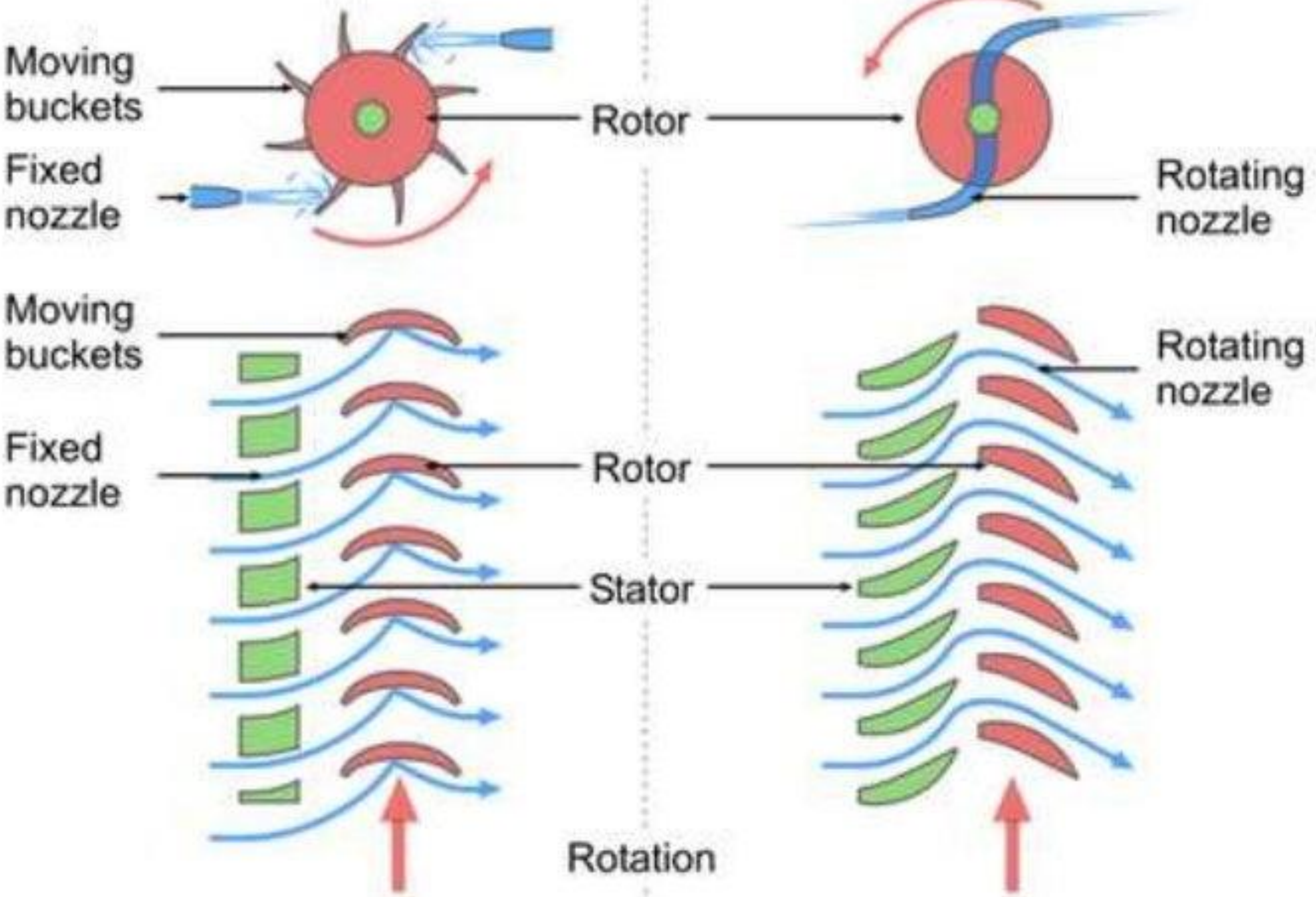
1. Classification of Turbines
2. Selection of Turbines
3. Design of Turbines - Pelton, Francis, Kaplan
4. Draft Tube
5. Surge Tanks
6. Governing of Turbines
7. Unit Speed, Unit Discharge, Unit Power
8. Characteristic Curves of Hydraulic Turbines
9. Similitude or Model Anlysis
10. Cavitations

Classification of Turbines

1. According to type of energy at Inlet
   a) Impulse Turbine - Pelton Wheel
      Requires High Head and Low Rate of Flow
   a) Reaction Turbine - Fancis, Kaplan
      Requires Low Head and High Rate of Flow
2. According to direction of flow through runner
   a) Tangential Flow Turbine - Pelton Wheel
   b) Radial Flow Turbine - Francis Turbine
   c) Axial Flow Turbine - Kaplan Turbine
   d) Mixed Flow Turbine - Modern Francis Turbine


Turbine
Reaction turbine
Impulse Turbine
Francis turbine
Kaplan and Propeller turbine
Pelton turbine

Impulse Turbine   Reaction Turbine



Classification of Turbines

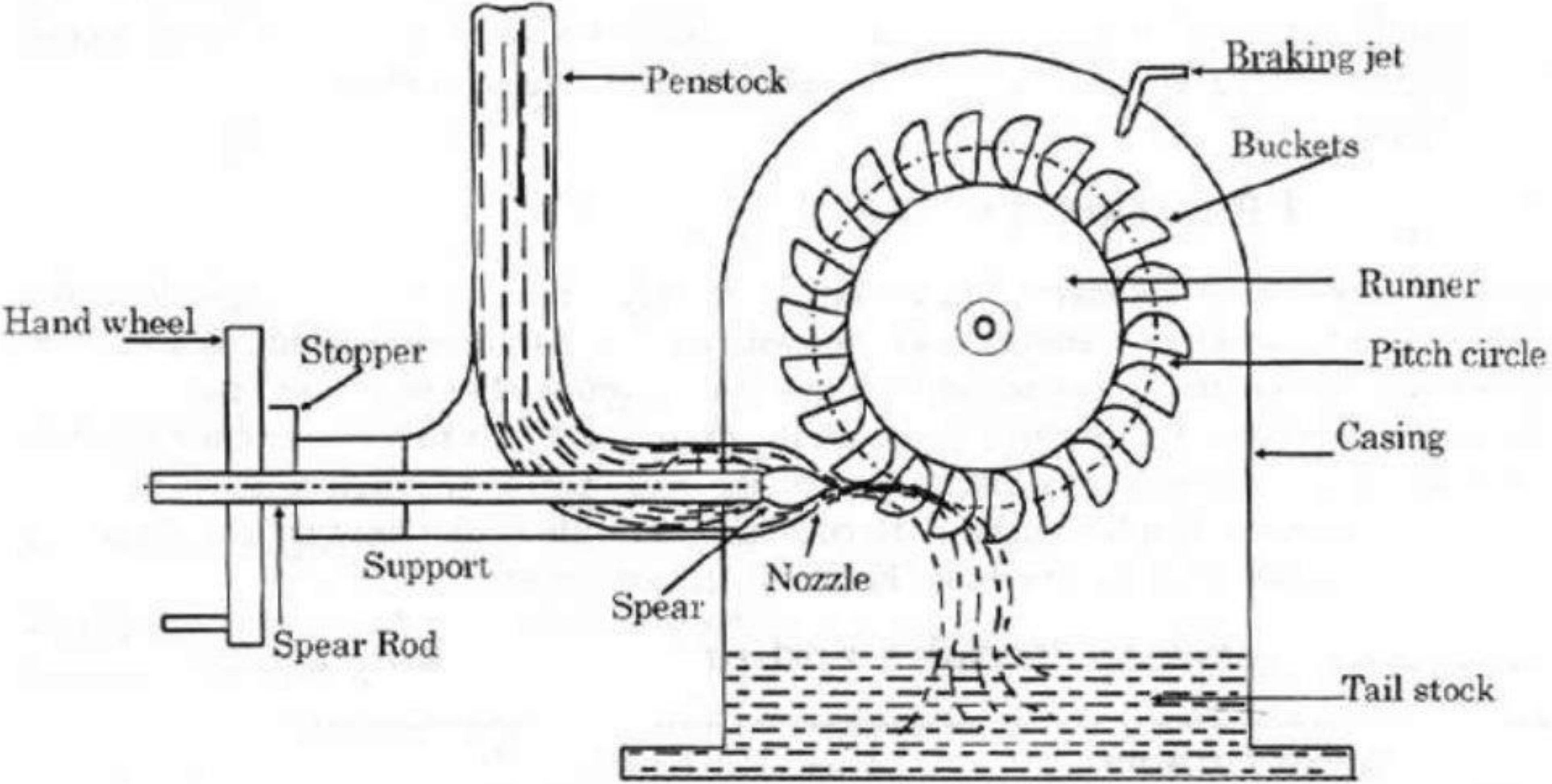
3. According to Head at Inlet of turbine
   a) High Head Turbine - Pelton Wheel
   b) Medium Head Turbine - Fancis Turbine
   c) Low Head Turbine - Kaplan Turbine
4. According to Specific Speed of Turbine
   a) Low Specific Speed Turbine - Pelton Wheel
   b) Medium Specific Speed Turbine - Fancis Turbine
   c) High Specific Speed Turbine - Kaplan Turbine

Classification according to Specific Speed of Turbines

Type of turbine	Type of runner	Specific speed
Pelton	Slow Normal Fast	10 to 20 20 to 28 28 to 35
Francis	Slow Normal Fast	60 to 120 120 to 180 180 to 300
Kaplan	–	300 to 1000

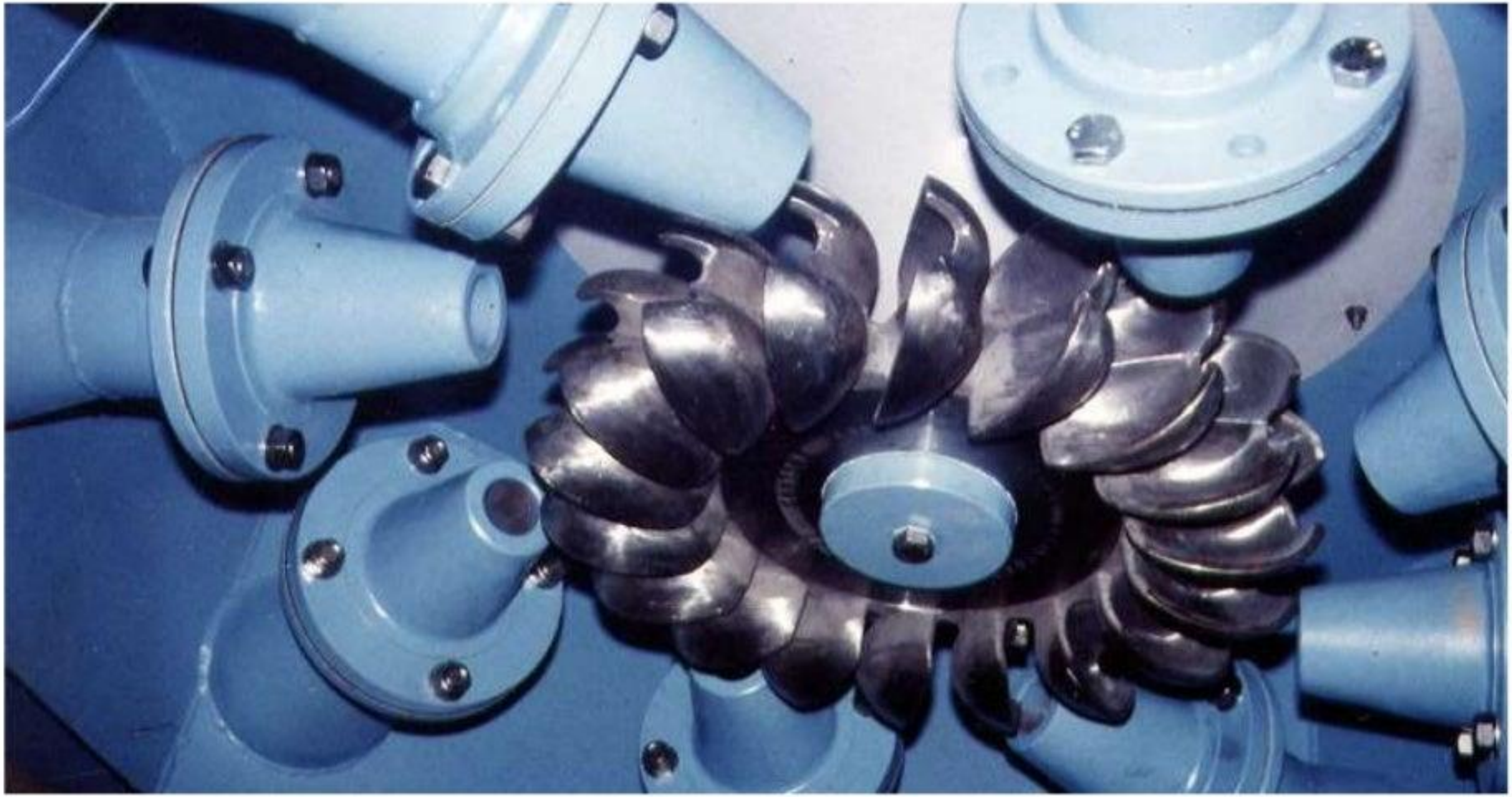
Classification of Turbines

5. According to Disposition of Turbine Shaft
   a) Horizontal Shaft - Pelton Wheel
   b) Vertical Shaft - Fancis & Kaplan Turbines



PELTON WHEEL

PELTON



PELTON WHEEL WITH MULTILE JETS

Design of Pelton Wheel

Guidelines:

1. Jet Ratio = Pitch Diameter of wheel / Dia. of Jet = D/d
2. Speed Ratio = Velocity of Wheel / Velocity of Jet = u/V
3. Velocity of Wheel, $u = u_1 = u_2 = \frac{\pi D N}{60}$
4. Overall Efficiency , $\eta_0 = \eta_m \times \eta_h$ OR $\eta_o = \frac{S.P.}{W.P.}$
5. Water Power, W.P. = $\frac{1}{2} m V^2 = \rho g Q H$
6. Shaft Power, S.P. = $\rho a V_1 [V_{w_1} + V_{w_2}] \times u = \rho Q [V_{w_1} + V_{w_2}] \times u$
7. No. of Buckets = (0.5 x Jet Ratio) + 15

Design of Pelton Wheel

Problems:

1. A Pelton wheel has a mean bucket speed of 10 m/s with a jet of water flowing at the rate of 700 lps under a head of 30 m. 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 the coefficient of nozzle as 0.98.

2. A Pelton wheel has to develop 13230 kW under a net head of 800 m while running at a speed of 600 rpm. If the coefficient of Jet C y = 0.97, speed ratio is 0.46 and the ratio of the Jet diameter is 1 /16 of wheel diameter. Calculate

   i) Pitch circle diameter

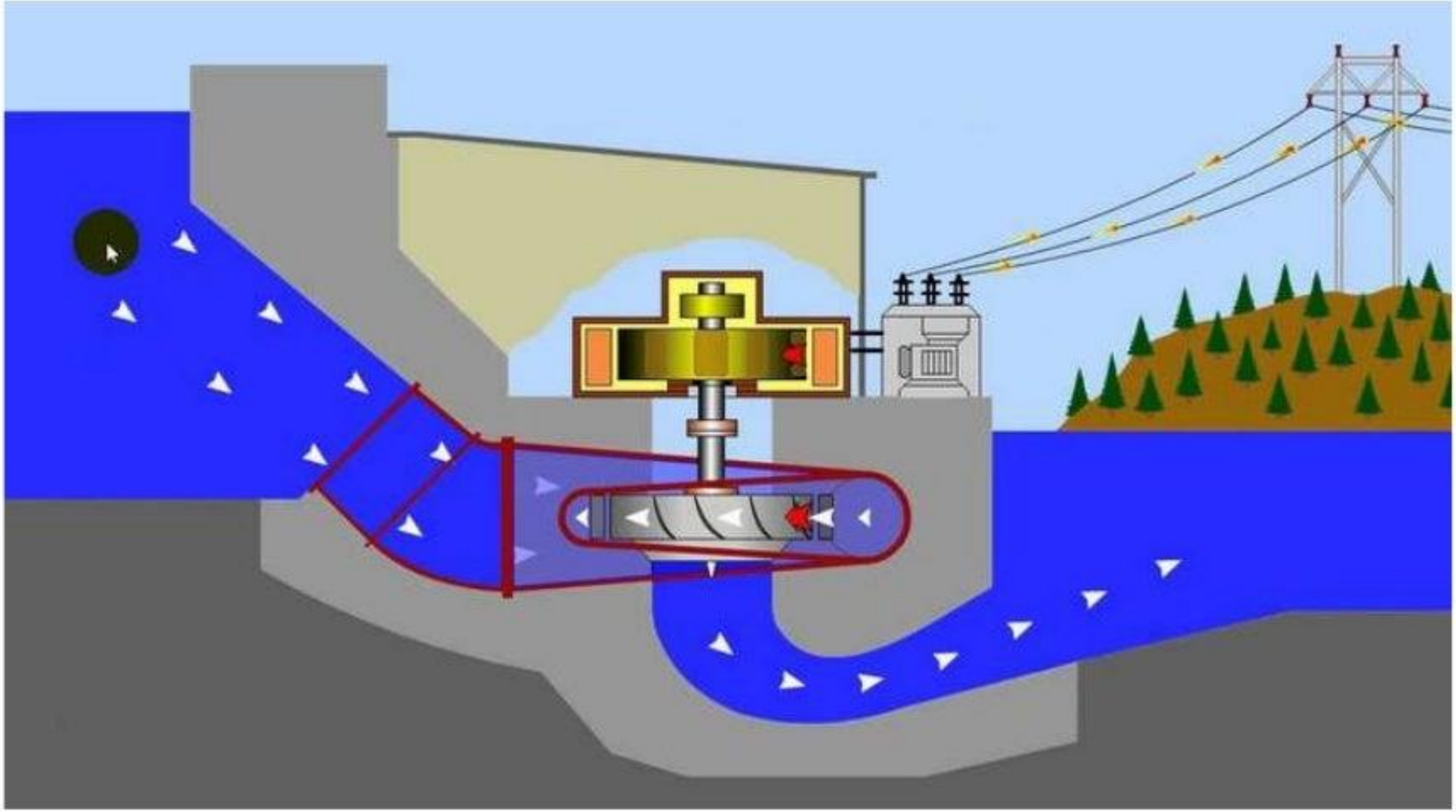
   ii) the diameter of jet

   iii) the quantity of water supplied to the wheel

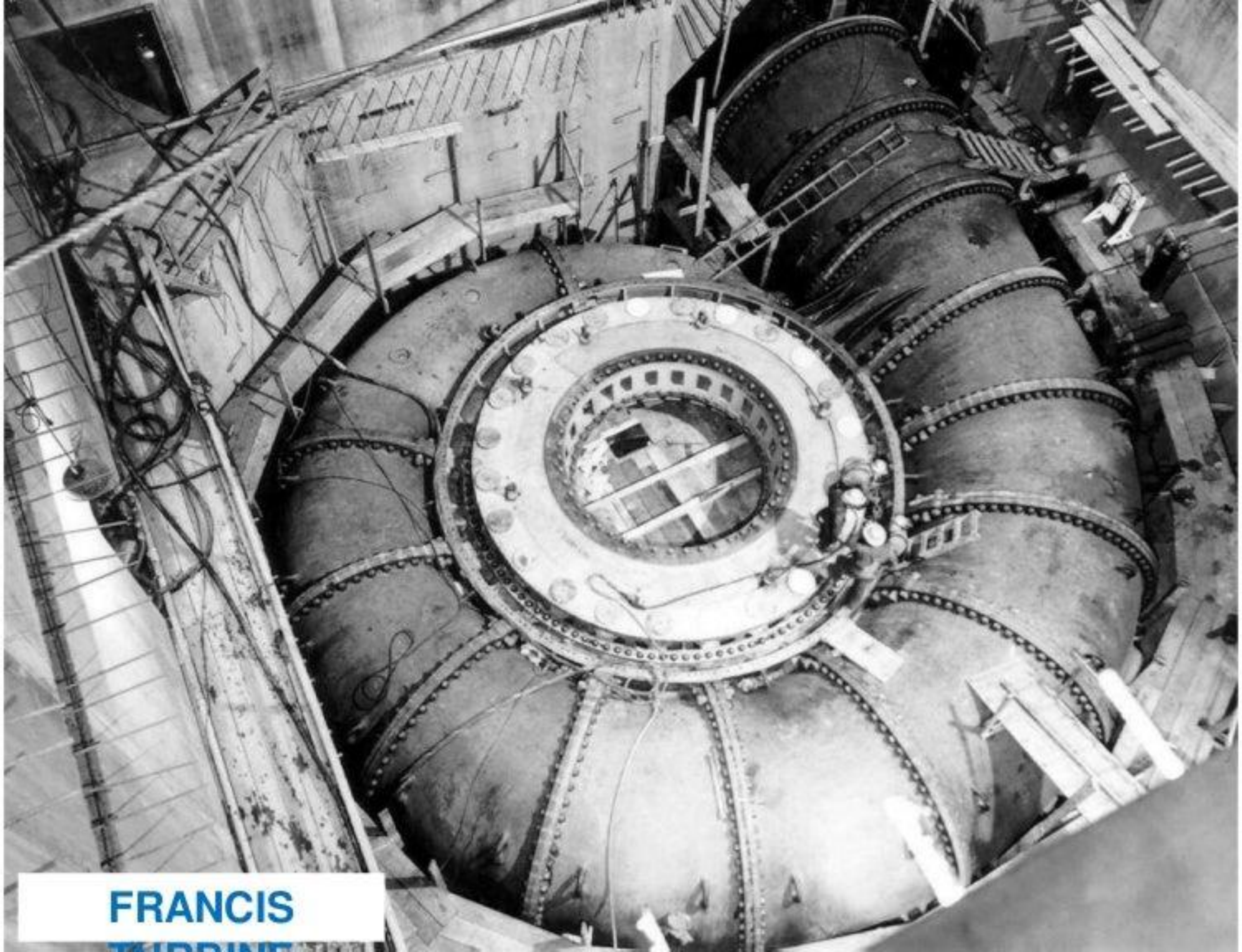
Design of Pelton Wheel

Problems:

3. Design a Pelton wheel for a head of 80m. and speed of 300 RPM. The Pelton wheel develops 110 kW. Take co-eficient of velocity= 0.98, speed ratio= 0.48 and overall efficiency = 80%.
4. A double jet Pelton wheel develops 895 MKW with an overall efficiency of 82% under a head of 60m. The speed ratio = 0.46, jet ratio = 12 and the nozzle coefficient = 0.97. Find the jet diameter, wheel diameter and wheel speed in RPM.



FRANCIS TURBINE


FRANCIS

FRANCIS TURBINE

Design of Francis Turbine

Guidelines:

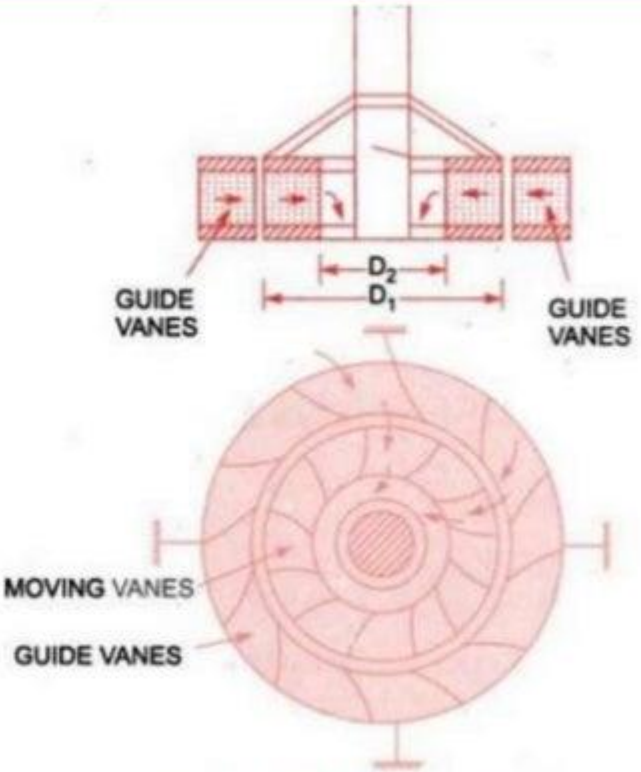
1. Velocity of Wheel, $u = u_1 = u_2 = \frac{\pi D N}{60}$

2. Work done per second or Power,

   $= \rho a V_1[V_{w_1} u_1 \pm V_{w_2} u_2] = \rho Q[V_{w_1} u_1 \pm V_{w_2} u_2]$

3. Velocity of Wheel, $u_1 = \frac{\pi D_1 \times N}{60}$, $u_2 = \frac{\pi D_2 \times N}{60}$

4. Discharge, $Q = \pi D_1 B_1 V_{f_1} = \pi D_2 B_2 V_{f_2}$

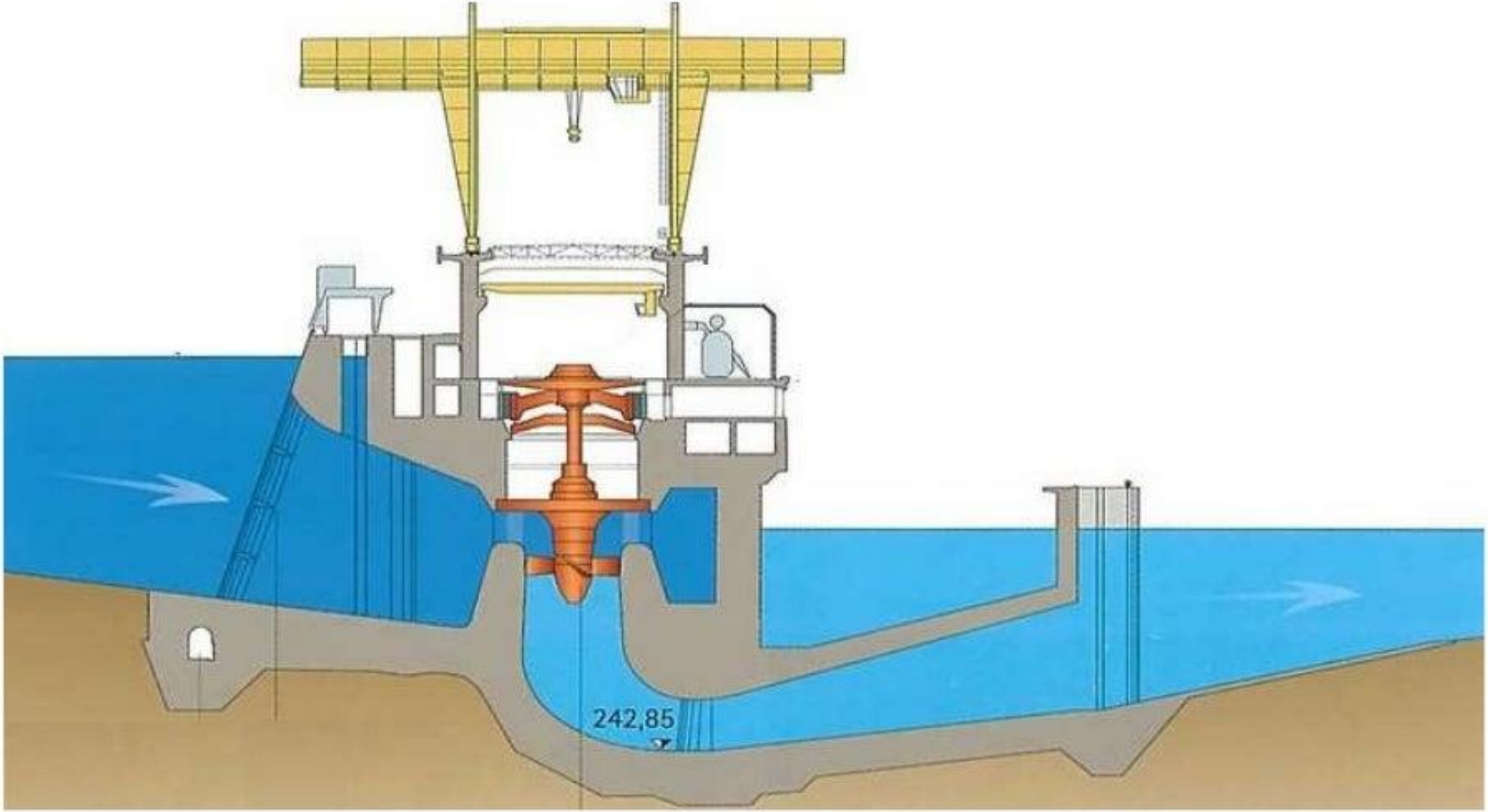


Inward radial flow turbine.

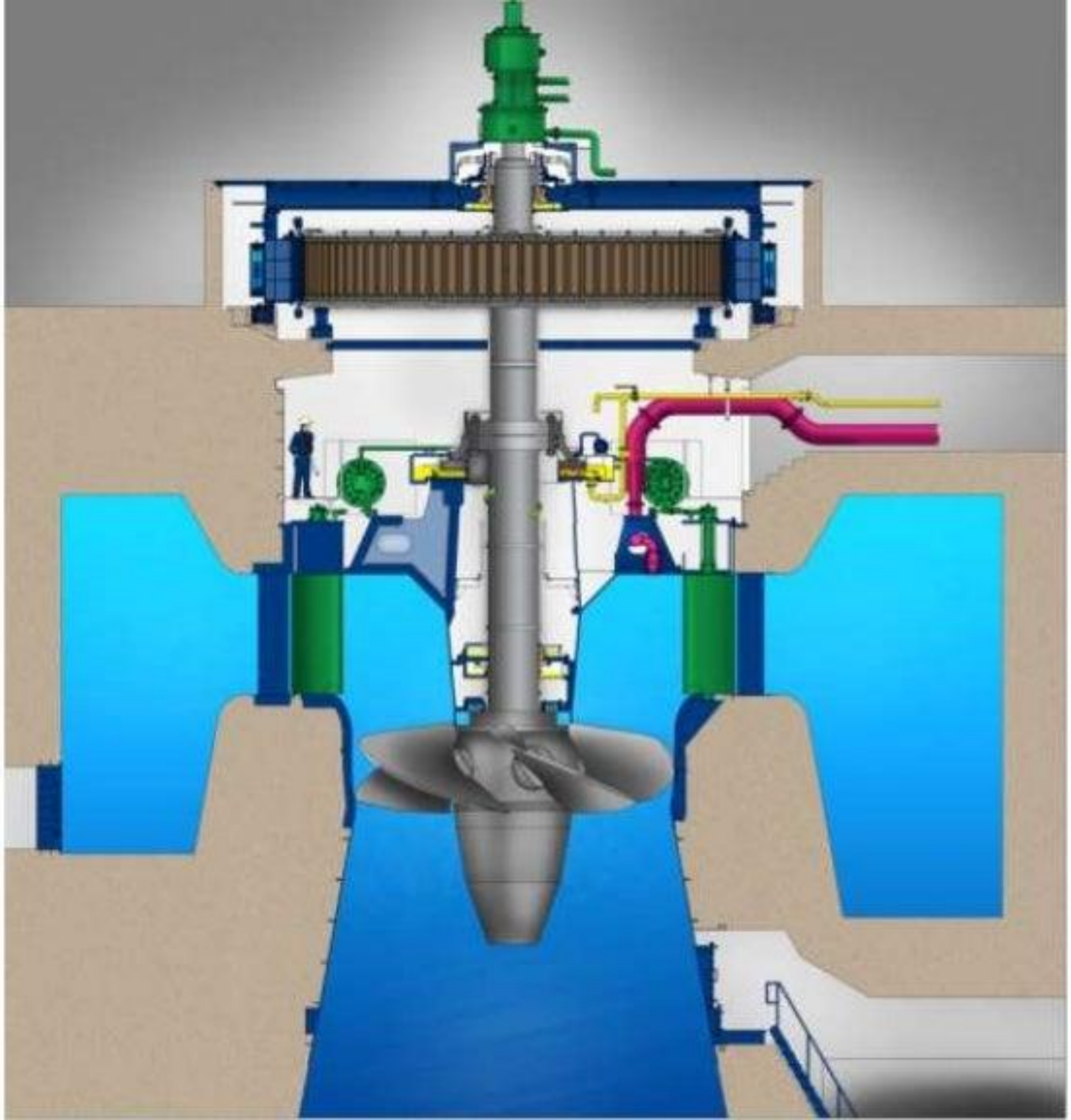
Design of Francis Turbine

Problems:

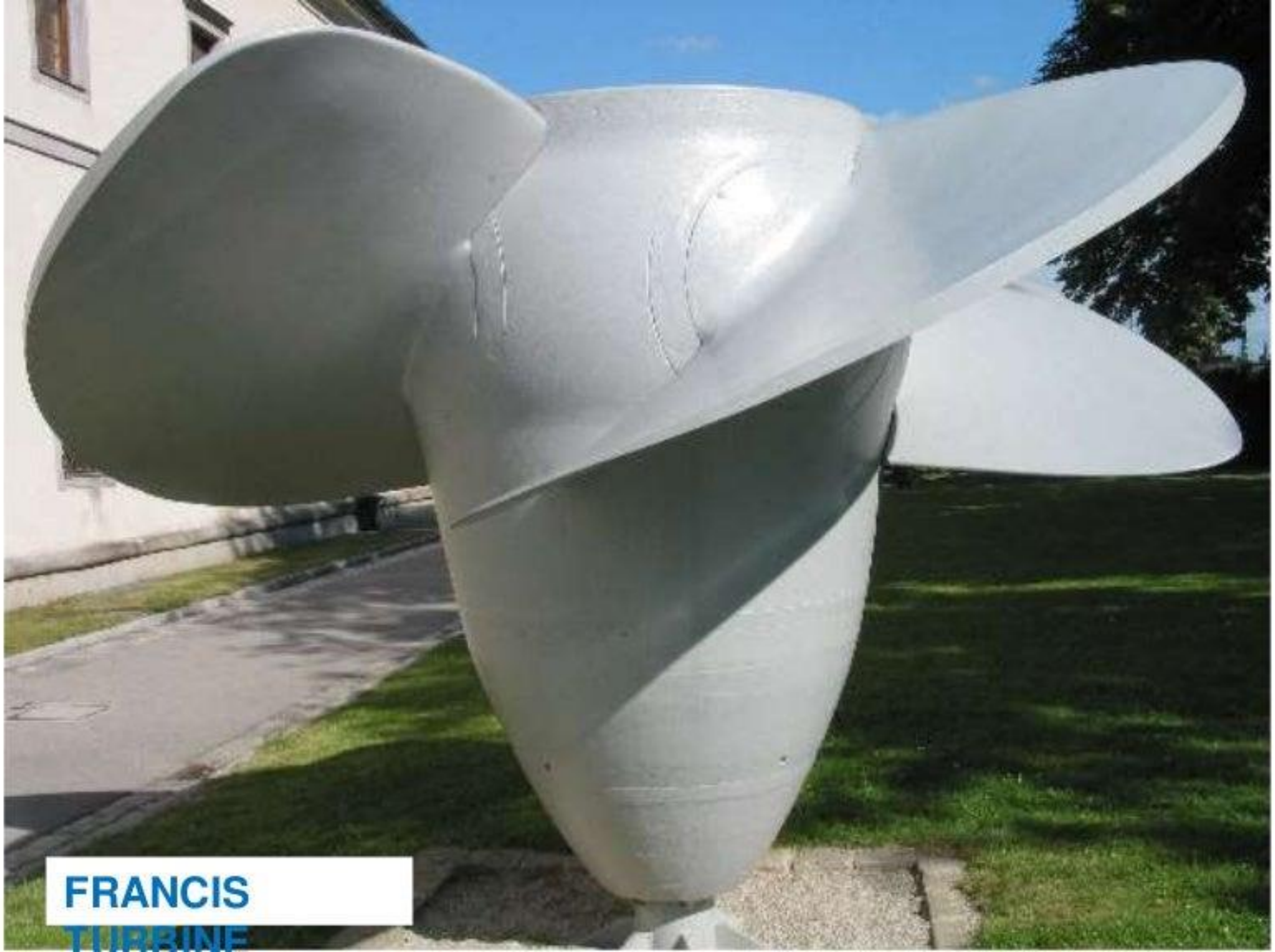
1. A reaction turbine works at 450 rpm under a head of 120 m. Its diameter at inlet is 1.2 m and the flow area is 0.4 m^2 . The angle made by the absolute and relative velocities at inlet are 20º and 60º respectively with the tangential velocity. Determine
   (i) the discharge through the turbine
   (ii) power developed   (iii) efficiency.
   Assume radial discharge at outlet.
2. A Francis turbine has inlet wheel diameter of 2 m and outlet diameter of 1.2 m. The runner runs at 250 rpm and water flows at 8 cumecs. The blades have a constant width of 200 mm. If the vanes are radial at inlet and the discharge is radially outwards at exit, make calculations for the angle of guide vane at inlet and blade angle at outlet



KAPLAN TURBINE



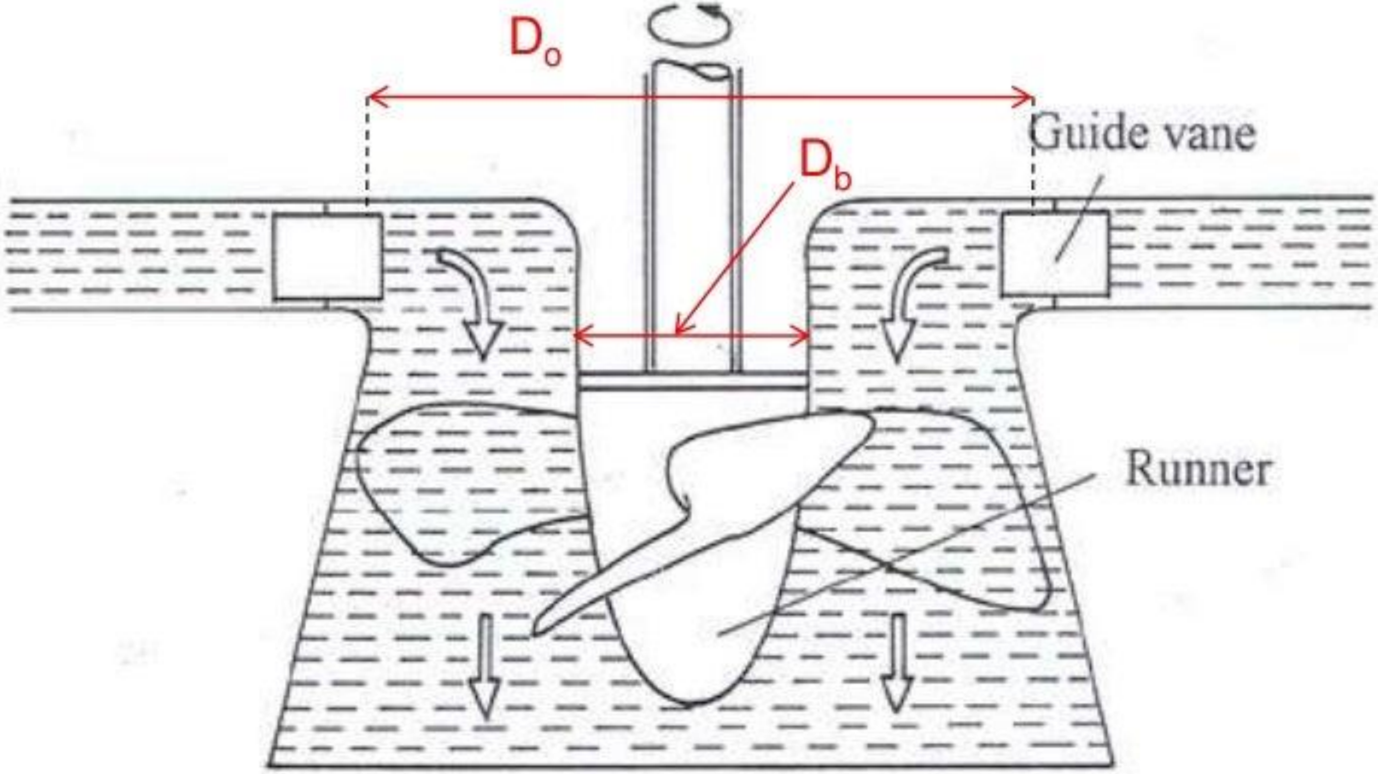
KAPLAN TURBINE


FRANCIS

Design of Kaplan Turbine

Guidelines:

1. Velocity of Wheel, $u_1 = u_2 = \frac{\pi D_m \times N}{60}$ where Mean diameter, $D_m = \frac{D_o + D_b}{2}$
2. Work done per second = $\rho a V_1 [V_{w_1} + V_{w_2}] \times u = \rho Q [V_{w_1} + V_{w_2}] \times u$
3. Velocity of Flow at Inlet and Outlet are equal $V_{f_1} = V_{f_2}$
4. Discharge, $Q = \frac{\pi}{4}\left(D_o^2 - D_b^2\right) \times V_{f_1}$
5. Flow Ratio = $\frac{V_{f_1}}{\sqrt{2gH}}$



Kaplan Turbine

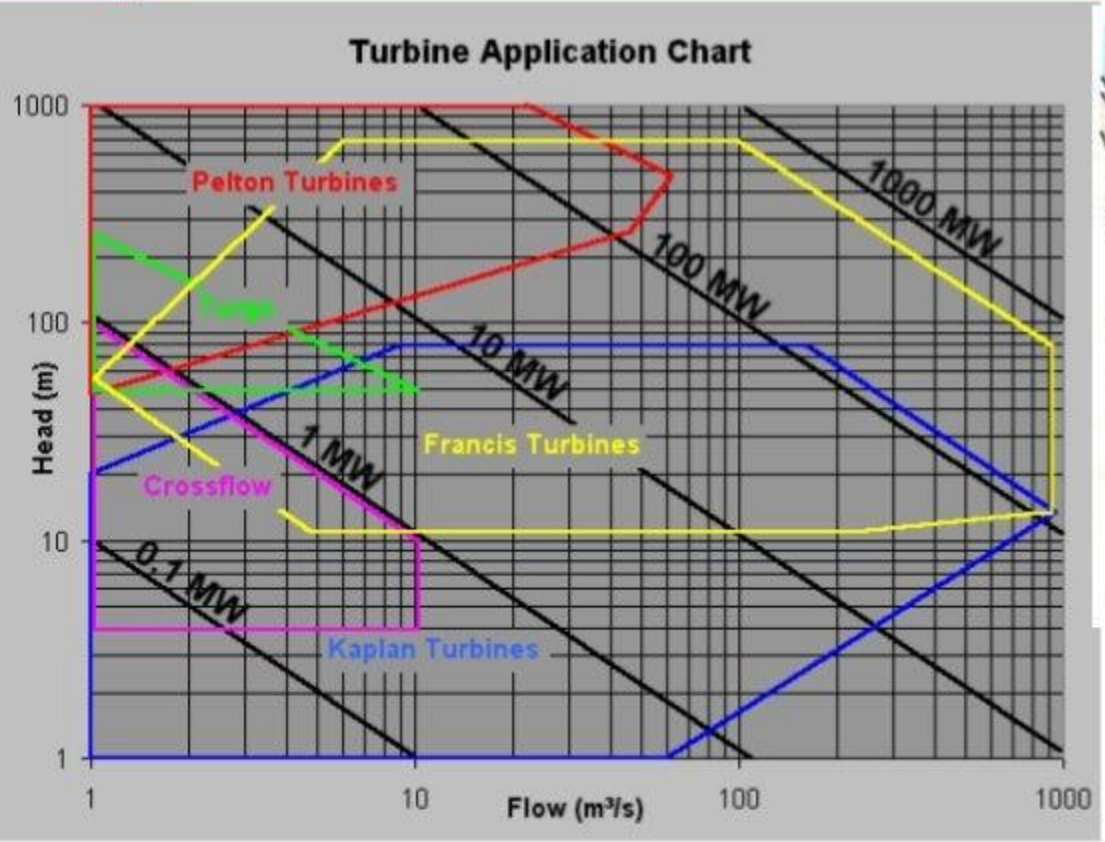
$$Q = \frac{\pi}{4}\left(D_o^2 - D_b^2\right) \times V_{f_1}$$

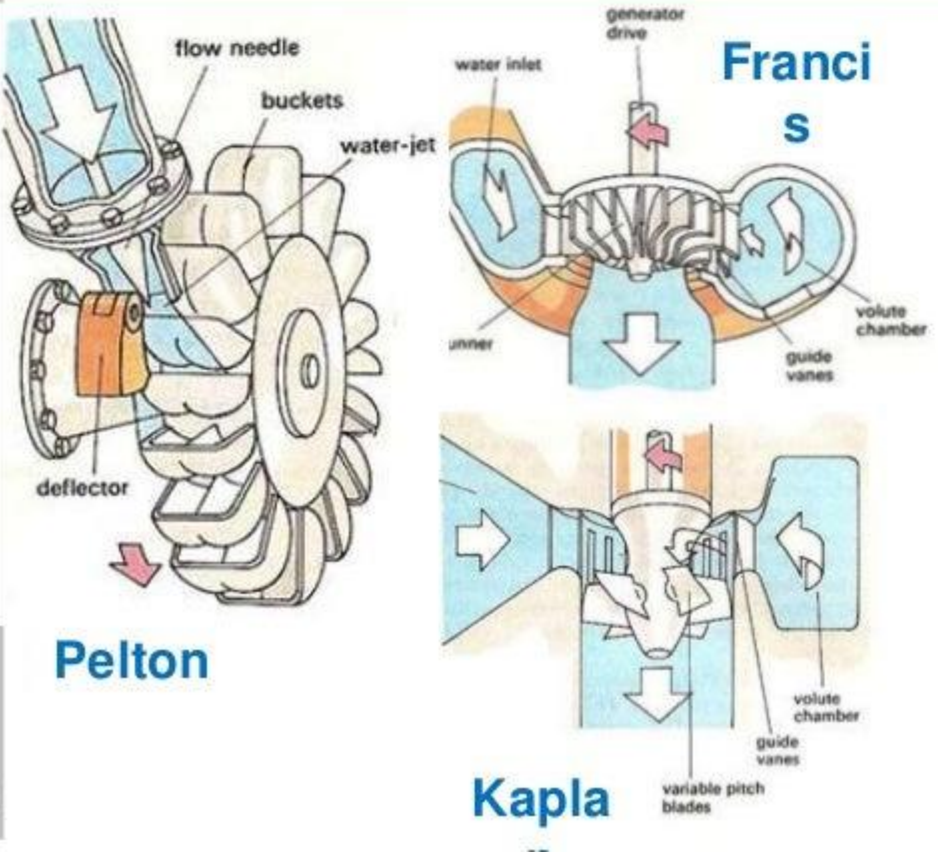
Design of Kaplan Turbine

Problems:

1. A Kaplan turbine develops 9000 kW under a net head of 7.5 m. Overall efficiency of the wheel is 86% The speed ratio based on outer diameter is 2.2 and the flow ratio is 0.66. Diameter of the boss is 0.35 times the external diameter of the wheel. Determine the diameter of the runner and the specific speed of the runner.
2. A Kaplan turbine working under a head of 25 m develops 16,000 kW shaft power. The outer diameter of the runner is 4 m and hub diameter is 2 m. The guide blade angle is 35°. The hydraulic and overall efficiency are 90% and 85% respectively. If the velocity of whirl is zero at outlet, determine runner vane angles at inlet and outlet and speed of turbine.

Selection of Turbine



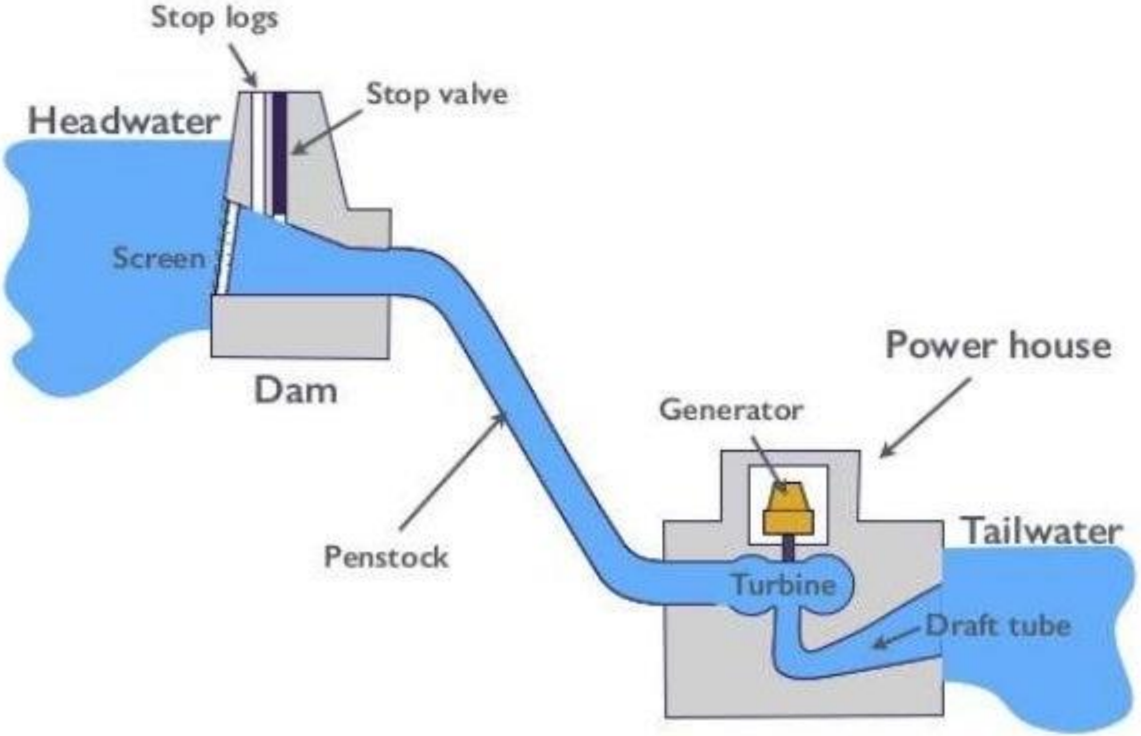


Draft Tube

The water after working on the turbine, imparts its energy to the vanes and runner, there by reducing its pressure less than that of atmospheric Pressure. As the water flows from higher pressure to lower Pressure, It can not come out of the turbine and hence a divergent tube is Connected to the end of the turbine.

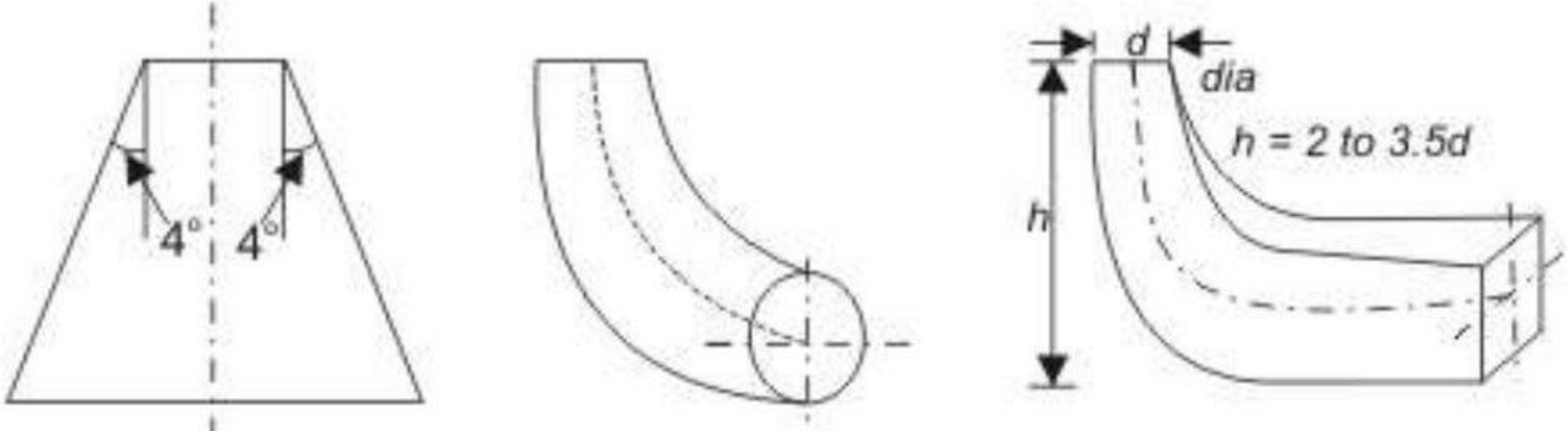
Draft tube is a divergent tube one end of which is connected to the outlet Of the turbine and other end is immersed well below the tailrace (Water level).

The major function of the draft tube is to increase the pressure from the inlet to outlet of the draft tube as it flows through it and hence increase it more than atmospheric pressure. The other function is to safely Discharge the water that has worked on the turbine to tailrace.


Stop logs
Stop valve
Headwater
Screen
Dam
Power house
Generator
Tailwater
Penstock
Turbine
Draft tube

Draft Tube

Types of Draft Tube



(a) Straight type

(b) Simple elbow type

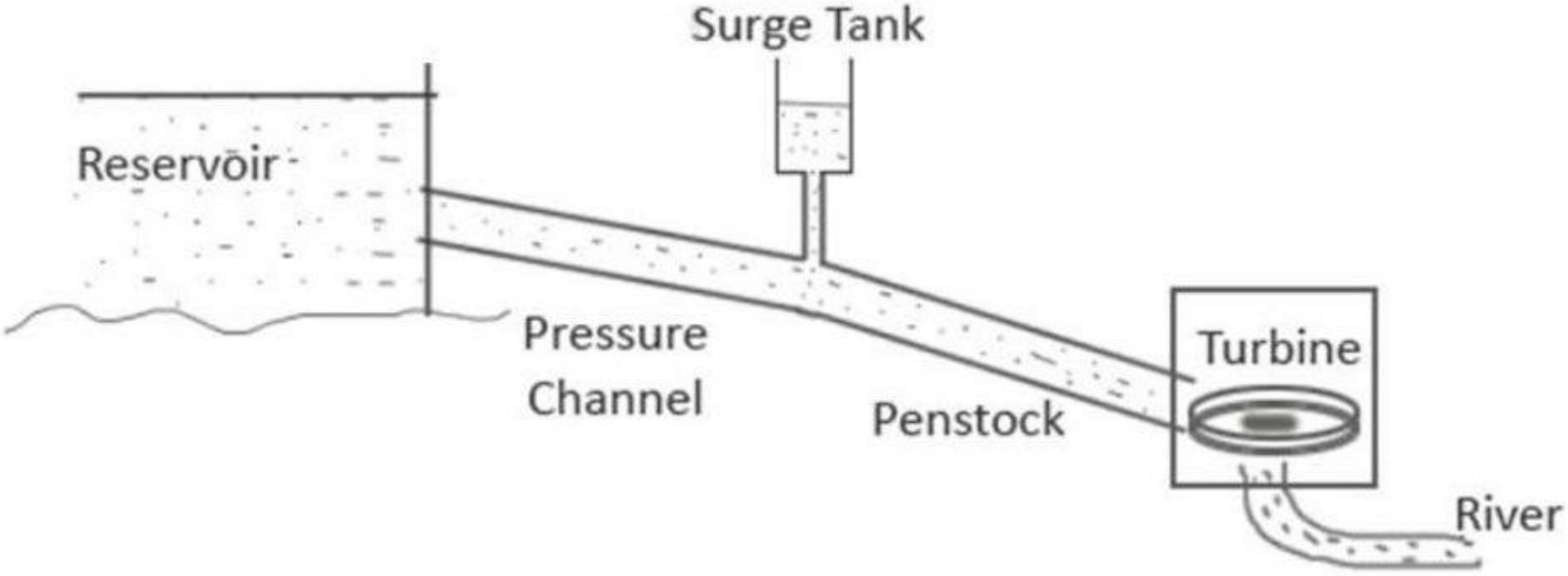
(c) Elbow type with varying cross-section

Surge Tanks

Surge tank (or surge chamber) is a device introduced within a hydropower water conveyance system having a rather long pressure conduit to absorb the excess pressure rise in case of a sudden valve closure. The surge tank is located between the almost horizontal or slightly inclined conduit and steeply sloping penstock and is designed as a chamber excavated in the mountain.

It also acts as a small storage from which water may be supplied in case of a sudden valve opening of the turbine.

In case of a sudden opening of turbine valve, there are chances of penstock collapse due to a negative pressure generation, if there is no surge tank.


Surge Tank
Reservoir
Pressure
Channel
Penstock
Turbine
River

Surge Tank

Governing of Turbines

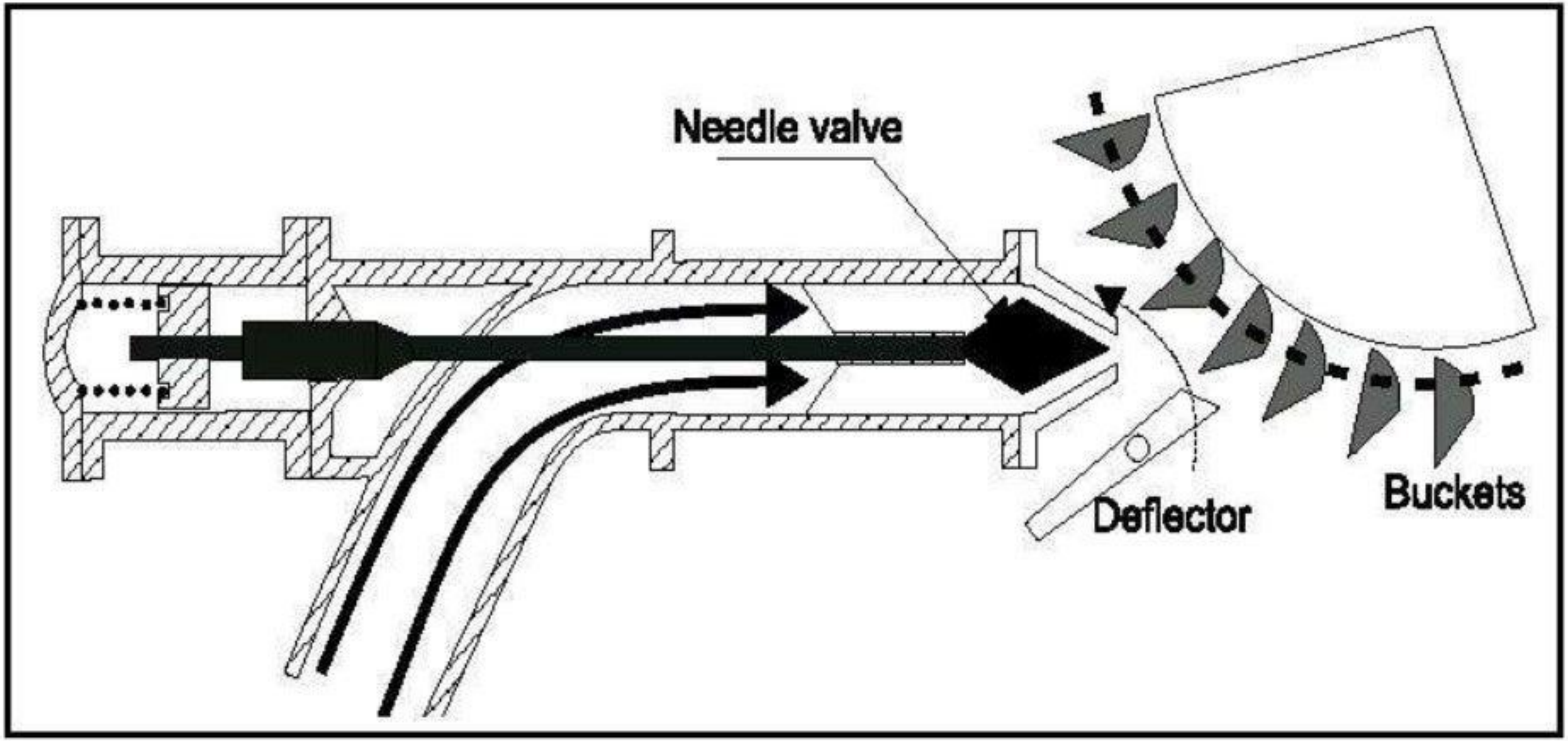
Governing means Speed Regulation.

Governing system or governor is the main controller of the hydraulic turbine. The governor varies the water flow through the turbine to control its speed or power output.

1. Impulse Turbine

a) Spear Regulation
b) Deflector Regulation
c) Combined

2. Reaction Turbine



Governor of Pelton Wheel

Performance of Turbines under unit quantities

The unit quantities give the speed, discharge and power for a particular turbine under a head of 1m assuming the same efficiency. Unit quantities are used to predict the performance of turbine.

1. Unit speed (N_u) - Speed of the turbine, working under unit head

$$Nu = \frac{N}{\sqrt{H}}$$

2. Unit power (P_u) - Power developed by a turbine, working under a unit head

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

3. Unit discharge (Q_u) - The discharge of the turbine working under a unit head

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

Unit Speed, Unit discharge and Unit Power is definite characteristics of a turbine.

If for a given turbine under heads $H_1, H_2, H_3, \ldots$ the corresponding speeds are $N_1, N_2, N_3, \ldots$, the corresponding discharges are $Q_1, Q_2, Q_3, \ldots$ and the powers developed are $P_1, P_2, P_3, \ldots$. Then

$$\text{Unit speed} = N_u = \frac{N_1}{\sqrt{H_1}} = \frac{N_2}{\sqrt{H_2}} = \frac{N_3}{\sqrt{H_3}}$$

$$\text{Unit Discharge} = Q_u = \frac{Q_1}{\sqrt{H_1}} = \frac{Q_2}{\sqrt{H_2}} = \frac{Q_3}{\sqrt{H_3}}$$

$$\text{Unit Power} = P_u = \frac{P_1}{H\sqrt{H_1}} = \frac{P_2}{H\sqrt{H_2}} = \frac{P_3}{H\sqrt{H_3}} \text{ or } P_u = \frac{P_1}{H_1^{3/2}} = \frac{P_2}{H_2^{3/2}} = \frac{P_3}{H_3^{3/2}}$$

Thus if speed, discharge and power developed by a turbine under a certain head are known, the corresponding quantities for any other head can be determined.

Specific Speed of Turbine

Specific Speed of a Turbine (N_s)

The specific speed of a turbine is the speed at which the turbine will run when developing unit power under a unit head. This is the type characteristics of a turbine. For a set of geometrically similar turbines the specific speed will have the same value.

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

Unit Quantities & Specific Speed

Problems:

1. Suggest a suitable type of turbine to develop 7000 kW power under a head of 20m while operating at 220 rpm. What are the considerations for your suggestion.
2. A turbine is to operate under a head of 25m at 200 rpm. The discharge is 9 m^3/s. If the efficiency is 90%, determine:
   i) Power generated ii) Speed and Power at a head of 20m

Characteristics Curves of Turbine

These are curves which are characteristic of a particular turbine which helps in studying the performance of the turbine under various conditions. These curves pertaining to any turbine are supplied by its manufacturers based on actual tests.

The characteristic curves obtained are the following:

a) Constant head curves or main characteristic curves
b) Constant speed curves or operating characteristic curves
c) Constant efficiency curves or Muschel curves

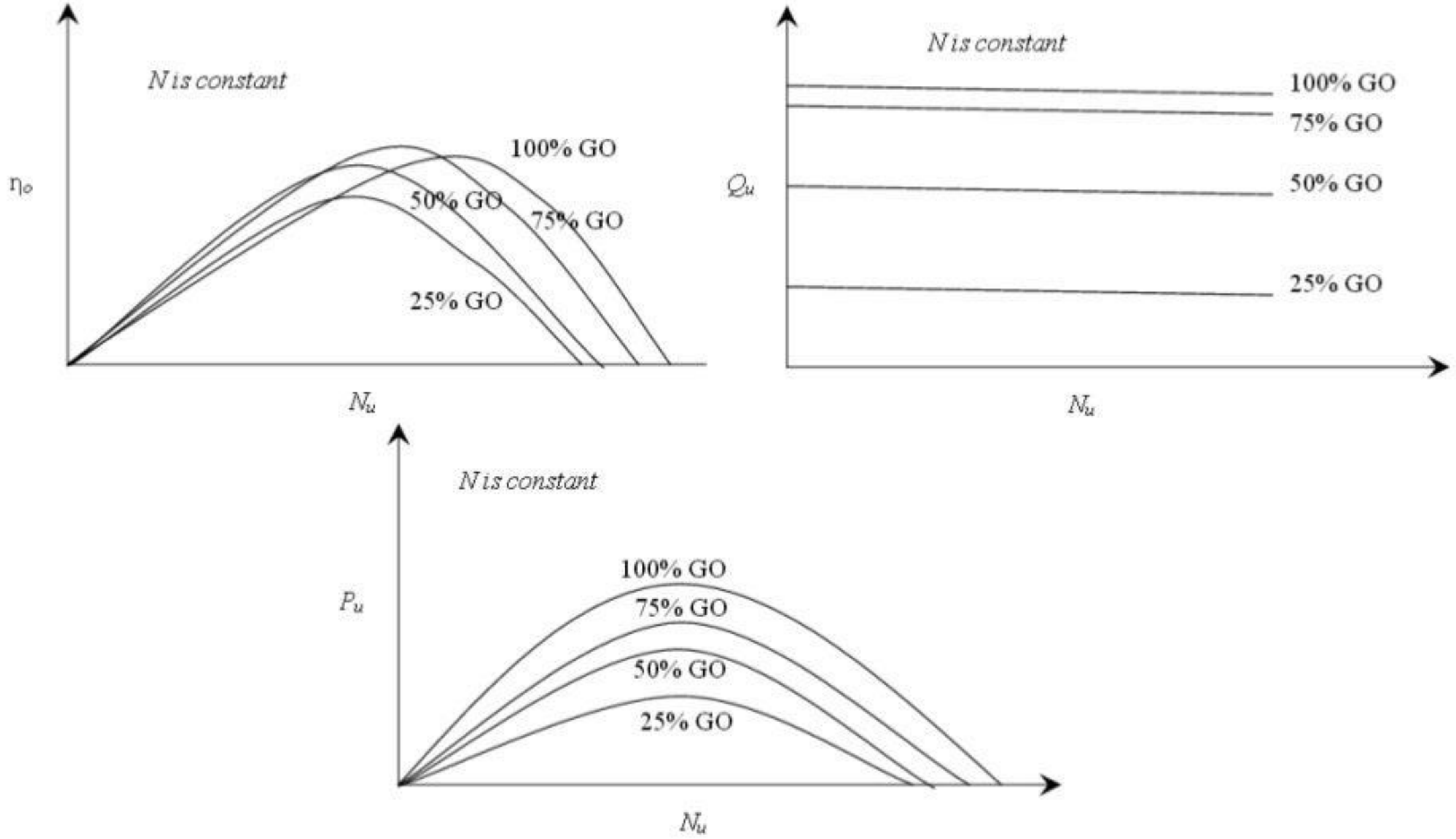
Constant head curves or main characteristic curves

Constant head curves:

Maintaining a constant head, the speed of the turbine is varied by admitting different rates of flow by adjusting the percentage of gate opening. The power P developed is measured mechanically. From each test the unit power Pu, the unit speed Nu, the unit discharge Qu and the overall efficiency are determined.

The characteristic curves drawn are

a) Unit discharge vs unit speed
b) Unit power vs unit speed
c) Overall efficiency vs unit speed



Main Characteristic curves of a Pelton turbine

Constant speed curves or operating characteristic curves

Constant speed curves:

In this case tests are conducted at a constant speed varying the head H and suitably adjusting the discharge Q. The power developed P is measured mechanically. The overall efficiency is aimed at its maximum value.

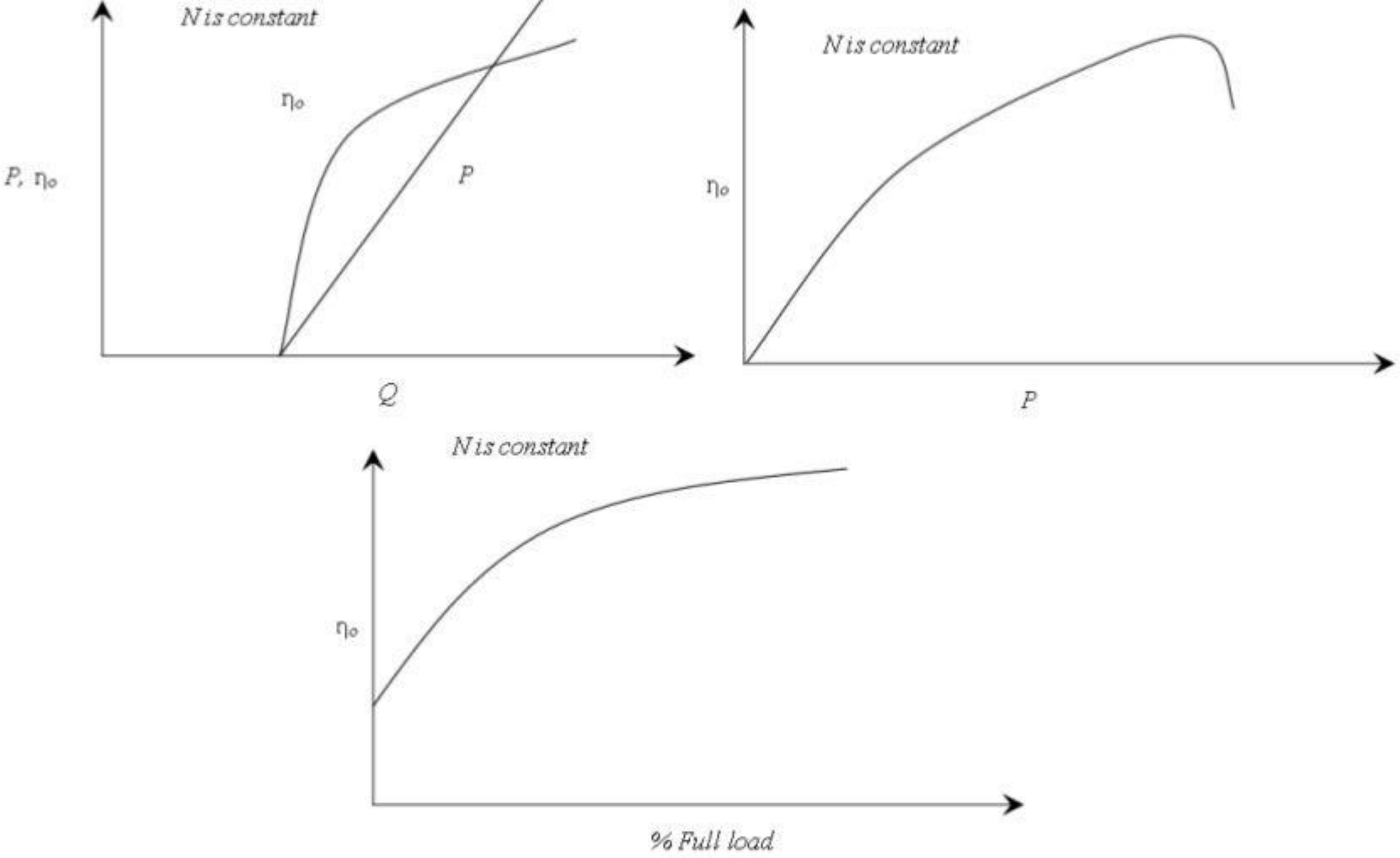
The curves drawn are

P vs Q

η_o vs Q

η_o vs P_u

$\eta_{o\,max}$ vs % Full load



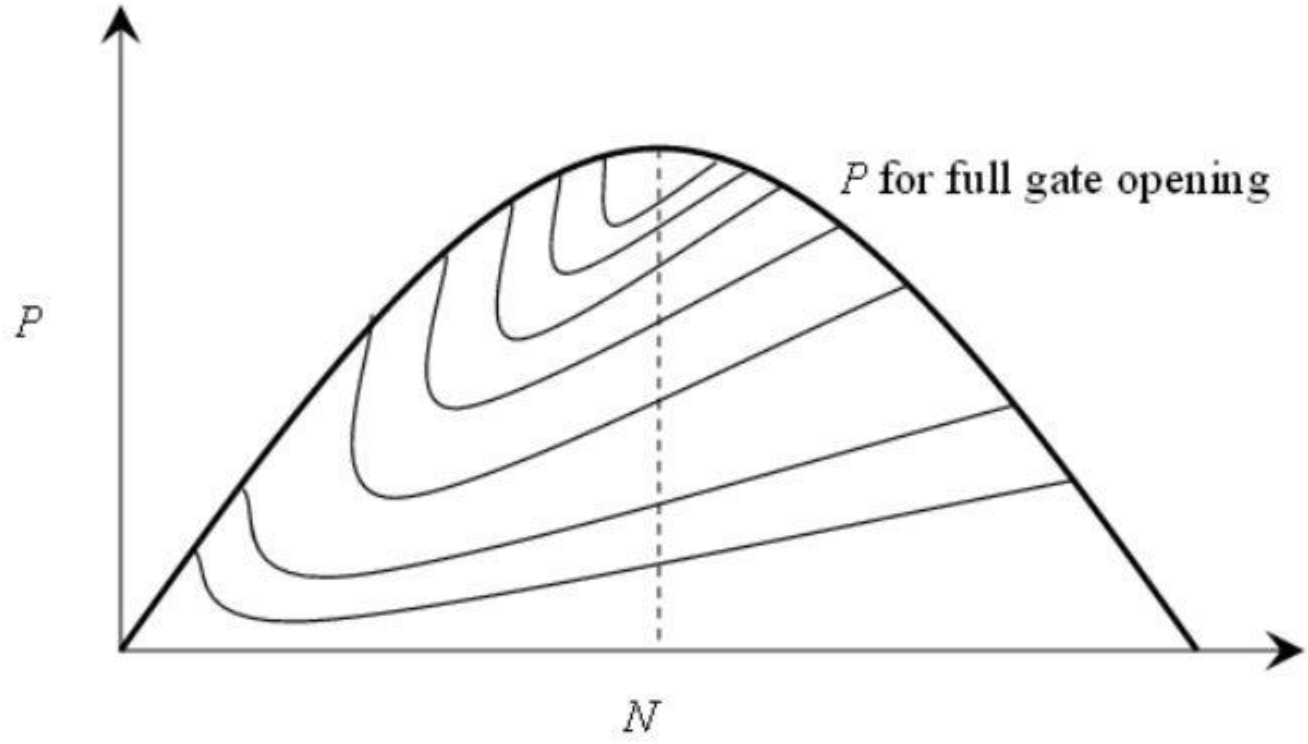
Operating Characteristic curves of a turbine

Constant efficiency curves or Muschel curves

Constant efficiency curves:

These curves are plotted from data which can be obtained from the constant head and constant speed curves. The object of obtaining this curve is to determine the zone of constant efficiency so that we can always run the turbine with maximum efficiency.

This curve also gives a good idea about the performance of the turbine at various efficiencies.



Constant Efficiency curves for Reaction turbine

Similitude of Turbines

Dimensionless Numbers:

$$\frac{Q}{ND^3}, \frac{gH}{N^2D^2}, \frac{P}{\rho N^3D^5}$$

Where

Q = Discharge

N = Speed of Wheel

D = Dia. of Wheel

H = Head

P = Shaft Power

Similitude of Turbines - Problems

Problems:

1. A hydraulic turbine develops 120 KW under a head of 10 m at a speed of 1200 rpm and gives an efficiency of 92%. Find the water consumption and the specific speed. If a model of scale 1: 30 is constructed to operate under a head of 8m what must be its speed, power and water consumption to run under the conditions similar to prototype.
2. A model turbine 1m in diameter acting under a head of 2m runs at 150 rpm. Estimate the scale ratio if the prototype develops 20 KW under a head of 225 m with a specific speed of 100.

Cavitations

If the pressure of a liquid in course of its flow becomes equal to its vapour pressure at the existing temperature, then the liquid starts boiling and the pockets of vapour are formed which create vapour locks to the flow and the flow is stopped. The phenomenon is known as **cavitation**.

To avoid cavitation, the minimum pressure in the passage of a liquid flow, should always be more than the vapour pressure of the liquid at the working temperature. In a reaction turbine, the point of minimum pressure is usually at the outlet end of the runner blades, i.e., at the inlet to the draft tube.

Methods to avoid Cavitations

(i) Runner/turbine may be kept under water.

(ii) Cavitation free runner may be designed.

(iii) By selecting materials that can resist better the cavitation effect.

(iv) By polishing the surfaces.

(v) By selecting a runner of proper specific speed for given load.

Reference

Chapter 18

A Textbook of Fluid Mechanics and Hydraulic Machines

Dr. R. K. Bansal
Laxmi Publications