UNIT II

Reaction Water Turbines

Turbo Machines

DEPARTMENT OF MECHANICAL ENGINEERING

Syllabus for Unit-II

Classifications, Francis, Propeller, Kaplan Turbines, construction features, velocity diagrams and analysis, DOR, draft tubes- types and analysis, cavitations causes and remedies, specific speed, performance characteristics and governing of reaction turbines, selection of turbines.

What are Hydraulic Machines?

- **Machines which convert hydraulic energy(energy possessed by water) into mechanical energy(which is further converted into electrical energy)-*Turbines.***
- **Machines which convert mechanical energy into hydraulic energy-*Pumps.***

Hydraulic Turbines

- **Hydraulic Turbines convert hydraulic energy of water into mechanical energy which is further converted into electrical energy. This energy obtained is known as hydro-electric power which is one of the cheapest forms of energy generation.**
- **Hydraulic turbines consist of Pelton Wheel, Francis Turbine and Kaplan Turbine.**

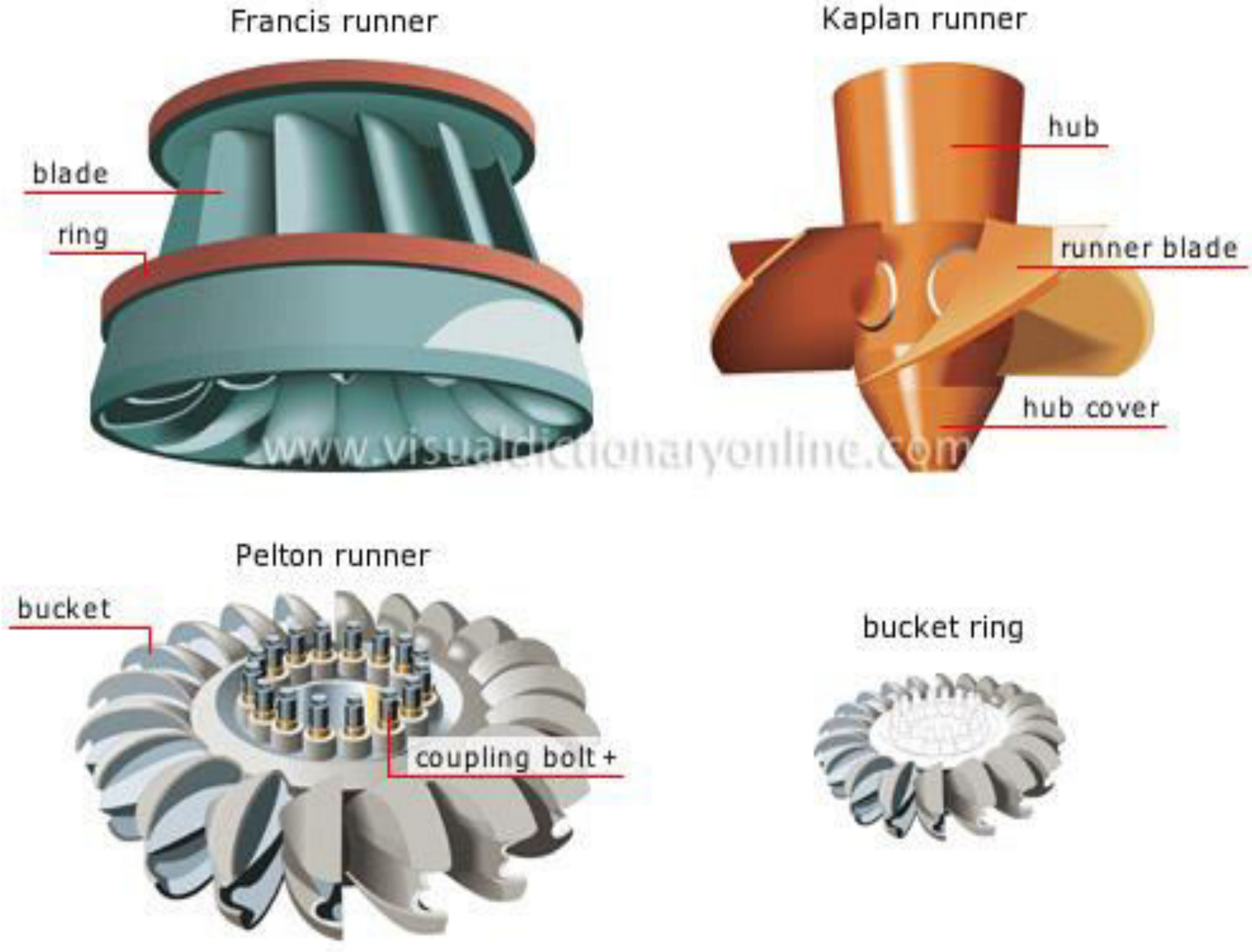
Comparison of IMPULSE and REACTION turbine

Impulse Turbine	Reaction Turbine
HE → KE → ME	HE → KE+PE → ME
Principal of Impulse	Principal of Impulse-reaction
Wheel revolves in open air	Wheel submerge in water
No pressure difference at I/L and O/L of runner	Pressure difference at I/L and O/L of runner
Casing has not to perform any hydraulic function Casing has to prevent splashing of water	Involute Casing has to perform hydraulic function i e to produce moment on the runner
$P_1 = P_2 = Patm$ V1 >>> V2	P_1>P2 V1 > V2
Pelton, Girard, Turgo, Banki	Francis, Kaplan, Propeller

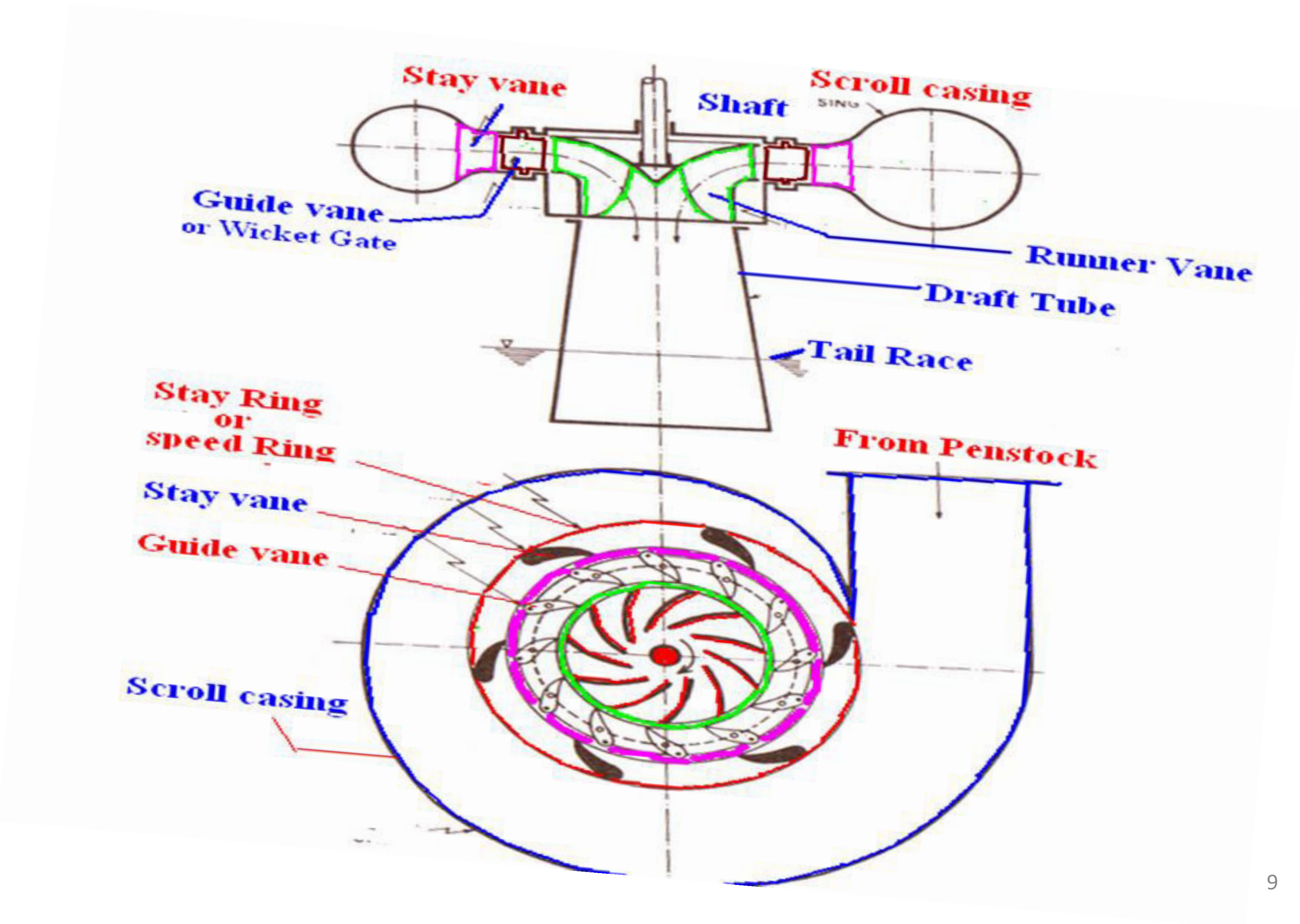
• Impulse Turbine	• Reaction Turbine
Used for high head	Used for low head
Energy transfer takes place due to impulsive action	Energy transfer takes place due to reaction between flowing water and vane surface & impulsive action
Casing need not be air tight	Casing must be air tight
No cavitation	Cavitation occur
For same head and power size of turbine is large	Relatively small
Simple in construction but poor efficiency	Complicated in construction but relatively high efficiency

Francis Turbine

- Francis Turbine is the first hydraulic turbine with radial inflow. It was designed by an American scientist James Francis. If the water flows radially through the runner , from outwards to inwards then it is known as an *inward radial flow turbine*.
- Francis turbine is a reaction turbine as the energy available at the inlet of the turbine is a combination of kinetic and pressure energy.


Francis runner
blade
ring
Kaplan runner
hub
runner blade
hub cover
Pelton runner
bucket
coupling bolt +
bucket ring

Francis Turbine

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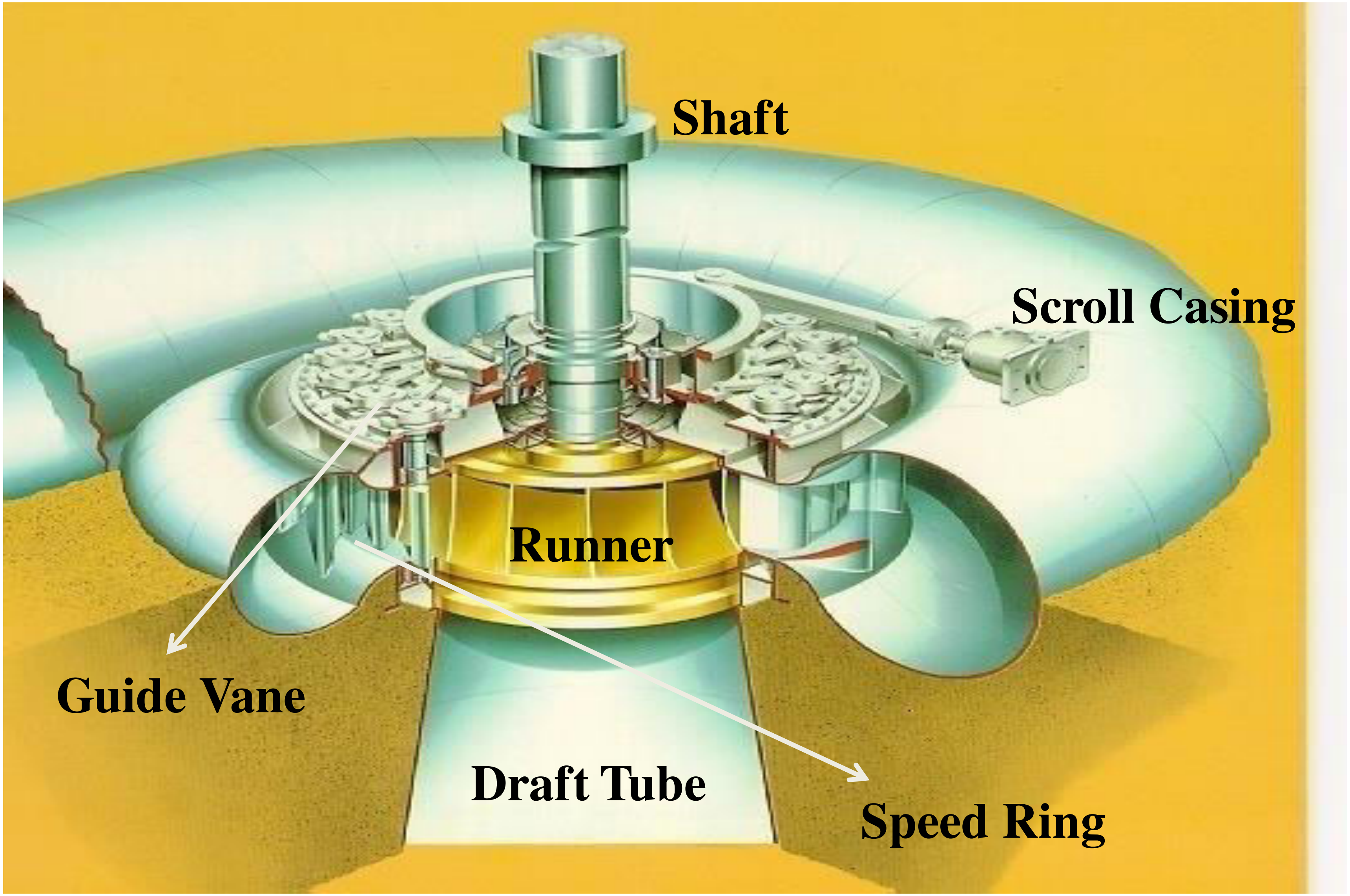
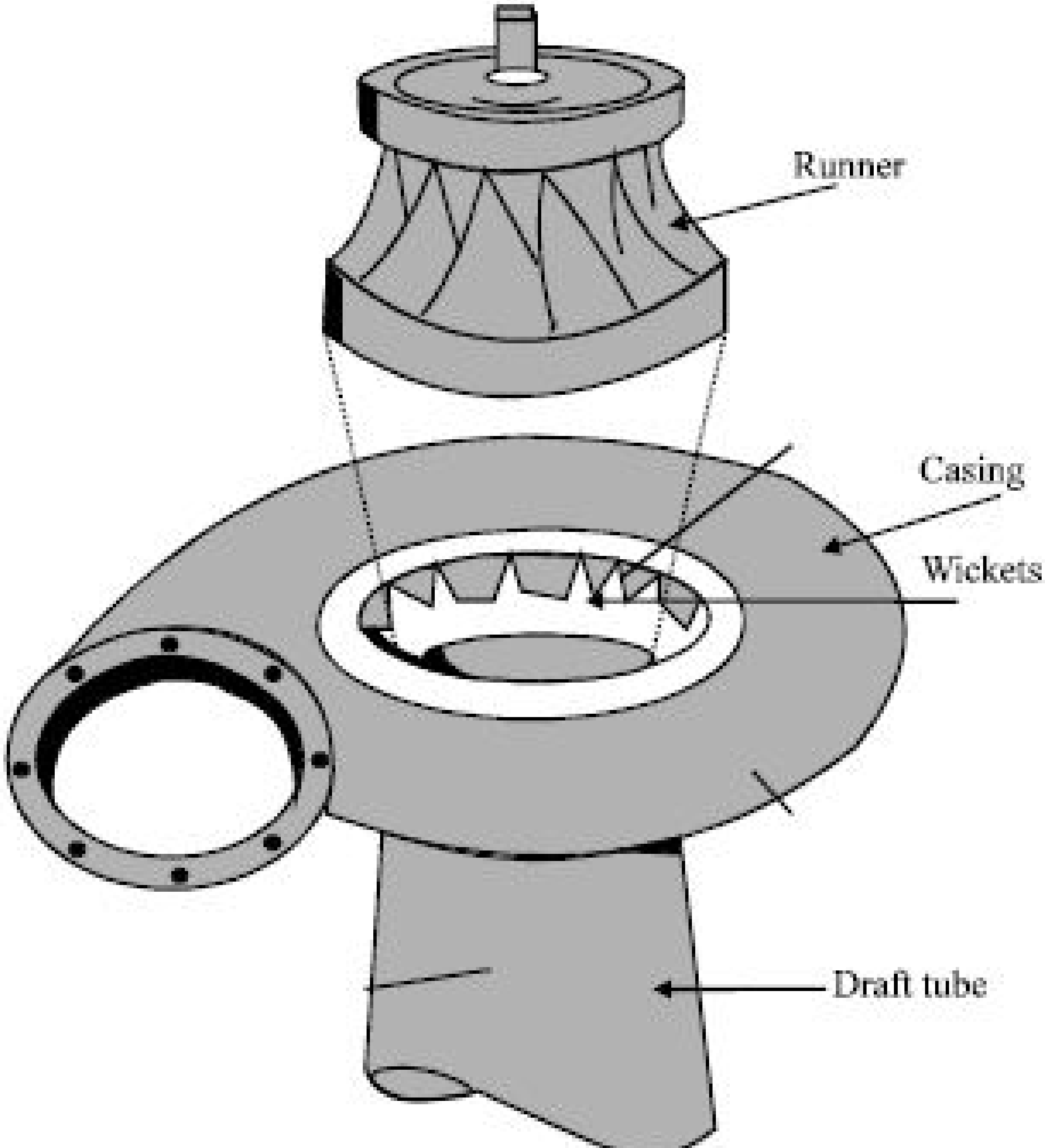
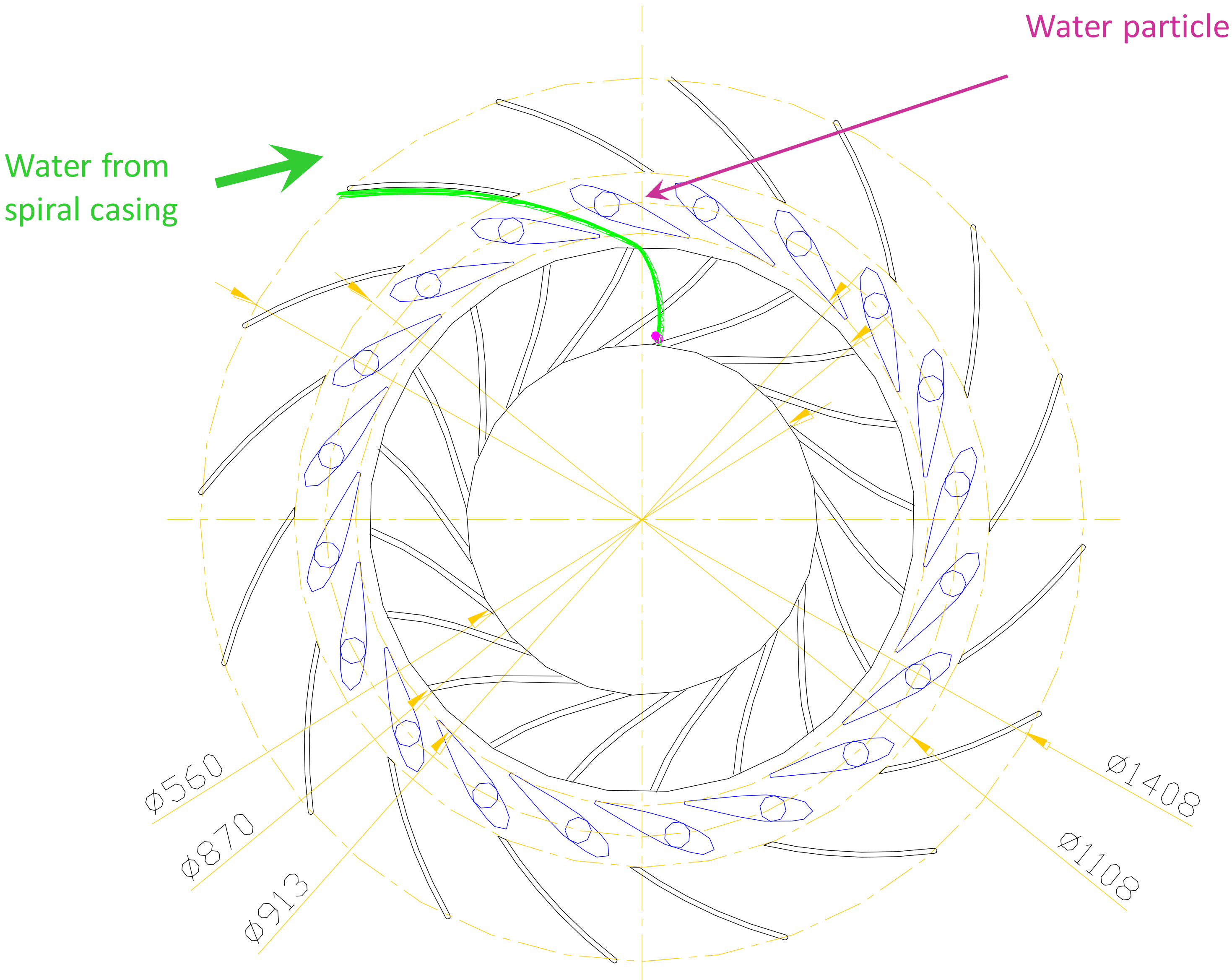
Guide Vanes

Francis turbines




Runner
Casing
Wickets
Draft tube

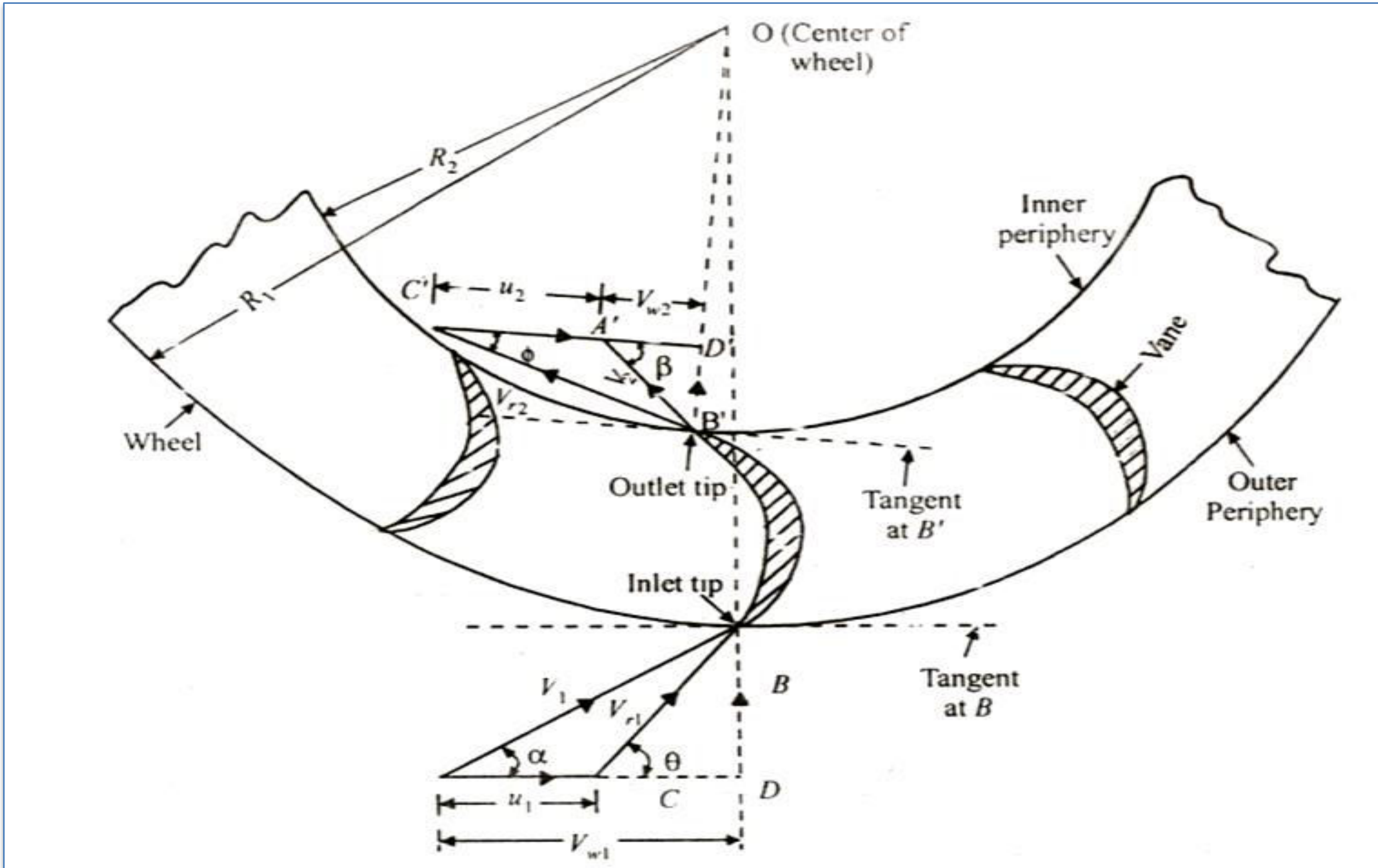


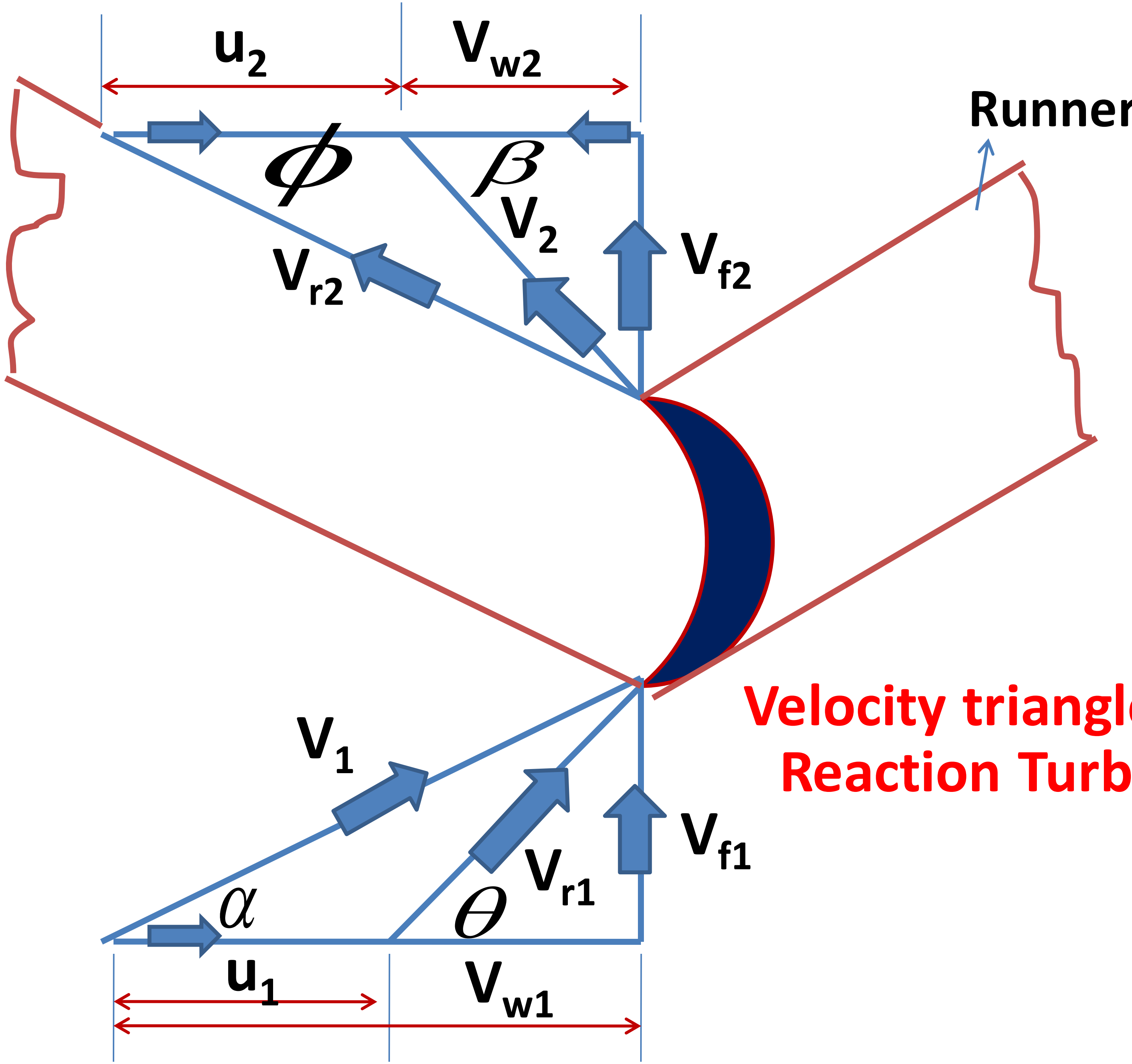
Radial view
runner guide vanes and stay vanes

Main parts of a Francis Turbine

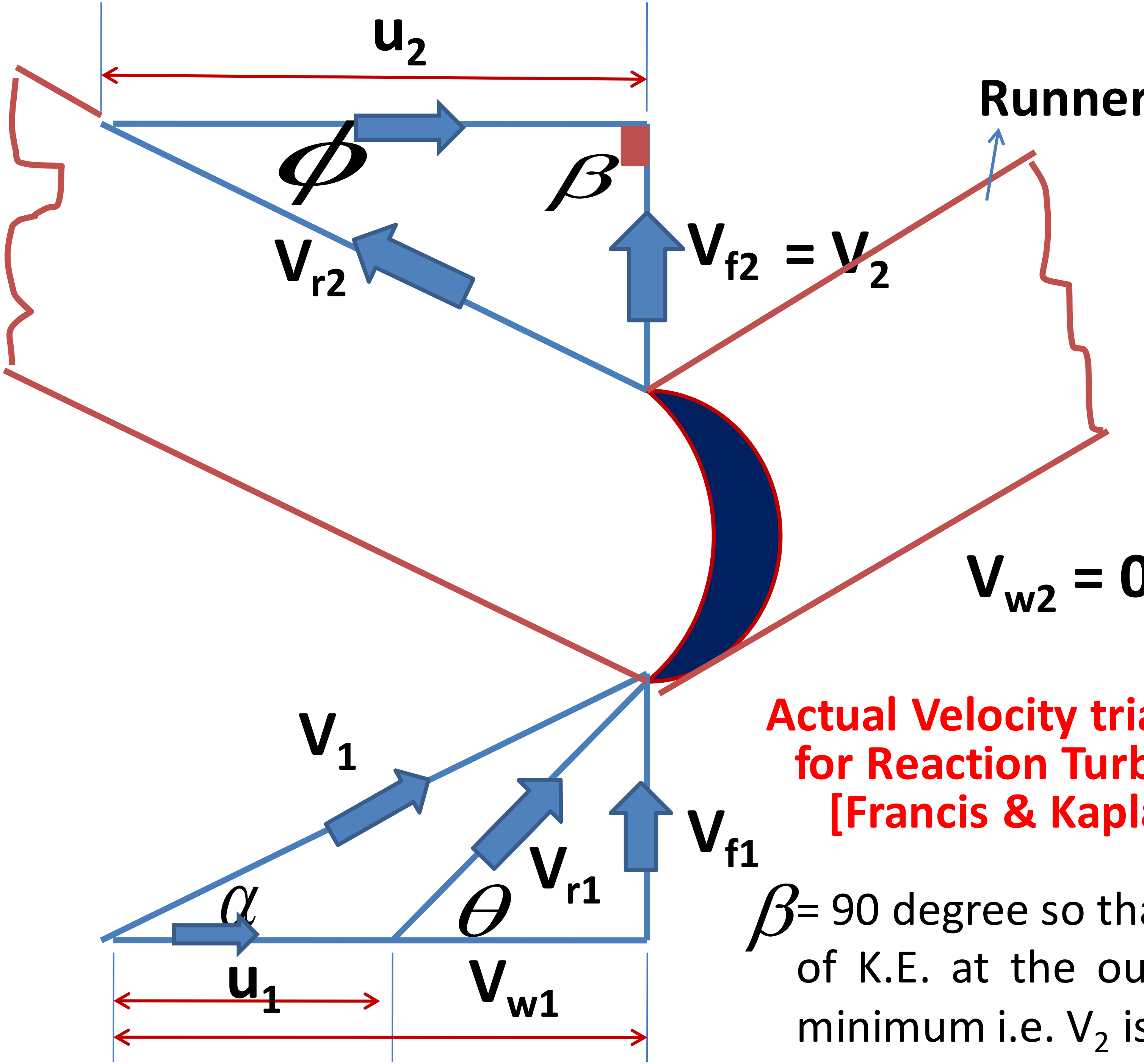
- **CASING**: The runner is completely enclosed in an air-tight spiral casing. The casing and runner are always full of water.
- **GUIDE MECHANISM**: It consists of a stationary circular wheel on which stationary guide vanes are fixed. The guide vanes allow the water to strike the vanes of the runner without shock at inlet
- **RUNNER**: It is a circular wheel on which a series of curved radial guide vanes are fixed.
- **DRAFT TUBE**: It is used for discharging water from the outlet of the runner to the tail race.

Force exerted on series of radial curved vanes



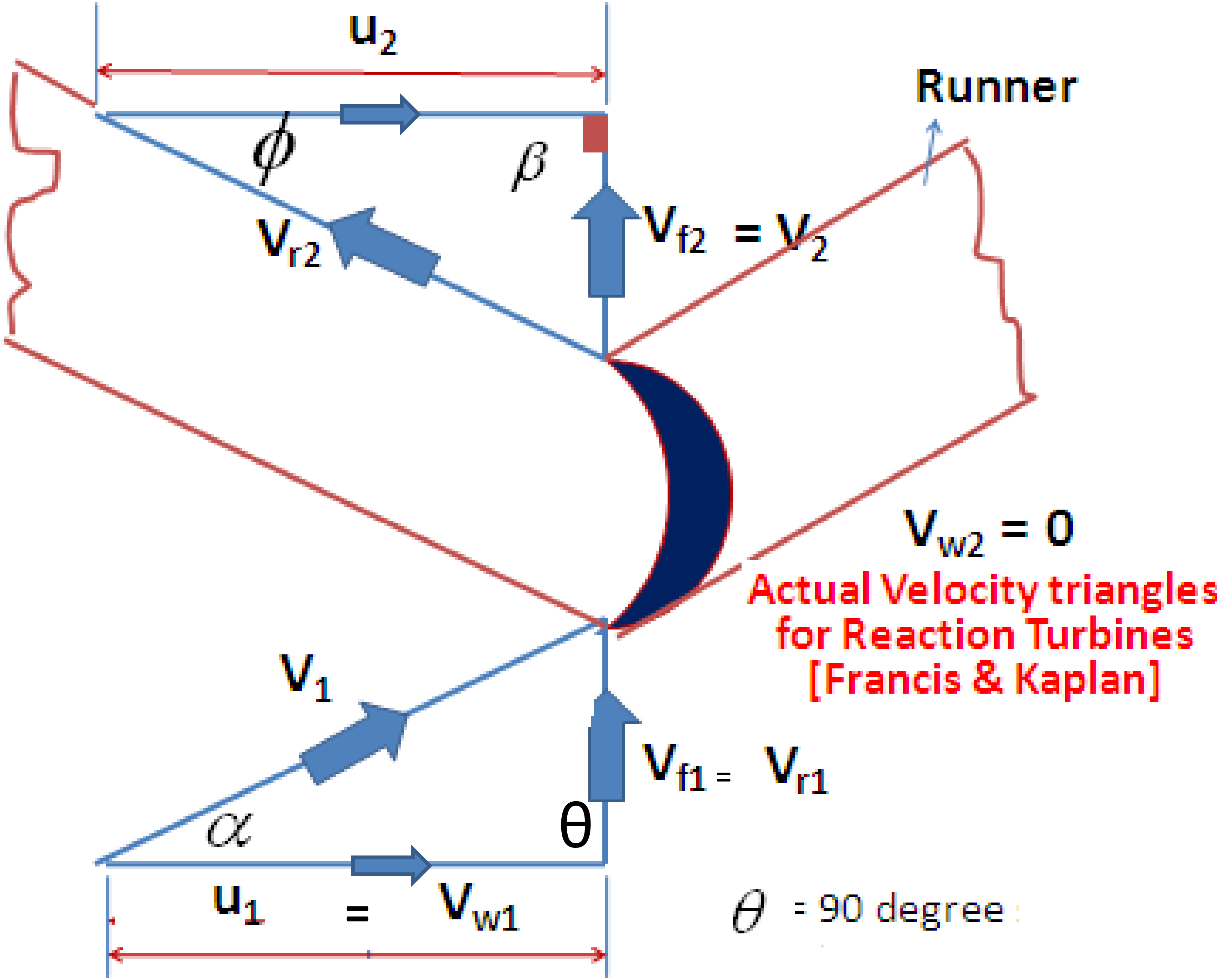


Velocity triangles for Reaction Turbines

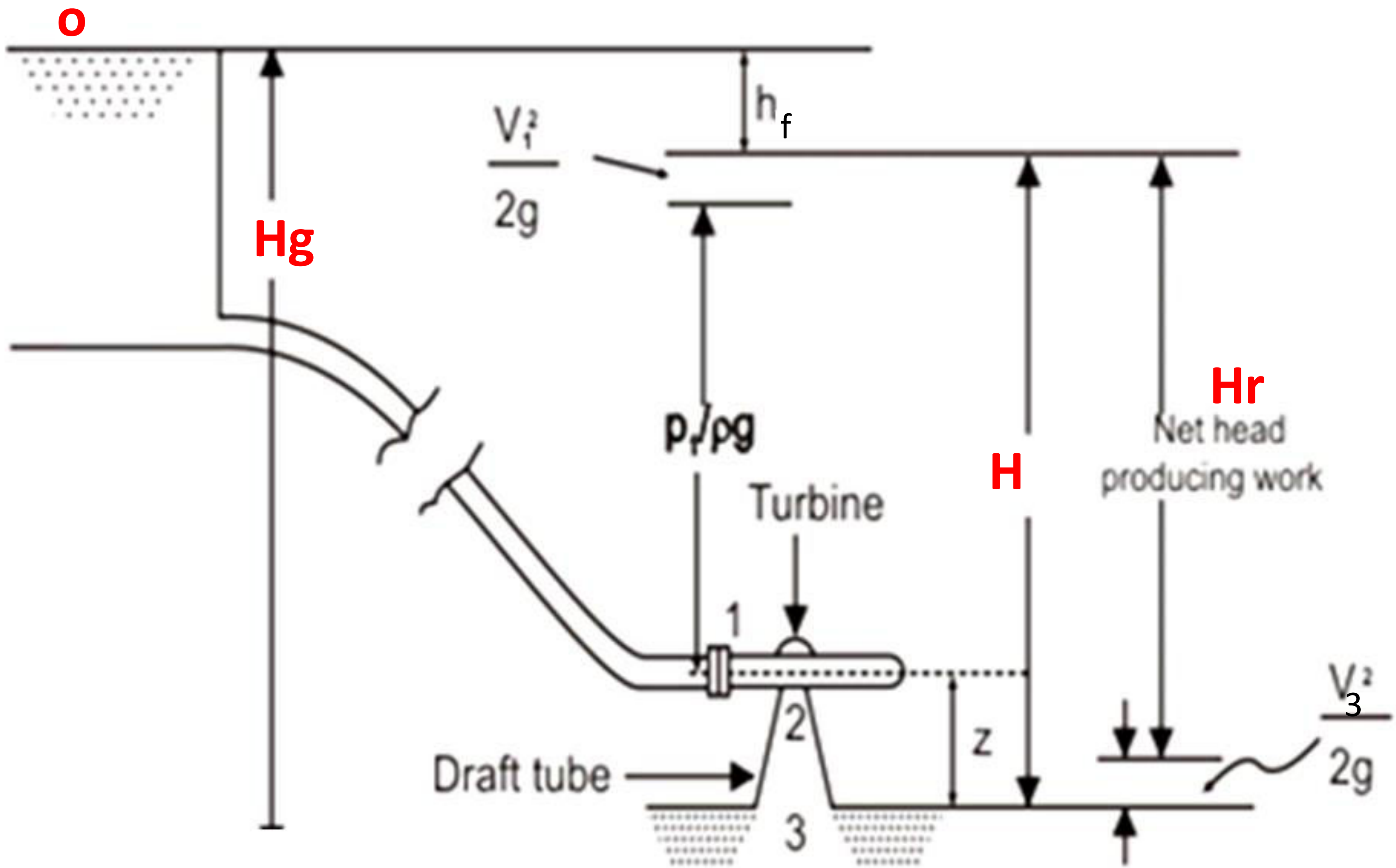


Actual Velocity triangles for Reaction Turbines [Francis & Kaplan]

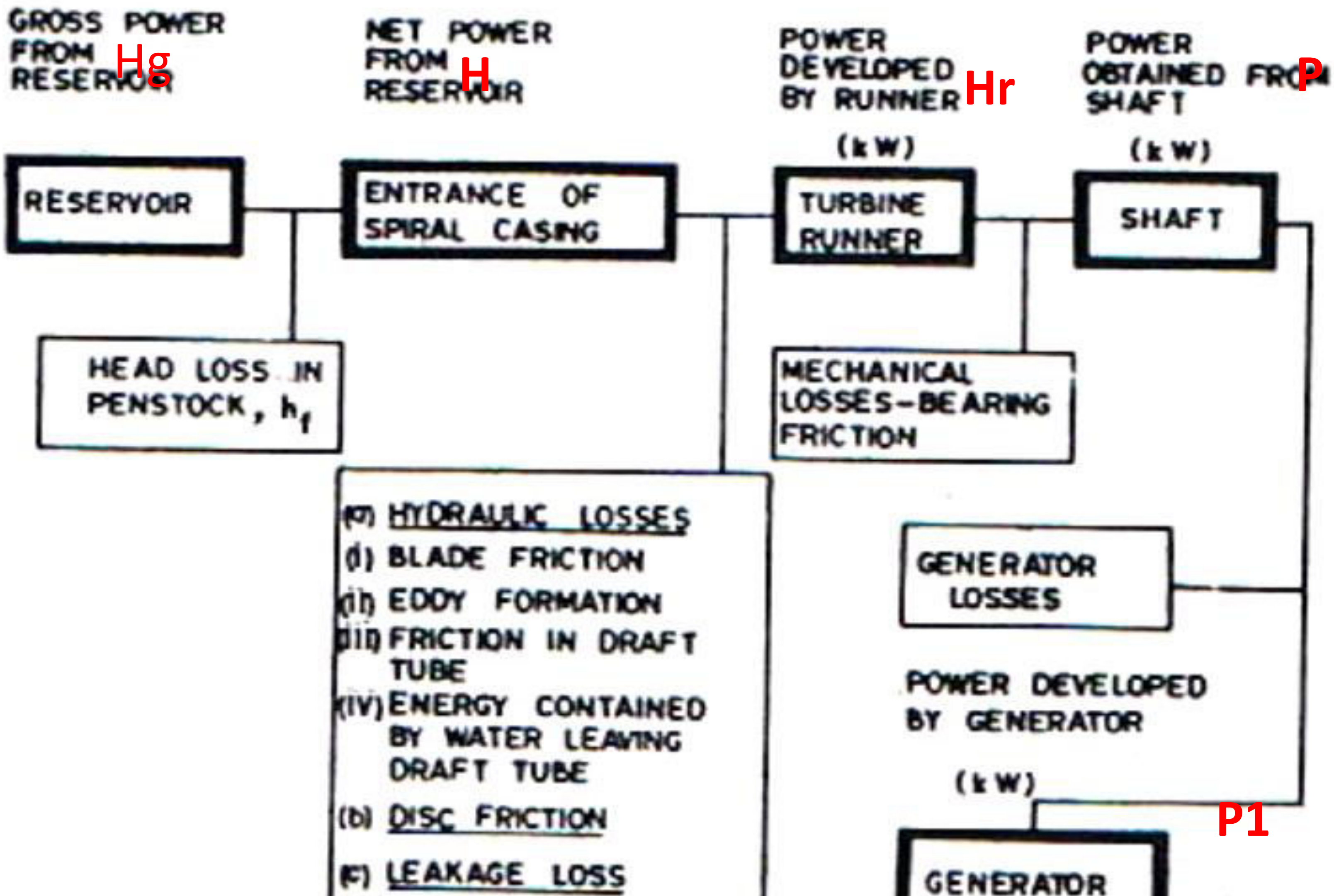
β = 90 degree so that loss of K.E. at the outlet is minimum i.e. V_2 is min.


u2
Runner
ϕ
β
Vr2
Vf2 = V2
Vw2 = 0
Actual Velocity triangles
for Reaction Turbines
[Francis & Kaplan]
V1
Vf1 = Vr1
α
θ
u1 = Vw1
θ = 90 degree

Head across a reaction turbine



Losses of energy in hydroelectric installations- reaction turbine



Working Proportions of Francis Turbine

1. **B/D Ratio:**

   It is the ratio of width B and Diameter D of the runner given as

$$n = \frac{B_1}{D_1}$$

It is ranging from 0.15 to 0.45

2. **Flow Ratio ψ** : It is ranging from 0.15 to 0.3

$$\psi = \frac{V_{f1}}{\sqrt{2gH}}$$

2. **Speed Ratio:**

$$Ku = \frac{u_1}{\sqrt{2gH}} \quad \text{Thus} \quad u_1 = Ku\sqrt{2gH}$$

It is ranging from 0.6 to 0.9

Design of Francis Turbine

1. Determine the discharge Q from the equation

$$P = \rho \times Q \times gH \times \eta_o$$

2. If Z- number of vanes on the runner

   t- thickness of vane at inlet

   B_1- Width of wheel at inlet

   Area of flow is given as

$$A_1 = (\pi D_1 - Zt)B_1 = K_1 \pi D_1 B_1$$

Similarly

Where K1,, K2 are the thickness factor

Thus

$$A_2 = (\pi D_2 - Zt)B_2 = K_2 \pi D_2 B_2$$

Discharge Q= (Area of Flow)(Velocity of flow)

Thus

$$Q = K_1 \pi D_1 B_1 \times Vf_1 = K_2 \pi D_2 B_2 \times Vf_2$$

Normally

$V_{f1} = V_{f2}$

And K1=K2=1 (neglecting vane tip thickness)

Thus

$$Q = \pi D_1 B_1 \times V_{f1} = \pi n D_1^{\,2} \times V_{f1}$$

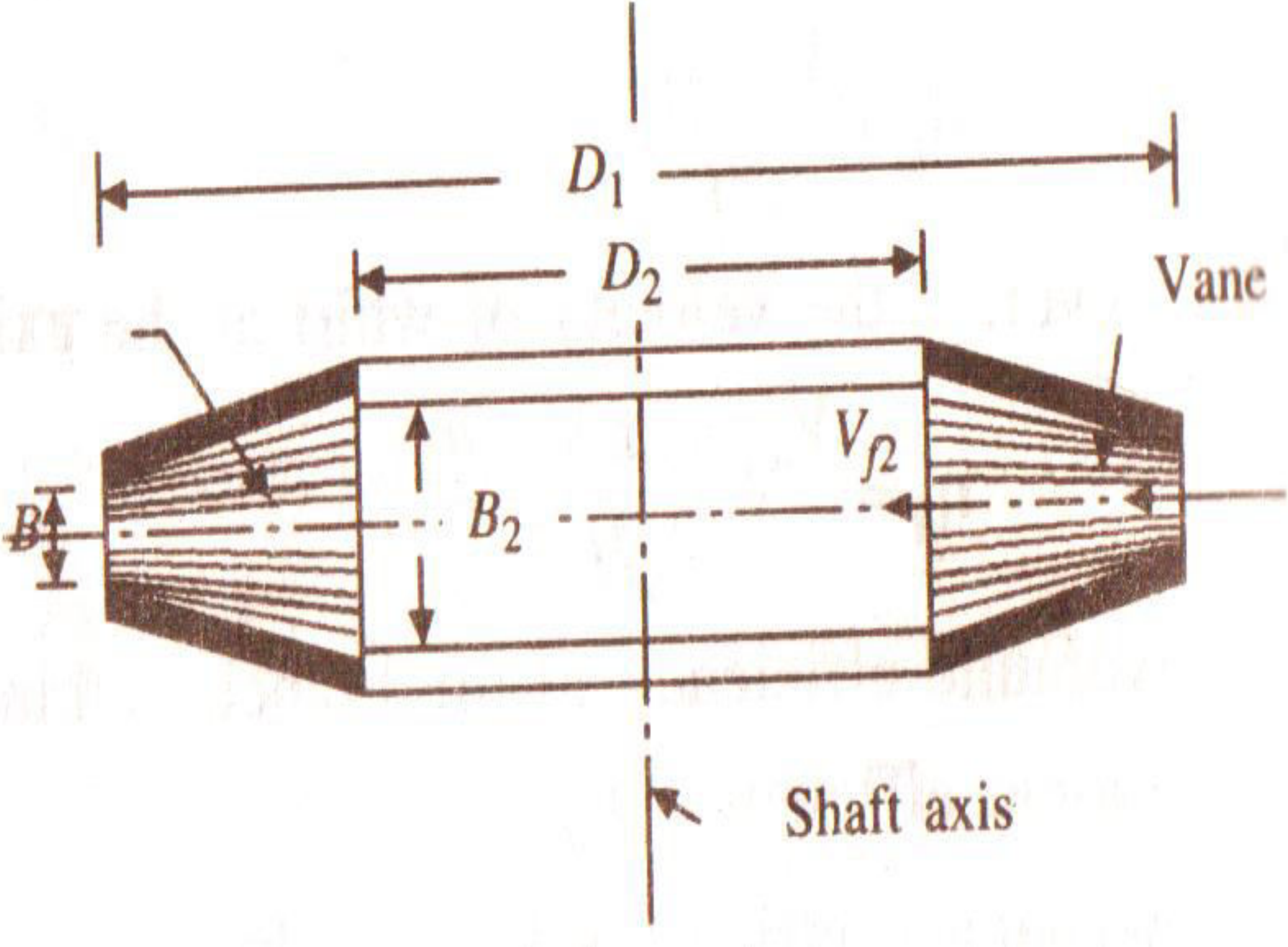
3. Velocity at inlet Vf1 is given as

$$V_{f1} = \psi\sqrt{2gH}$$

4. The Tangential velocity

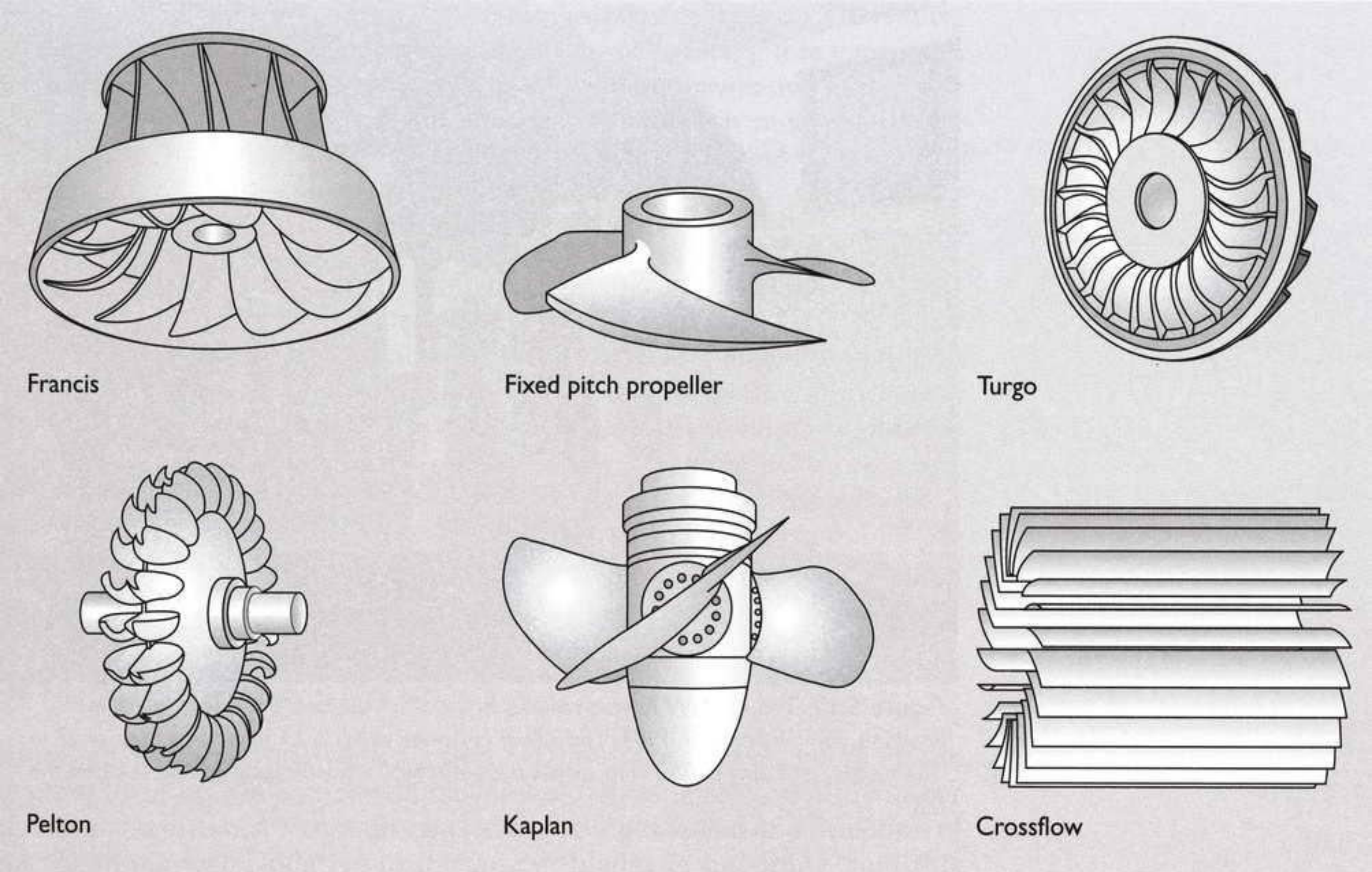
$$u_1 = \frac{\pi D_1 N}{60} = Ku\sqrt{2gH}$$

5. The runner diameter D2 at outlet varies from 1/3 to 2/3 of runner diameter D1 at inlet , usually it is taken as D1/2
6. Width B2=2B1
7. If flow is Radial at inlet then θ=90 degree and Vf1=Vr1



D_1
D_2
Vane
V_{f2}
B
B_2
Shaft axis

Types of Turbine Runner



Propeller Turbine

- The **Kaplan turbine** is a Propeller Type Turbine which has adjustable blades.
- The runner of Kaplan turbine resembles with propeller of ship , That is why Kaplan turbine is also called as Propeller Turbine.

The propeller turbines have the following favorable characteristics:

- relatively small dimensions combined with high rotational speed
- large overloading capacity.
- The comparatively high efficiencies at partial loads and the ability of overloading is obtained by a coordinated regulation of the guide vanes and the runner blades to obtain optimal efficiency for all operations.

Kaplan Turbine

- Kaplan turbine is an axial flow reaction turbine. The water flows through the runner of the turbine in an axial direction and the energy at the inlet of the turbine is the sum of kinetic and pressure energy .
- In an axial flow reaction turbine the shaft is vertical. The lower end of the shaft is larger and is known as '*hub*' or '*boss*'. It is on this hub that the vanes are attached. If the vanes are adjustable then it is known as *kaplan Turbine* and if the vanes are non adjustable then it is known as *Propeller Turbine*.
- Kaplan turbines have adjustable runner blades, that offers significant advantage to give high efficiency even in the range of partial load, and there is little drop in efficiency due to head variation or load

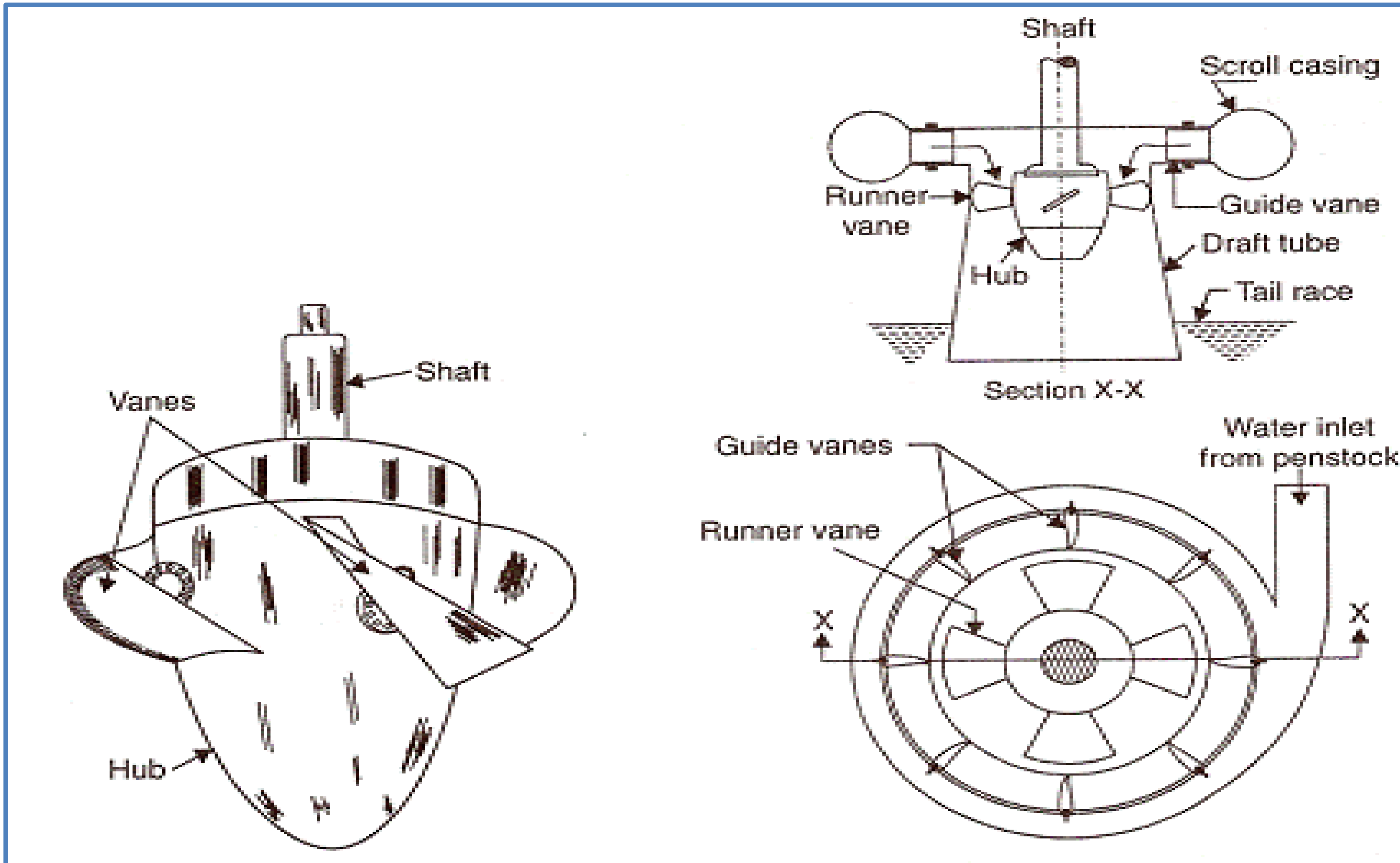
- Kaplan turbine is best suited where large quantity of low head water is available. Kaplan Turbine is named after V. Kaplan, the Australian Engineer.
- Kaplan turbines are now widely used throughout the world in high-flow, low-head power production.
- **The main parts of a kaplan Turbine are:**

1. Scroll Casing
2. Guide vane Mechanism
3. Hub with Vanes
4. Draft Tube

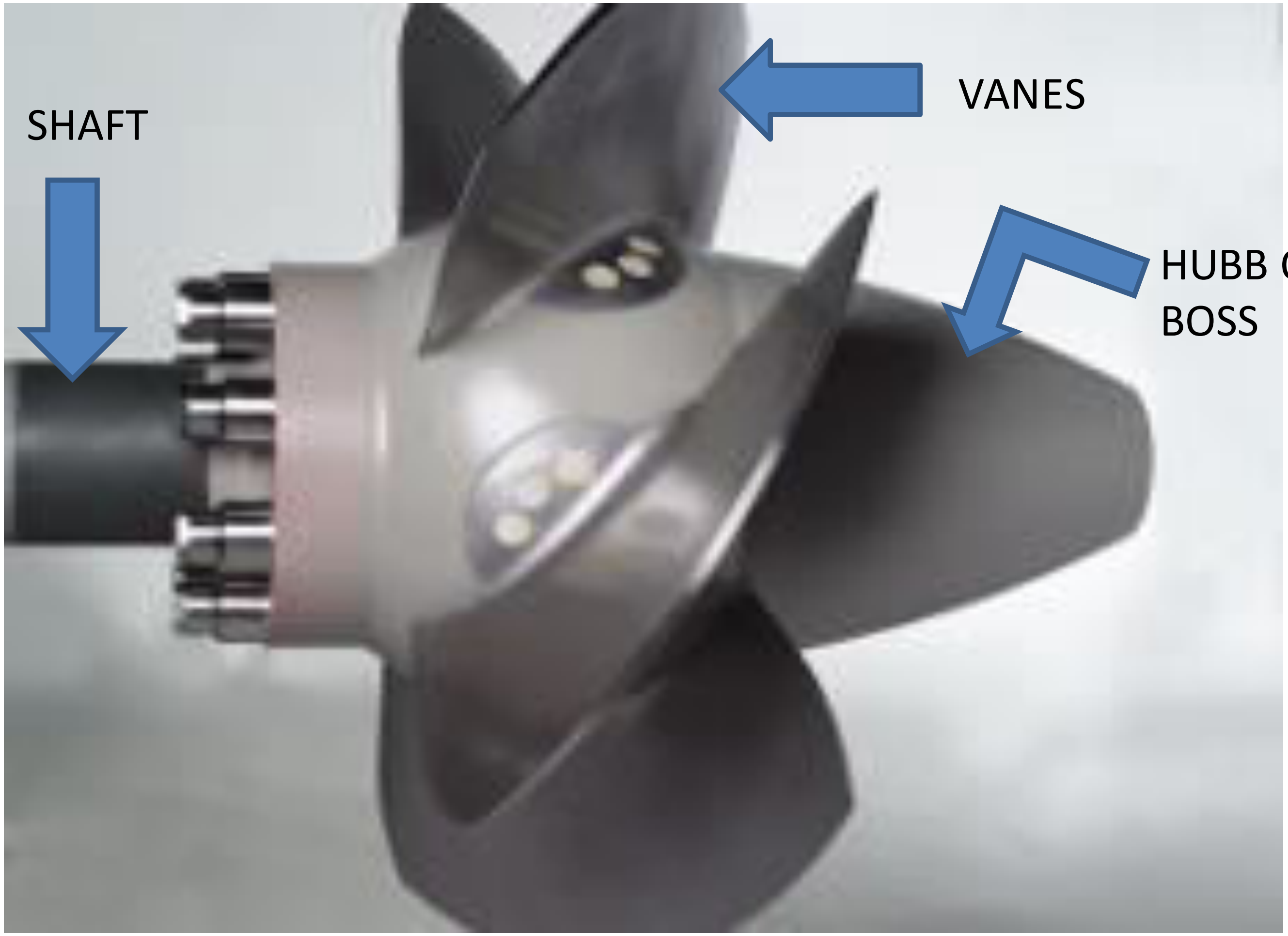
Working Principle

- The water enters the turbine through the guide vanes which are aligned such as to give the flow a suitable degree of swirl. The flow from guide vanes pass through the curved passage which forces the radial flow to axial direction.
- The axial flow of water with a component of swirl applies force on the blades of the rotor and looses its momentum, both linear and angular, producing torque and rotation (their product is power) in the shaft. The scheme for production of hydroelectricity by Kaplan Turbine is same as that for Francis Turbine.

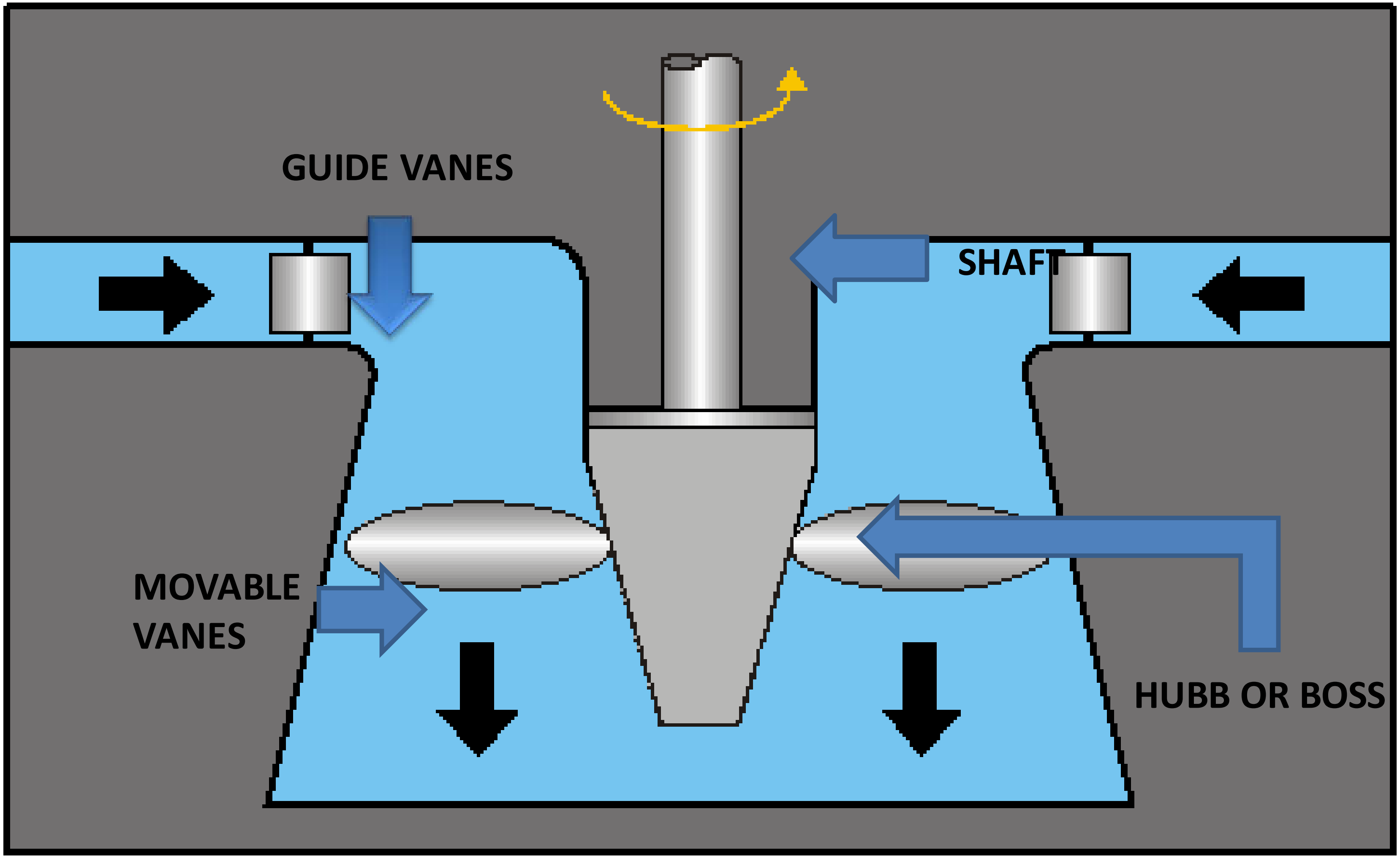
Kaplan turbine Schematic



Kaplan Turbine Runner



Schematic View



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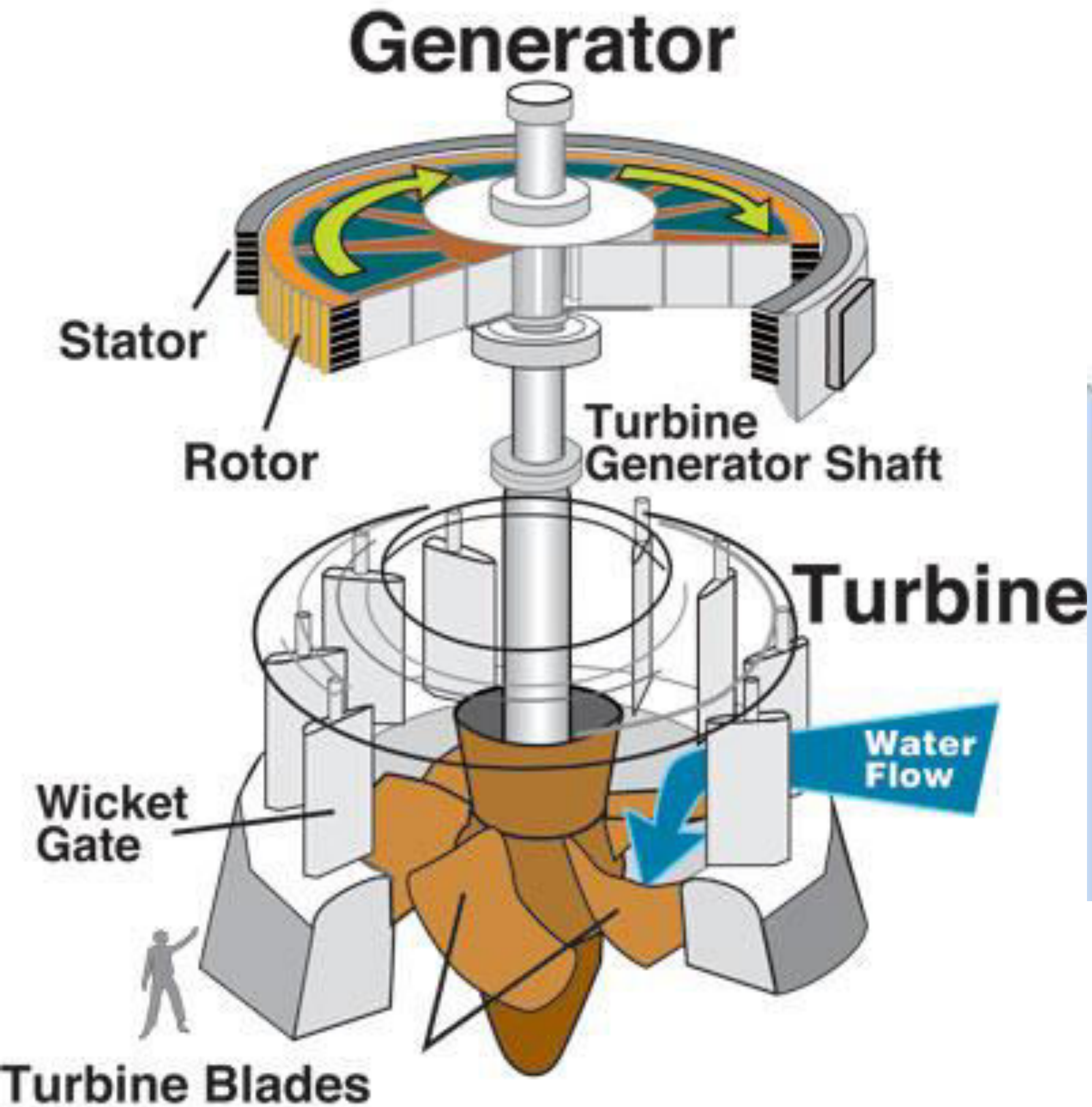
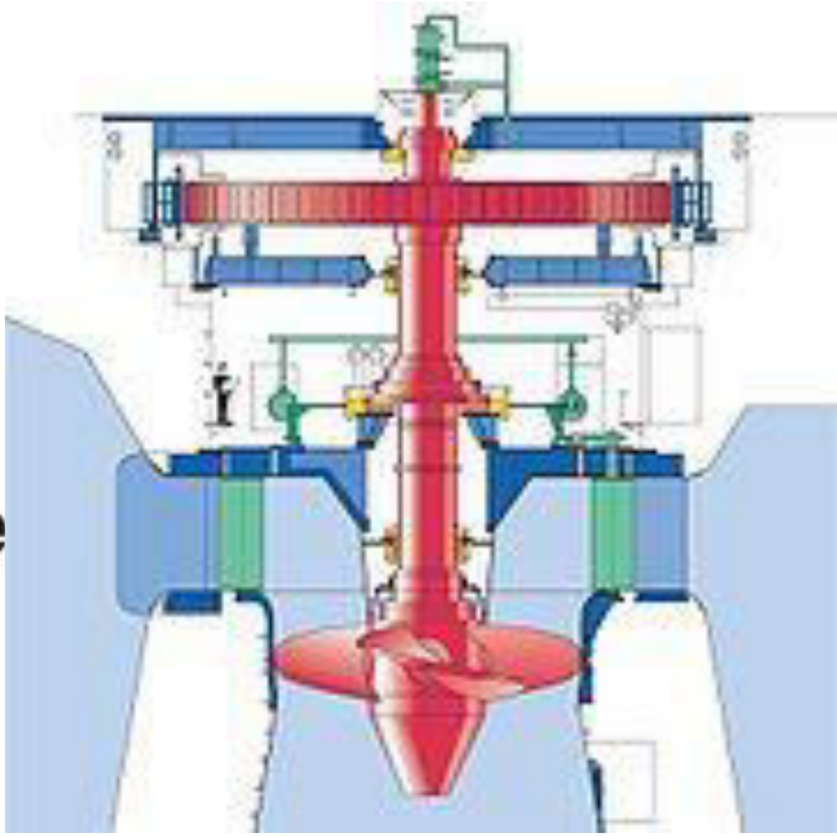
Kaplan Turbine





Working Proportions of Kaplan Turbine

d/D Ratio:

It is the ratio of Hub diameter Db and outer Diameter Do of the runner given as (Ranges from 0.35 to 0.65) .

$$\frac{D_b}{D_o}$$

Flow Ratio ψ : It is ranging from 0.35 to 0.6

$$\psi = \frac{V_{f1}}{\sqrt{2gH}}$$

Vf1 = Vf2

Speed Ratio: (0.9-2.1)

$$Ku = \frac{u}{\sqrt{2gH}} \text{ Thus } u = Ku\sqrt{2gH}$$

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

Discharge :-

$$Q = \frac{\pi}{4}(D_o^2 - D_b^2)V_{f1}$$

Unit Quantities

- In order to predict the behavior of a turbine working under varying conditions of Head, Speed and Gate opening,,,, the results are expressed in terms of quantities which may be obtained when the Head on the Turbine is reduce to Unity.
- The condition of the turbine under unit head are such that, the efficiency of turbine remain unaffected

- The Important Unit Quantities are

  1) Unit Speed 2) Unit Power 3) Unit Discharge

Unit Speed:

It is speed of the turbine working under the Unit Head

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

Unit Discharge:

It is discharge passing through the turbine working under the Unit Head

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

Unit Power :

It is the power developed by the turbine working under unit head

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

- **Specific Speed (Ns) :-**

- Specific speed is the speed of geometrically similar turbine working under the unit head and develop the unit power at maximum efficiency.

- It is used in comparing the different types of turbine and also used for the turbine selection.

Type of Turbine	Ns	Head	Efficiency
Pelton -Single jet - Two Jet -Three Jet -Four Jet - Six jet	 13-30 20-34 26-40 32-47 38-52	 Greater than 300m	 85 -90
Francis	52-225	50- 370 m	90-95
Kaplan	225-860	Less than 60m	85-95

Comparison of the Turbines

	Pelton	Francis	Kaplan
Energy at inlet	Impulse	Reaction	Reaction
Head	High	Medium	Low
Flow Direction	Tangential	Mixed (Radial entry and axial outlet)	Axial flow
Discharge Required	Low	Medium	High
Specific Speed	Low	Medium	High

Draft Tube

- In a reaction turbine, water leaves the runner with remaining kinetic energy. To recover as much of this energy as possible, the runner outlet is connected to a diffuser, called draft tube. The draft tube converts the dynamic pressure (kinetic energy) into static pressure.
- Draft tube permits a suction head to be established at the runner exit, thus making it possible for placing the wheel and connecting machinery at a level above that of water in the tail race under high water flow conditions of river, without loss of head.
- To operate properly, reaction turbines must have a submerged discharge.
- The water after passing through the runner enters the draft tube, which directs the water to the point of discharge.
- The aim of the draft tube is also to convert the main part of the kinetic energy at the runner outlet to pressure energy at the draft tube outlet.
- This is achieved by increasing the cross section area of the draft tube in the flow direction.
- In an intermediate part of the bend, however, the draft tube cross sections are decreased in the flow direction to prevent separation and loss of efficiency.

Function of draft tube

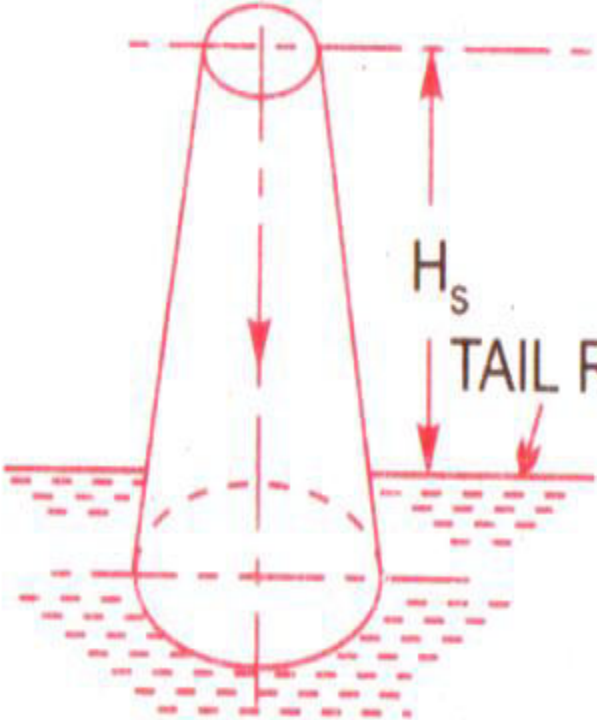
- Complete recovery of installation head
- Partially recovery of kinetic head

Limitations of draft tube

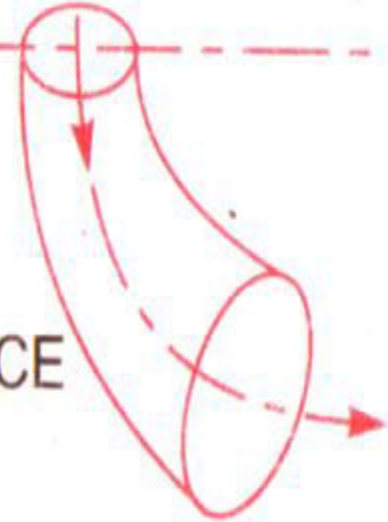
- In actual practice, turbine should not installed more than 4-5 m above TRL otherwise cavitations starts
- Semi vertex angle of draft tube should not be greater than 7- 8^0

Types of draft tube

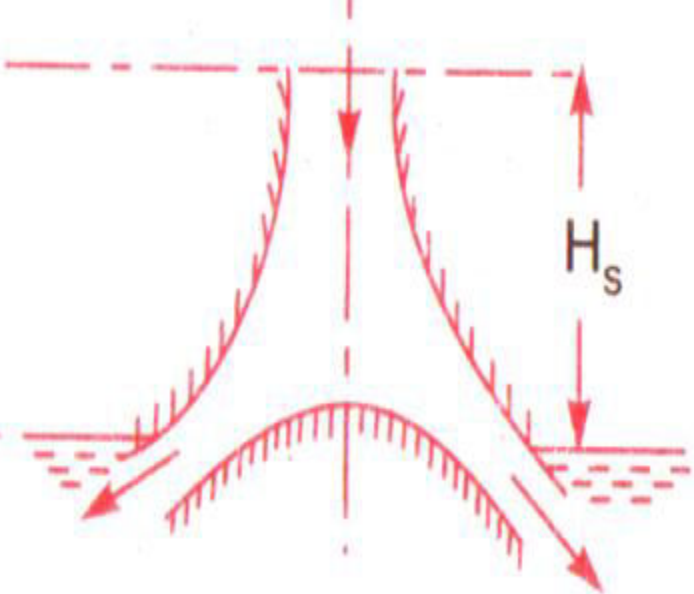
- Straight divergent tube
- Moody spreading tube or Hydra cone
- Moody bell mounted draft tube
- Simple elbow tube



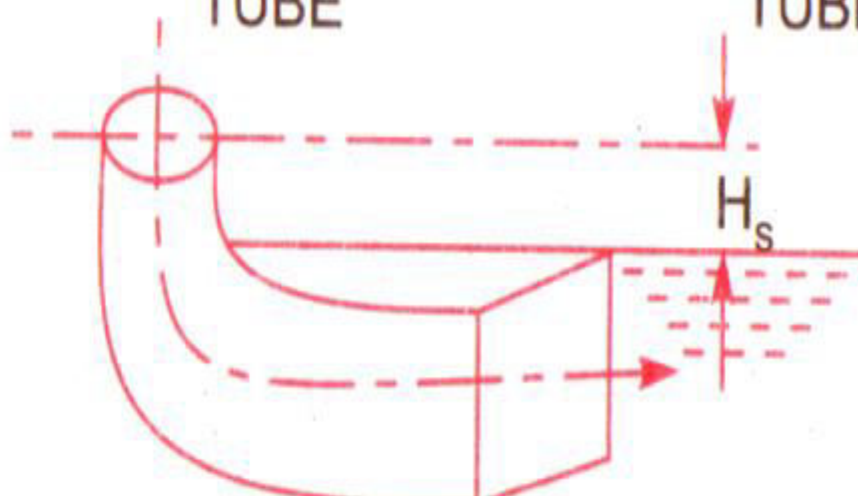
(a) CONICAL DRAFT TUBE



(b) SIMPLE ELBOW TUBE



(c) MOODY SPREADIN TUBE

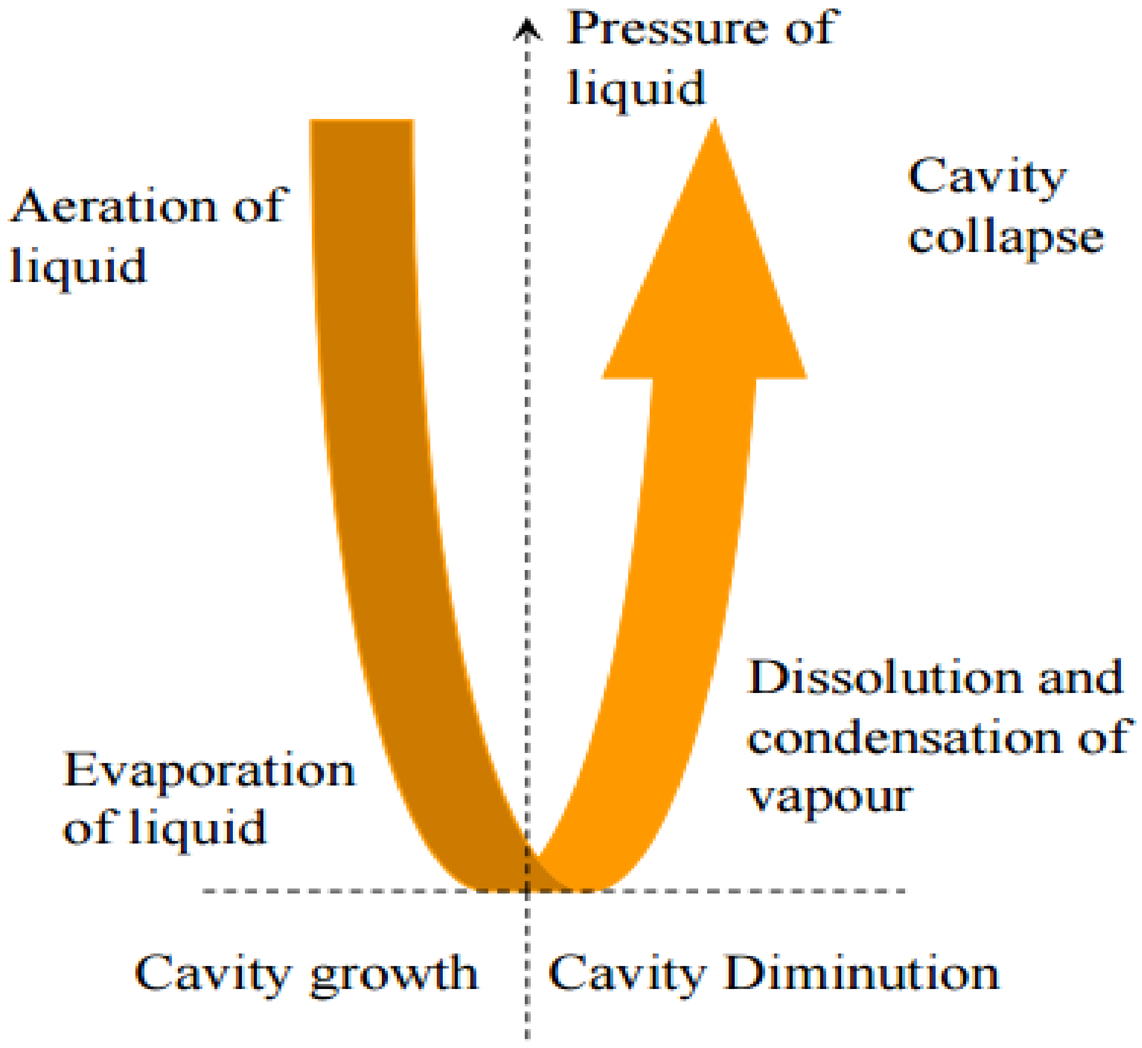


(d) DRAFT TUBE WITH CIRCULAR INLET AND RECTANGULAR OUTLET

Cavitation in Turbines

- Cavitation is a term used to describe a process, which includes nucleation, growth and implosion of vapour or gas filled cavities. These cavities are formed into a liquid when the static pressure of the liquid for one reason or another is re duce d b e low its vapour pressure at the prevailing temperature. When cavities are carried to high-pressure region, they implode violently.
- Cavitation is an undesirable effect that results in pitting, mechanical vibration and loss of efficiency.
- If the nozzle and buckets are not properly shaped in impulse turbines, flow separation from the boundaries may occur at some operating conditions that may cause regions of low pressure and result in cavitation.
- The turbine parts exposed to cavitation are the runners, draft tube cones for the Francis and Kaplan turbines and the needles, nozzles and the runner buckets of the Pelton turbines.
- Measures for com b ating erosion an d damage un der cavit ation conditions include improvements in hydraulic design and production of components with erosion resistant materials and arrangement of the turbines for operations within good range of acceptable cavitation conditions.

Cavitation Process



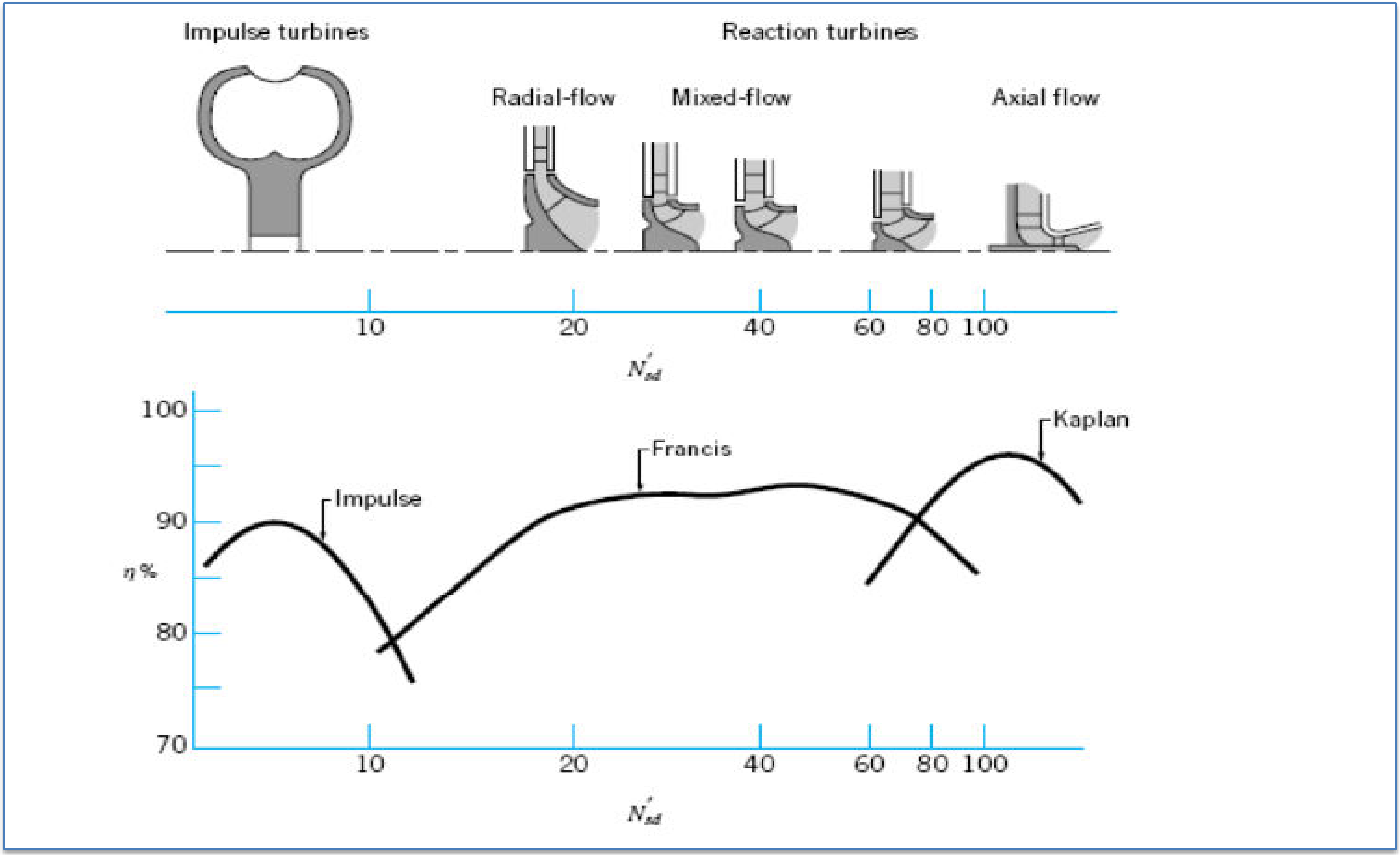
Specific Speed

- It is defined as the speed of a turbine which is identical in shape, geometrical dimensions, blade angles, gate opening etc., with the actual turbine but of such a size that it will develop unit power when working under unit head
- This is the speed at which the runner of a particular diameter will develop 1 kW (1 hp) power under 1 m (1 ft) head.

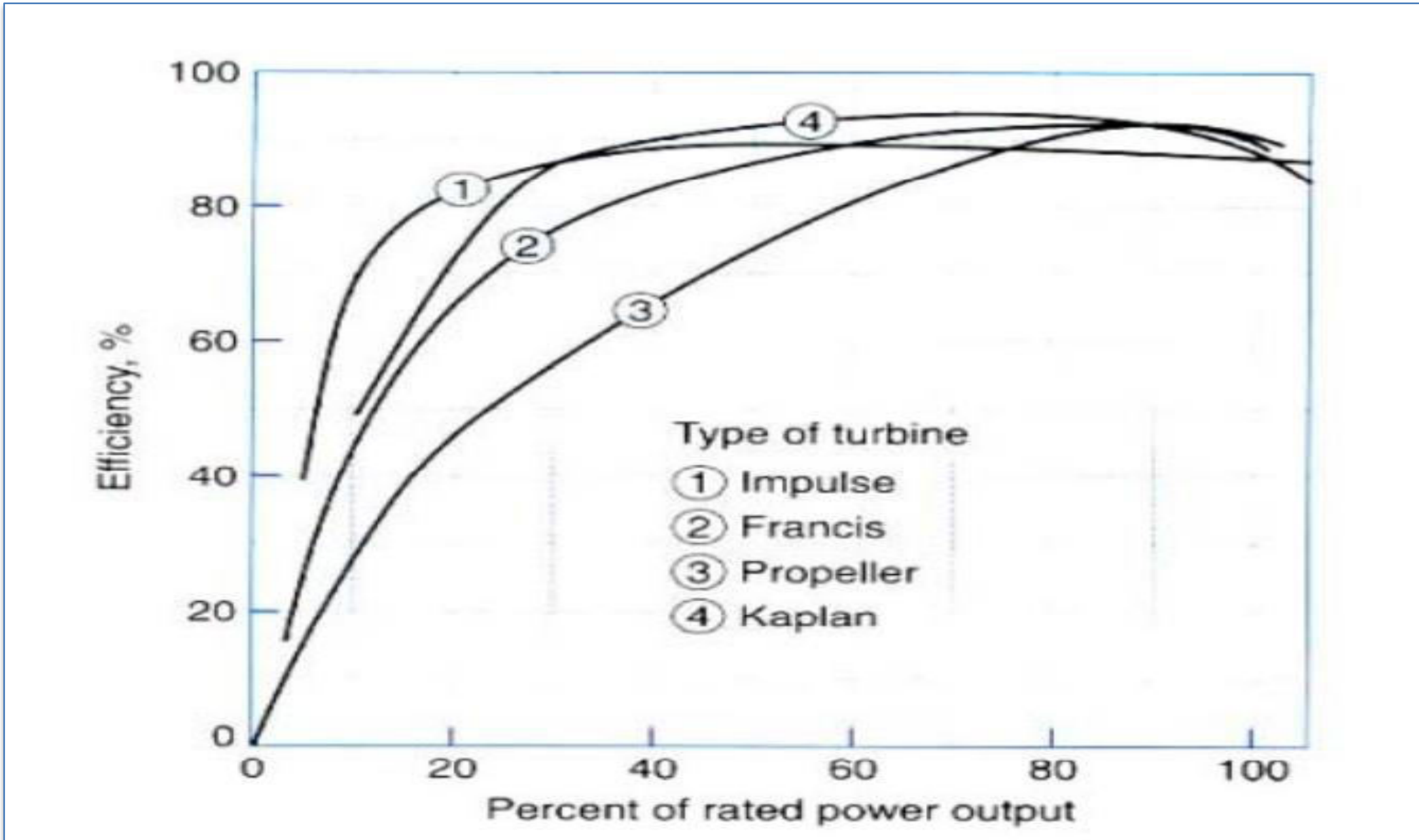
$$N_s = \frac{N\sqrt{P}}{H^{\frac{5}{4}}}$$

- The specific speed is an important factor governing the selection of the type of runner best suited for a given operating range. The impulse (Pelton) turbines have very low specific speeds relative to Kaplan turbines. The specific speed of a Francis turbine lies between the impulse and Kaplan turbine.

Efficiency vs. Specific Speed



Efficiency vs. Load for Turbines



Governing of Turbines

- It is the operation by which the speed of the turbine is kept constant under all conditions of working load. This is done automatically by a governor which regulates the rate flow through the turbines according to the changing load conditions on the turbine.
- Governing of a turbine is absolutely necessary if the turbine is coupled to an electric generator which is required to run at constant speed under all fluctuating load conditions.

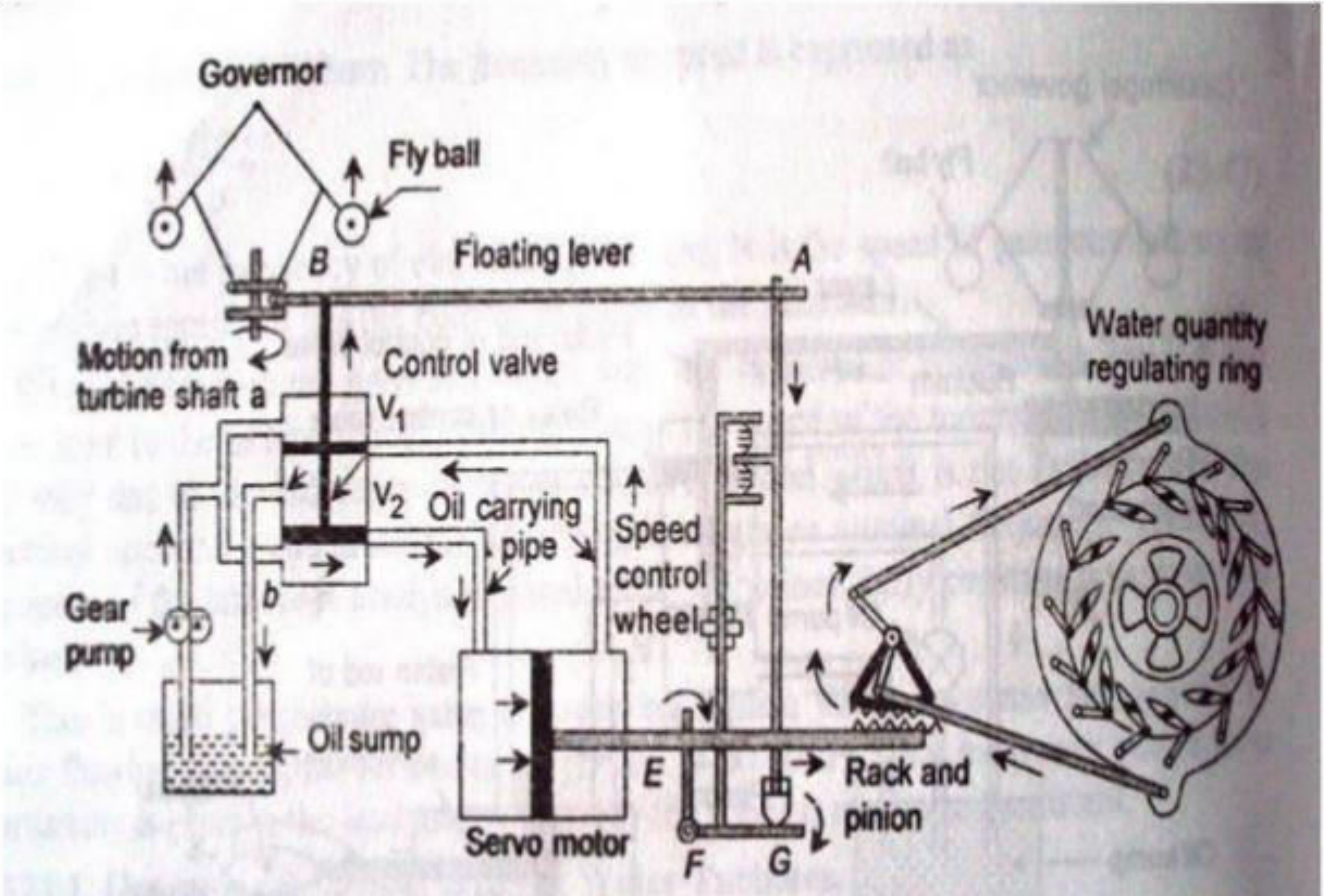
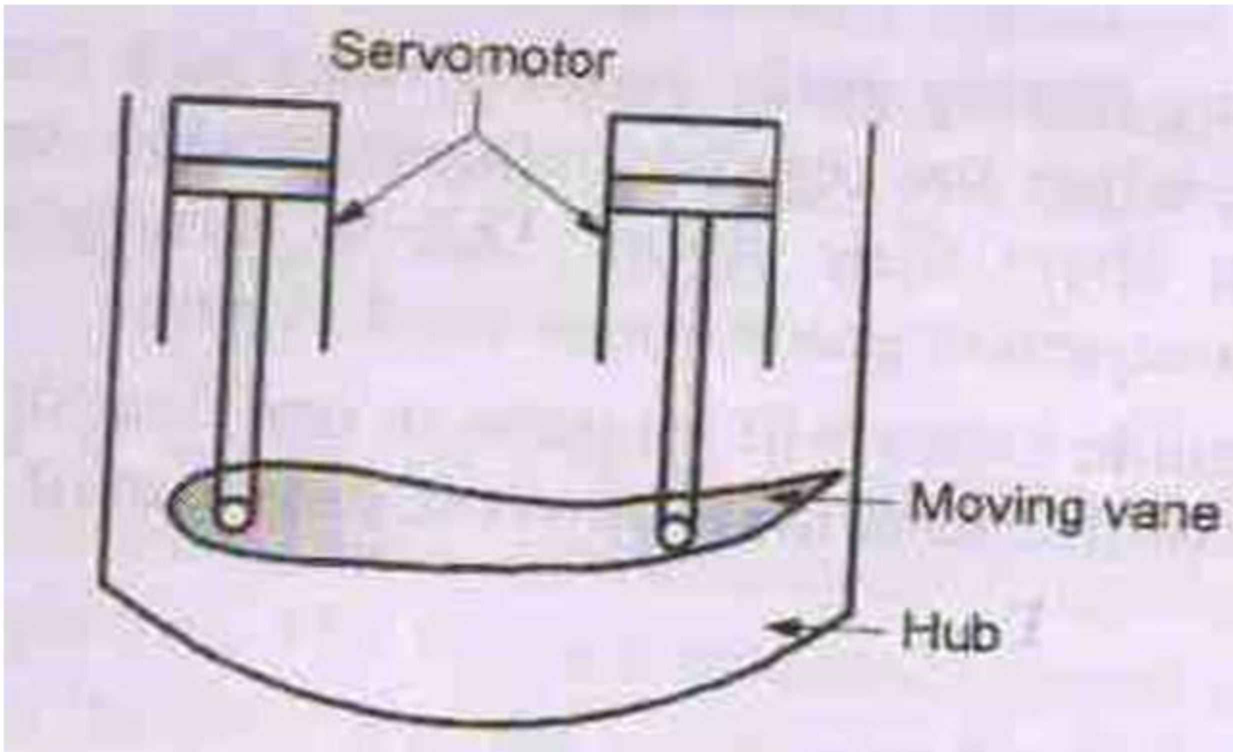
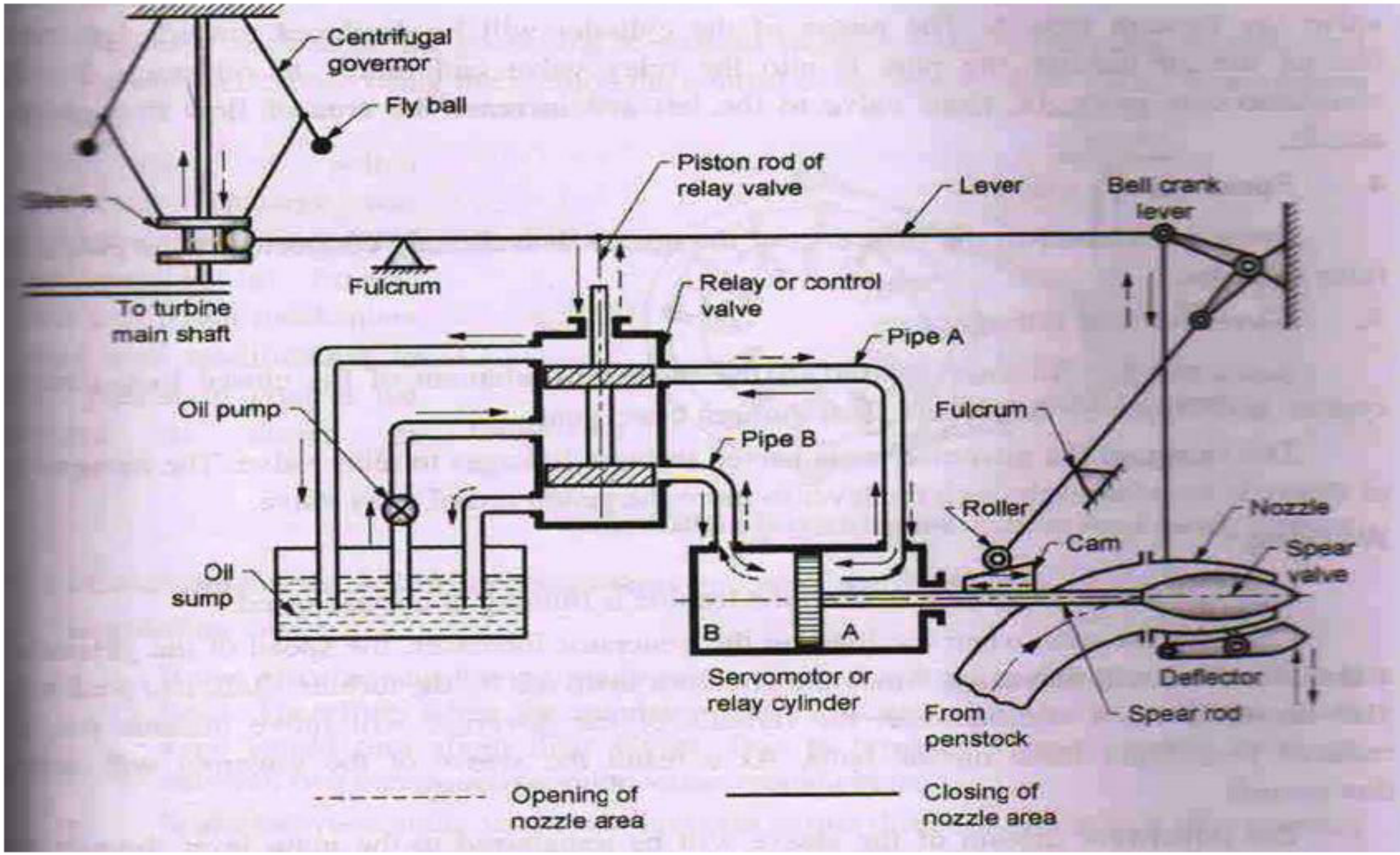


Fig. (1) Governing of Francis Water Turbine

Governing mechanism of Kaplan Turbine



Governing mechanism of Pelton Turbine



Selection of Turbines

Turbine	**Head**	**Specific Speed (SI)**
Pelton Wheel	>300 m	8.5-30 (Single Jet) 30-51 (2 or More)
Francis Turbine	50-450 m	51-255
Kaplan Turbine	Up to 60 m	255-860

Thank You