Hydraulic Turbines

(A part of UNIT-4 of the course "Fundamentals of Mechanical Engineering", B.Tech. 1st Year, AKTU (2023-24)

By

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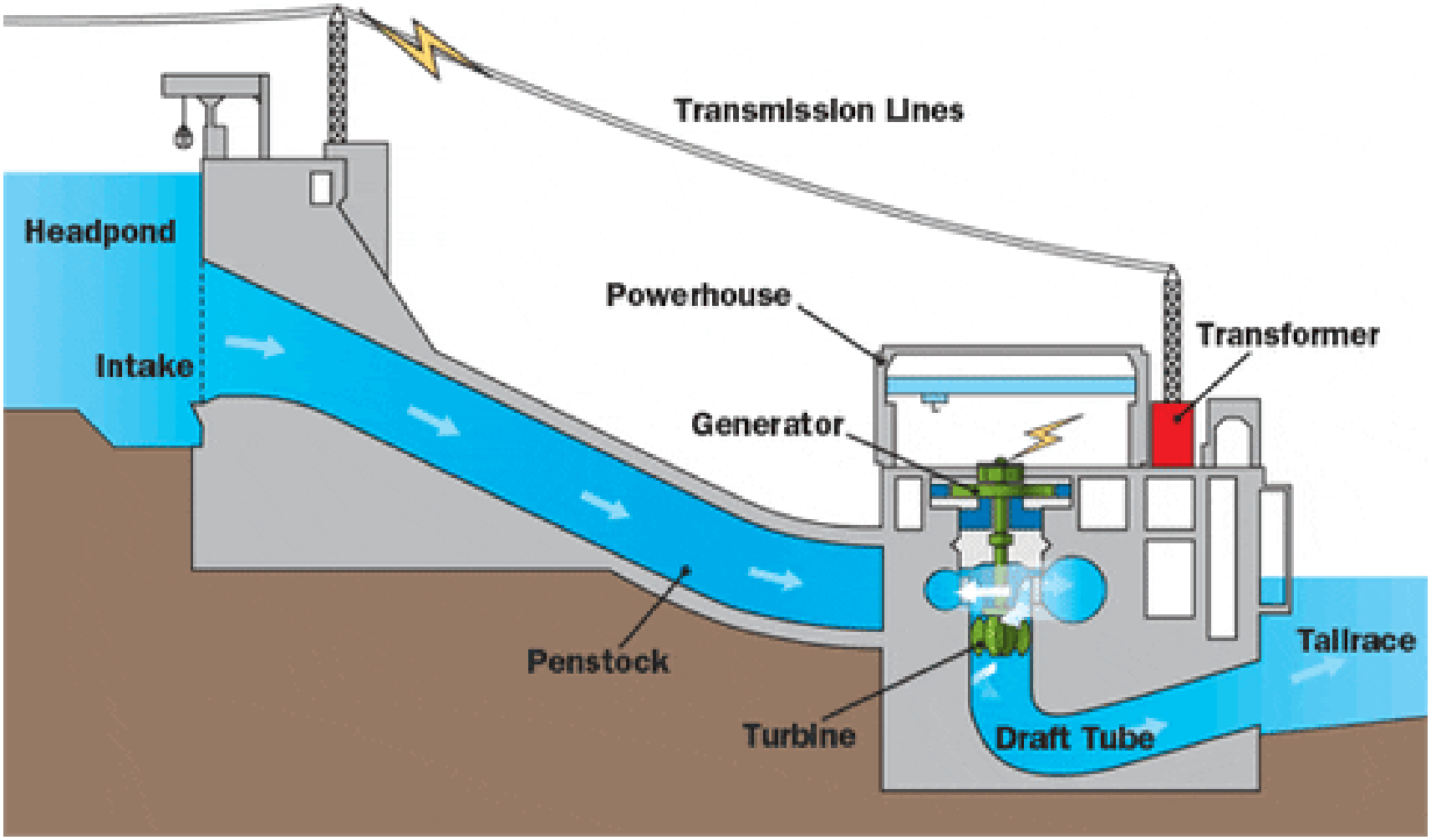
Introduction

- Hydraulic turbines are the mechanical devices which use the energy of flowing water (hydro-power) and convert it into mechanical energy (in form of rotation).
- As such these may be considered as hydraulic motors.
- The mechanical energy developed by a turbine is used in running an electric generator.

Hydroelectric Powerplant



Gross head and Net head (or effective head)

- The total hydrodynamic head available at the water reservoir before it enters into the penstock, is called gross head. It is basically the difference between head race and tail race levels when water is not flowing.
- Net head is defined as gross head minus all pipe losses due to friction and turbulence. It is the head available at the entry of turbine, after passing through the penstock.

Classification of Turbines

- **On the basis of working principle (action of water)**

  (i) Impulse : Only K.E. of water is used to rotate the turbine blades. $\frac{1}{2}mv^2$

  (ii) reaction turbines : K.E. as well as pressure energy is used to rotate the turbine blades. $\frac{1}{2}mv^2$, p

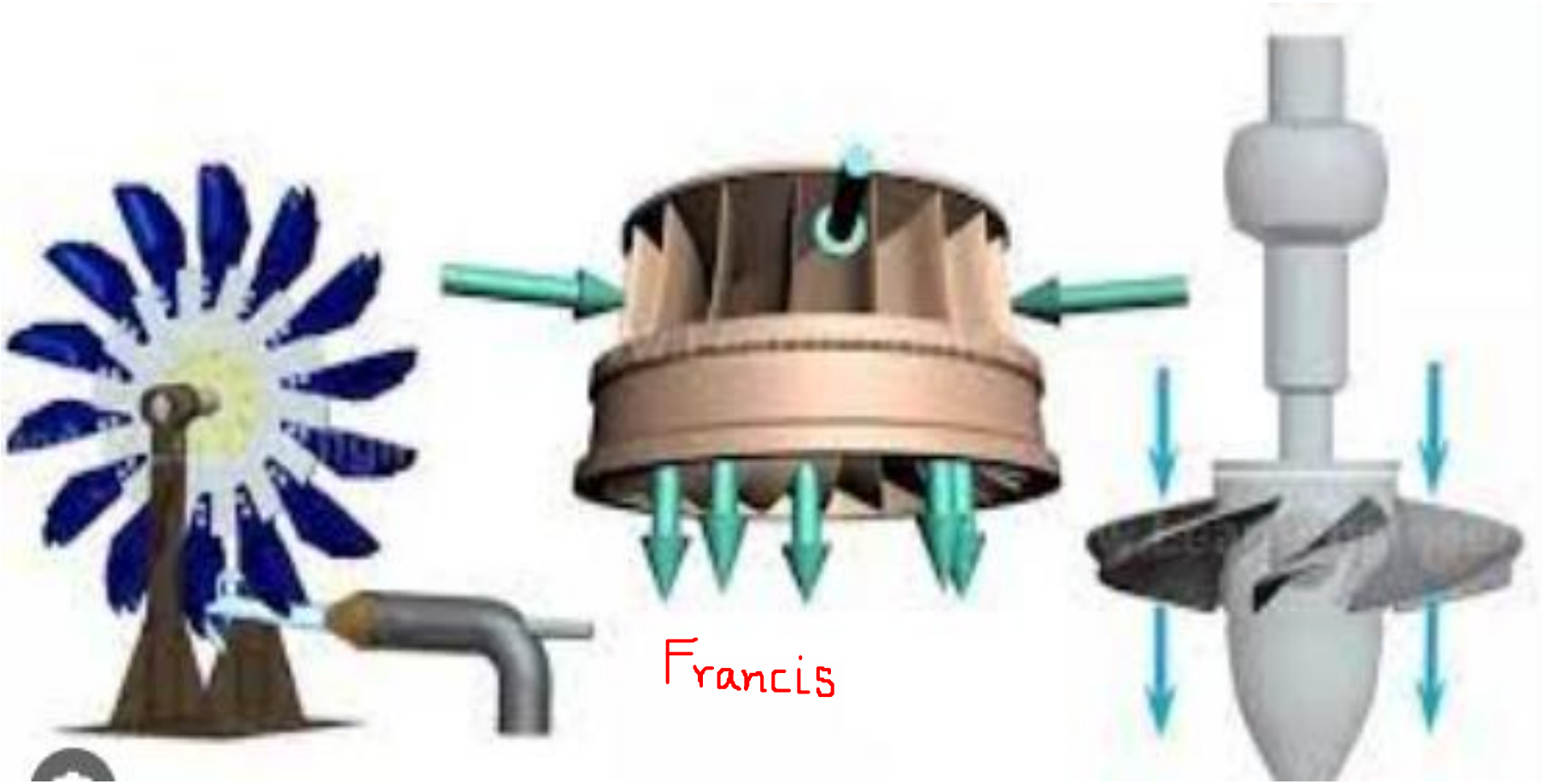
- **On the basis of direction of flow of water in the runner**

  i. tangential flow turbine (Pelton wheel i.e. Pelton turbine)

  ii. radial flow turbine (Francis turbine old, obsolete design)

  iii. axial flow turbine (Kaplan, propeller turbine)

  iv. Mixed flow turbine (Modern Francis turbine)


Pelton
Francis
Kaplan

Classification of Turbines (Contd.)

- **On the basis of head and rate of flow of water**

1. High head and small rate of flow (impulse turbine),
2. low head and high rate of flow (Kaplan reaction turbine)
3. medium head and medium rate of flow (reaction turbines)

- **On the basis of specific speed of turbine**

i. Low ((8.5 – 30 rpm) -- Pelton wheel)

ii. Medium ((51-255 rpm) -- Francis turbine)

iii. High ((255-860- rpm) -- Kaplan, propeller turbine)

(*Speed of a geometrically similar turbine, that would develop 1 kW power under 1 m head*)

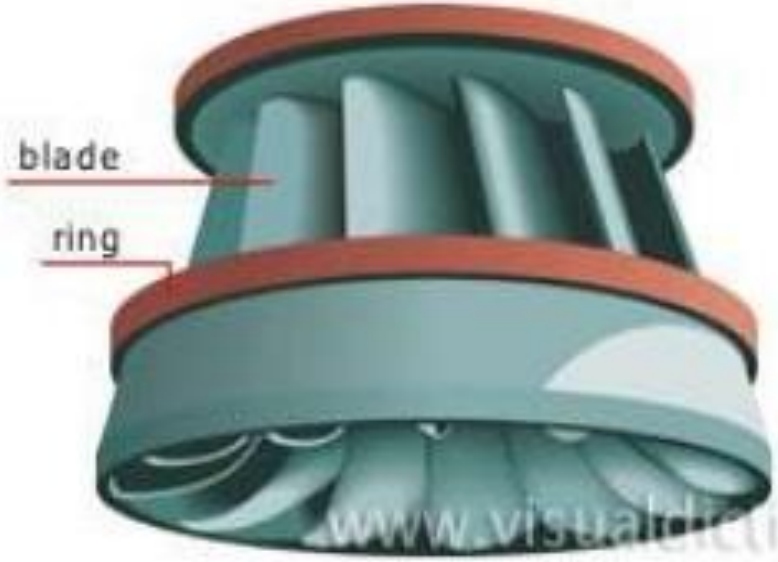
Turbine	Head / Discharge	Specific Speed (SI)
Pelton Wheel (Impulse T.)	>300 m (high) / (Low)	8.5-30 (Single Jet) 30-51 (2 or More) (L)
Francis Turbine (Reaction T.)	50-450 m (M.) / (M)	51-255 (M)
Kaplan Turbine (Reaction T.)	Up to 60 m (L.) / (H)	255-860 (H)

Classification of Turbines (Contd.)

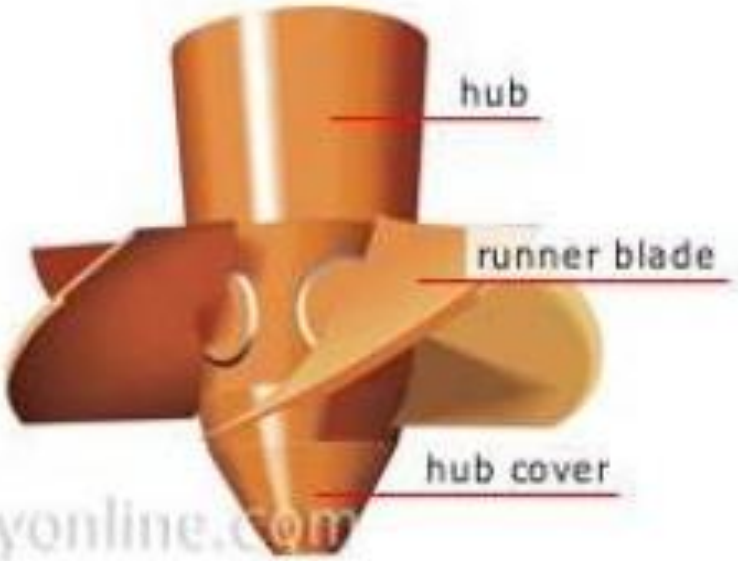
- **According to position of turbine shaft**

1. Horizontal shaft (Pelton wheels i.e., Pelton turbine),
2. Vertical shaft (reaction turbines, large units).

Francis runner



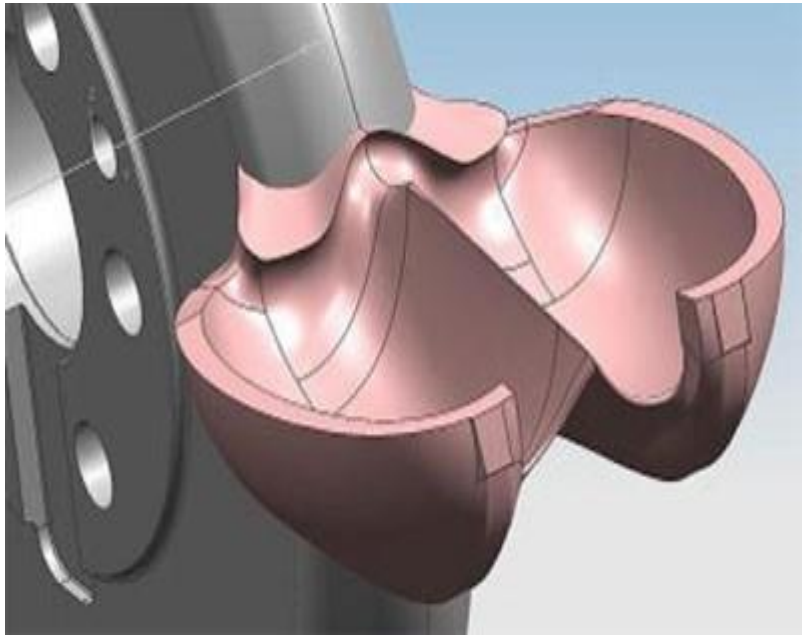
Kaplan runner



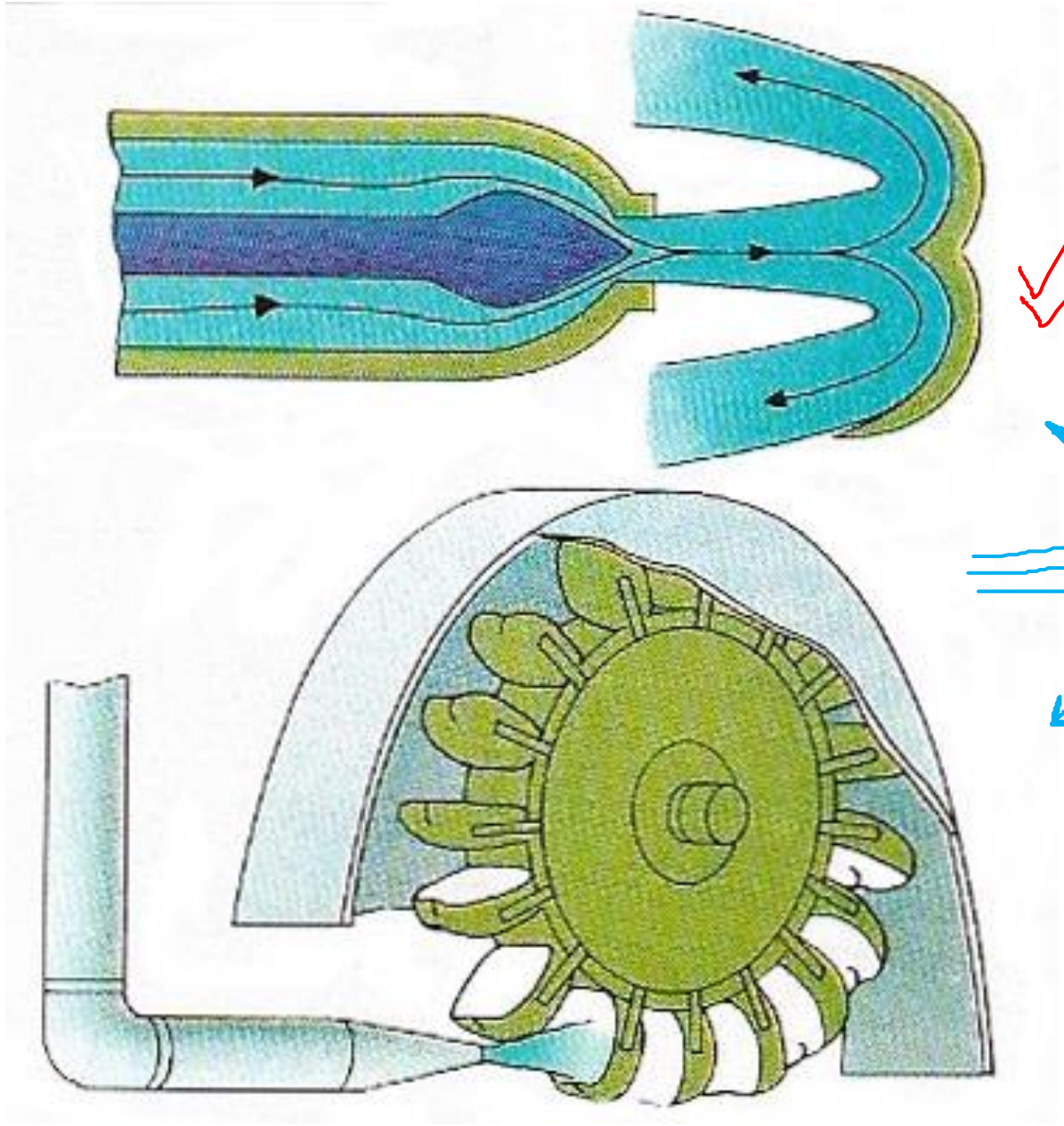
Pelton runner

bucket ring

Pelton Wheel or **Pelton Turbine** (tangential flow impulse turbine)



Pelton wheel and Buckets


OR
160°–
170°
(DRAW)

WORKING

- **The flow is tangential to the runner and the available energy at the entrance is completely kinetic energy.** Almost all the hydrodynamic head is converted in to K.E. through a nozzle.

- it is preferred at a **very high head and low discharges** with low specific speeds.

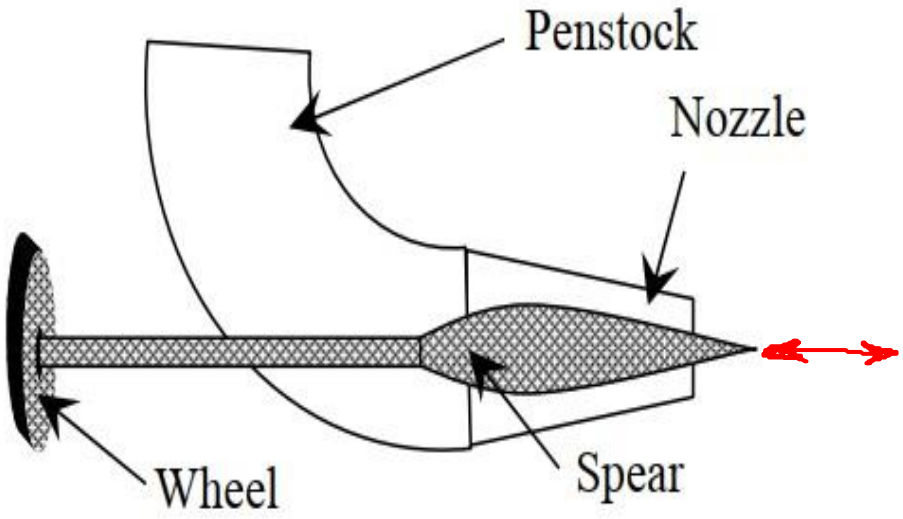
- The pressure available at the inlet and the outlet is atmospheric. (No change in pressure).

- These turbines can work even without the outer casing, but still, casing is used to avoid splashing of water on the other nearby electrical and mechanical items, to avoid any chances of short circuits or rust formation.

CONSTRUCTIONAL DETAILS:

Nozzle and flow regulating arrangement

Nozzle is having a continuously decreasing cross sectional area.
It cause increase in velocity.
The amount of water striking the buckets is controlled by the forward and backward motion of the spear.



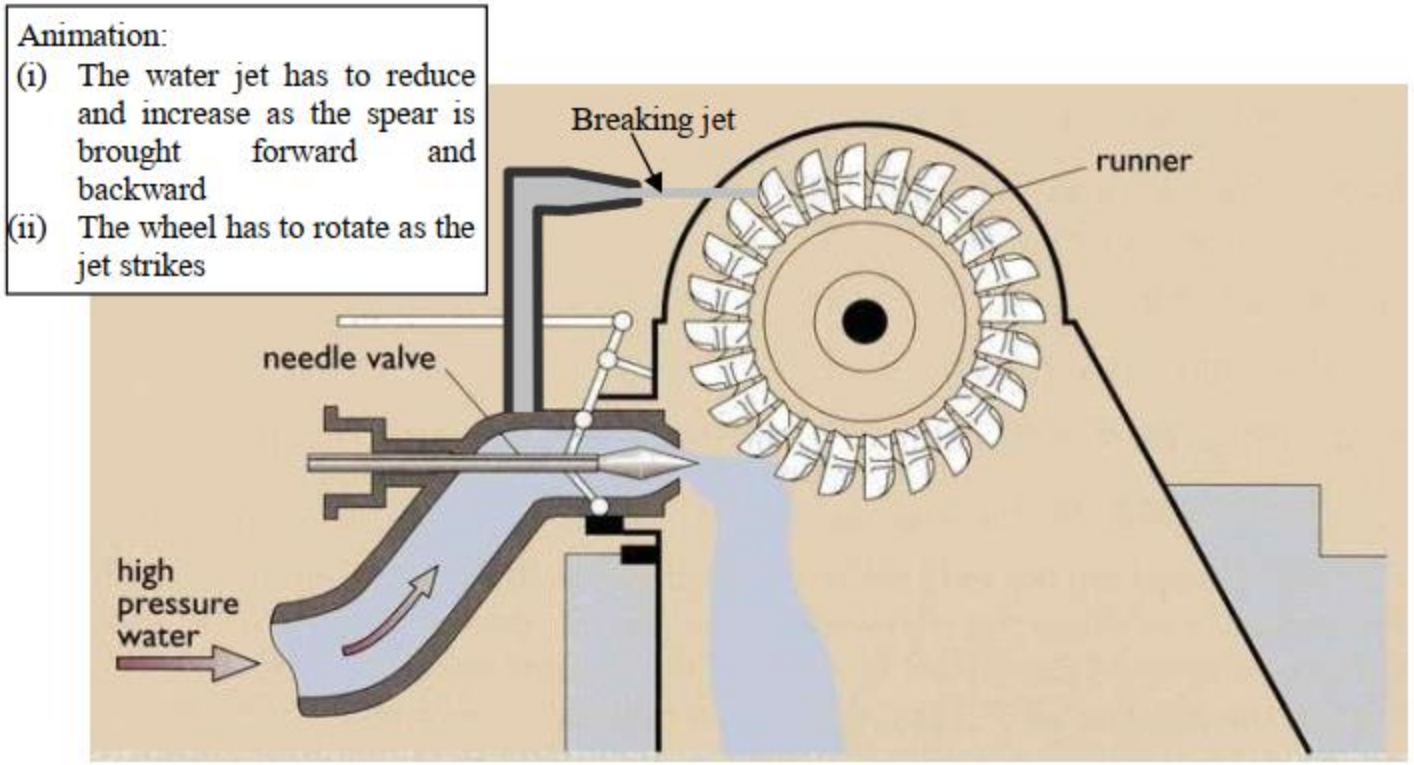
- *Runner with buckets*

The buckets are made of cast-iron, cast-steel, bronze or stainless steel depending upon the head at the inlet of the turbine.
The water jet strikes the bucket on the splitter of the bucket and gets deflected through 160°-170°

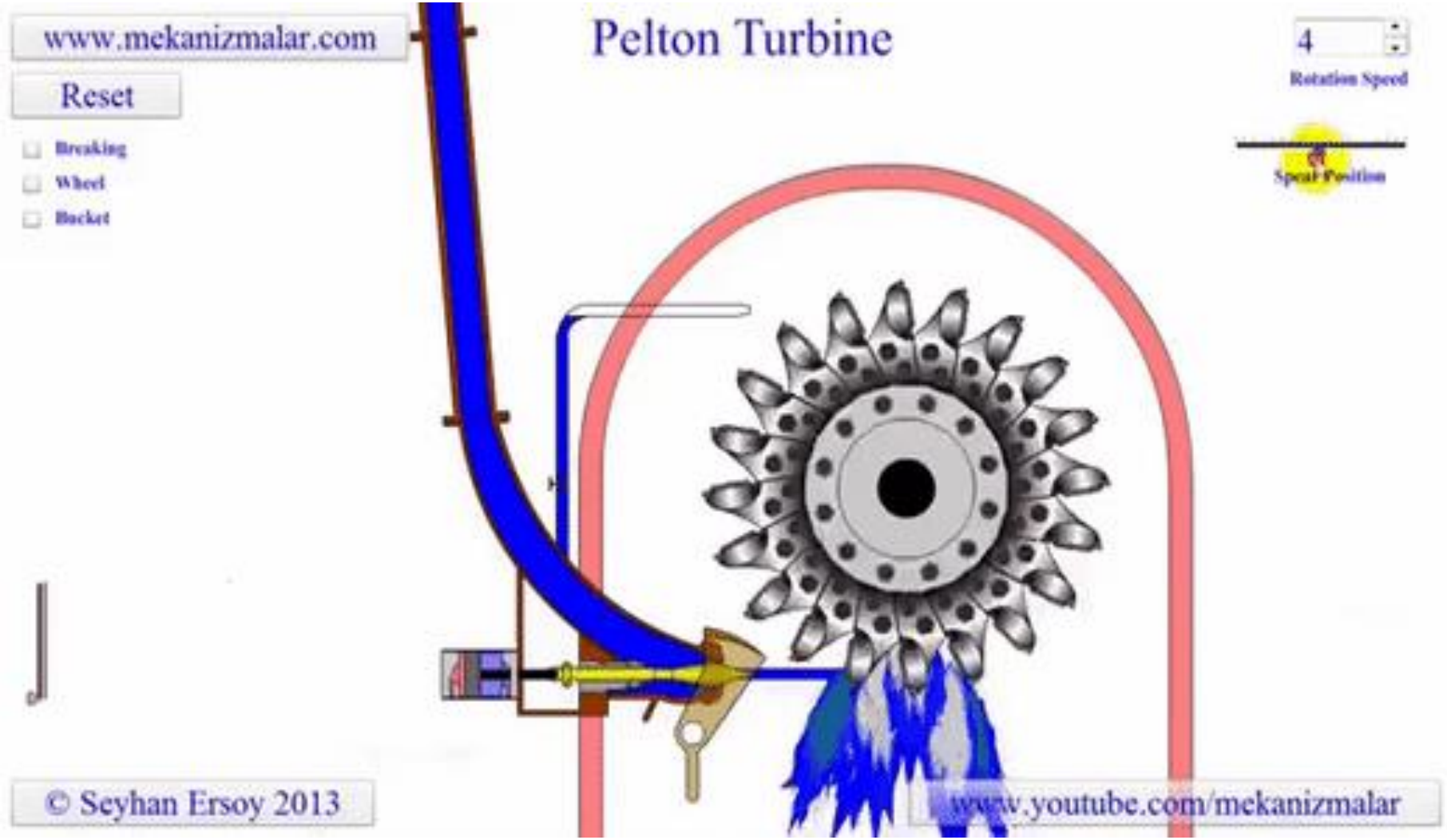
- *Casing*

  It is made of cast-iron or fabricated steel plates. The main function of the casing is to prevent splashing of water and to discharge the water into tailrace.

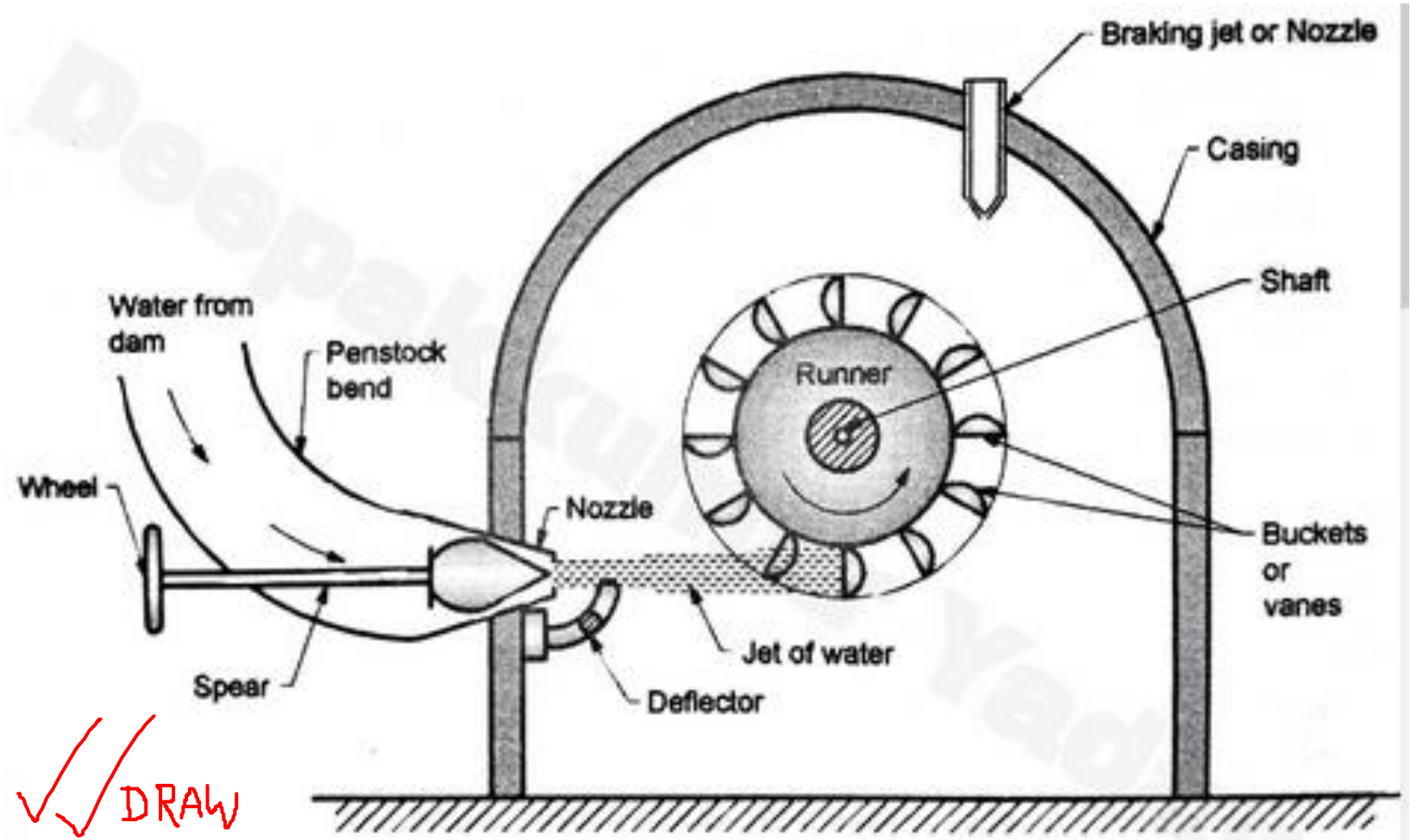
- *Breaking jet*



Working of Pelton wheel (turbine)



Construction and Working (Diagram)



REACTION TURBINES

REACTION TURBINES

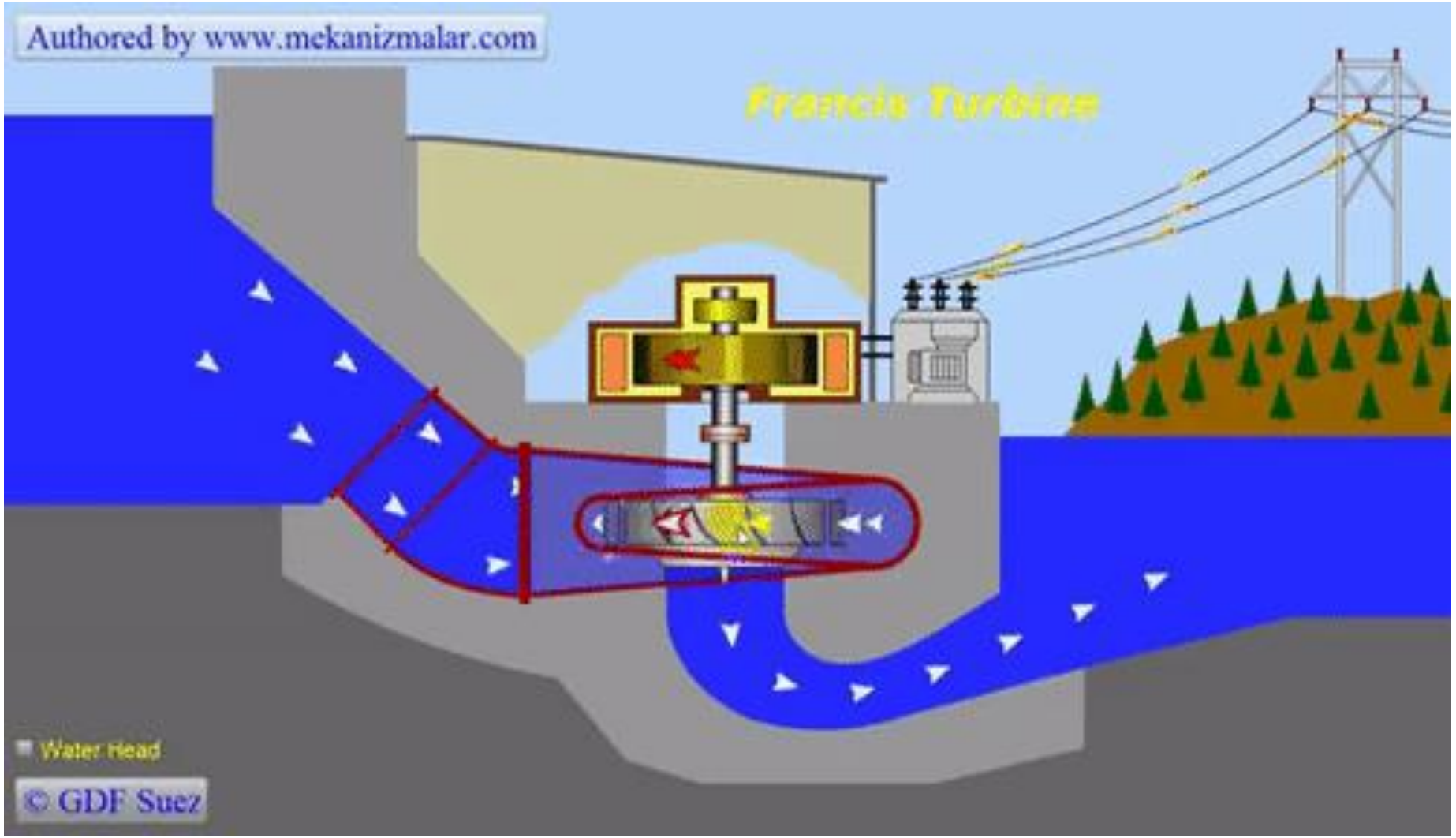
- Reaction turbine works on the principle of partial change of hydraulic energy into kinetic energy during the passage of fluid through its runner. Runner utilizes both – pressure and kinetic energies.
- These are **medium head and medium discharge, or low head and high discharge turbines**.
- It has two set of blades:
  - **Fixed blades** : Convert a part of pressure energy in to KE (Stay vanes and adjustable Guide vanes are there).
  - **Runner blades** : Have shape of an airfoil

REACTION TURBINES

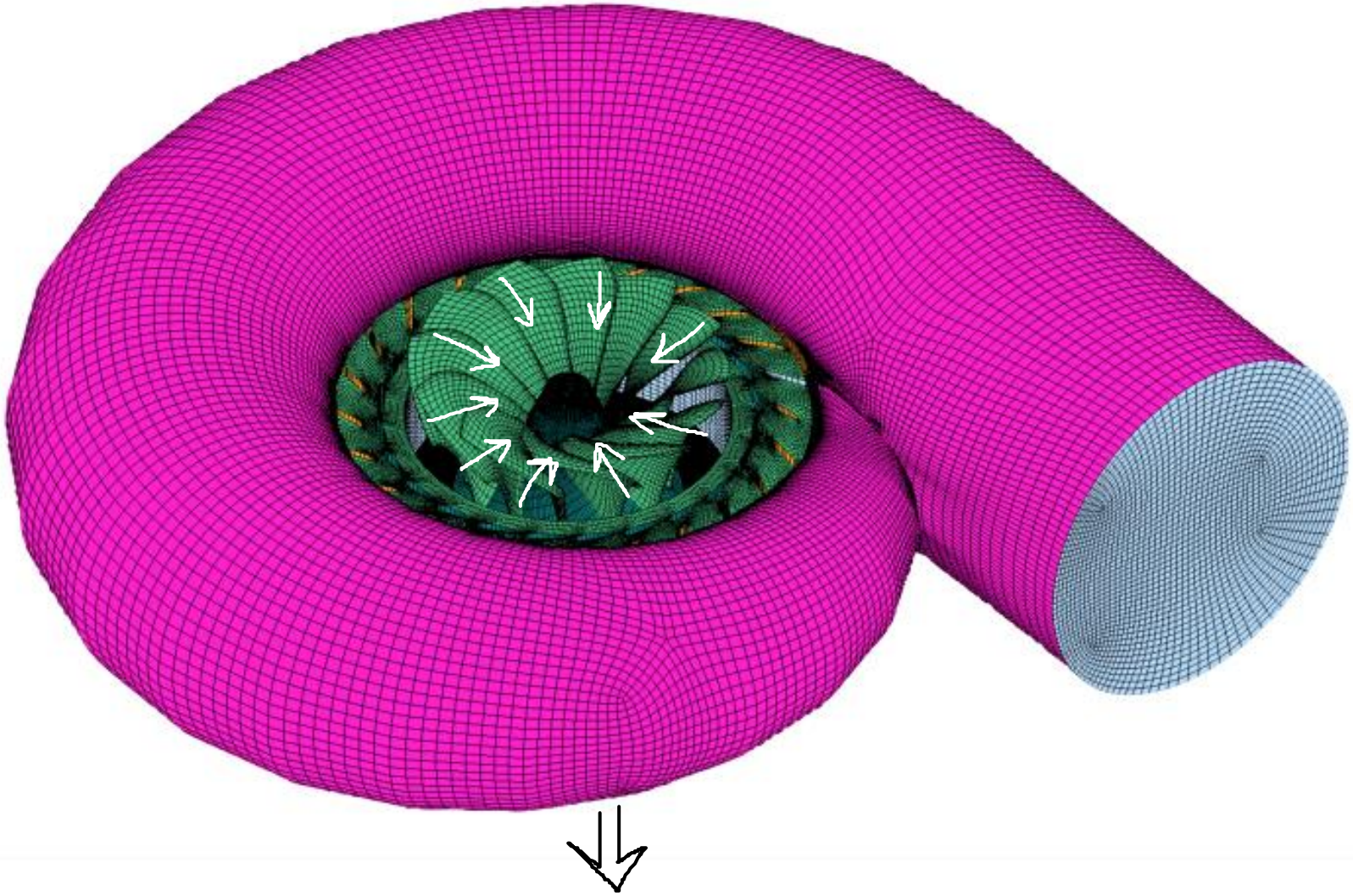
- Water exerts a thrust force on turbine blades, which cause its rotation.
- Rotation of blades is partly due to impulse and partly due to change in pressure.
- As the water glides over the airfoil shaped blades, its pressure is reduced along the blades.
- There is a difference of pressure between the guide vanes and the runner exit which is called reaction pressure. It cause the runner to rotate.

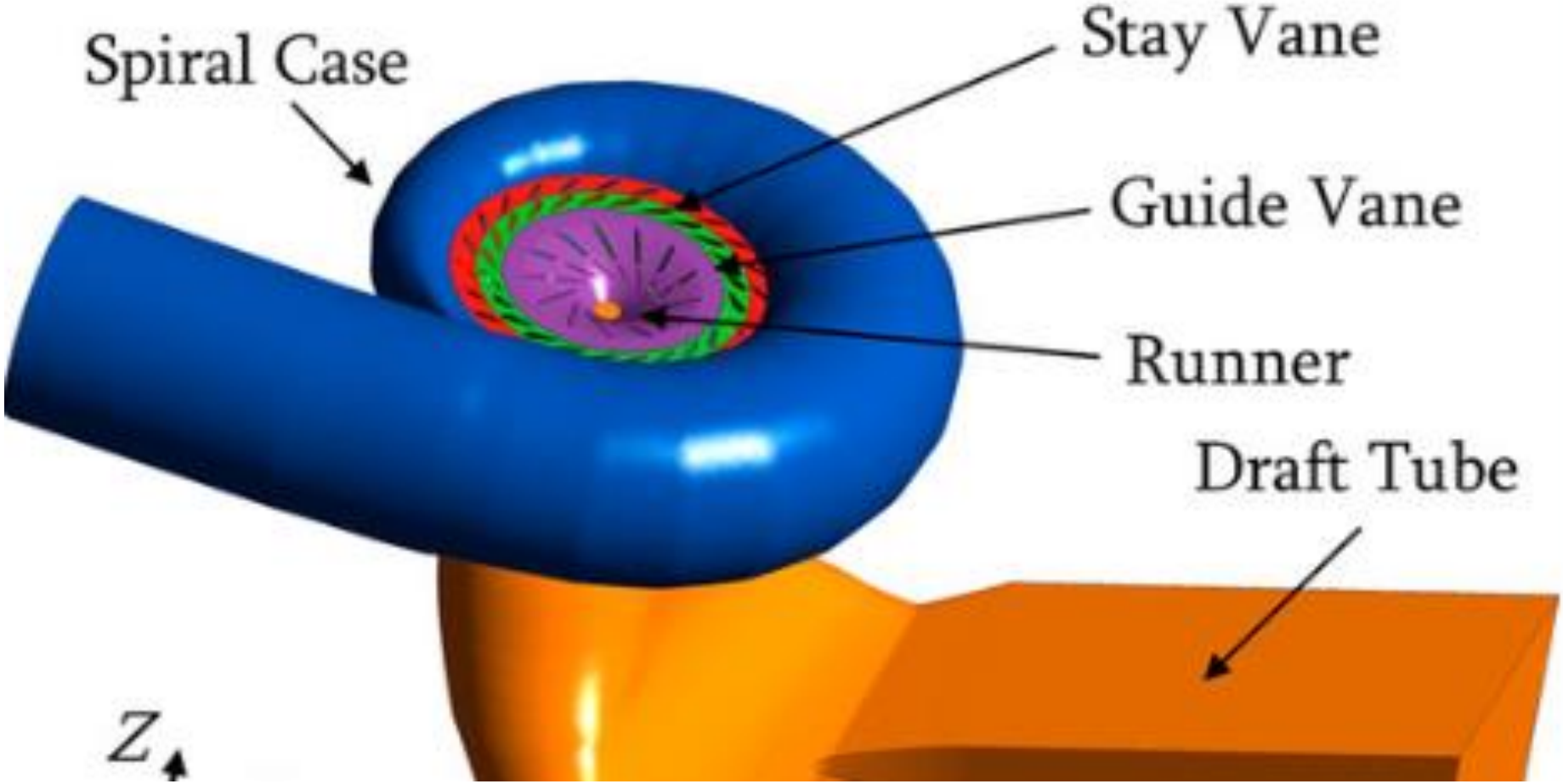
Draft Tube in Reaction Turbine

- It is a tapered (diverging to the lower side) tube which provides exit passage to the water mass coming out of the runner centre.
- At the runner exit, the water pressure is generally vacuum pressure (below atmP) which needs to be increased. For this, draft tube is used.
- Draft tube is having increasing cross-sectional area and hence, decreasing velocity of water (As per continuity Eqn). This in turn, cause increase in pressure(as per Bernoulli's principle). The last pressure may be close to atm. pressure. This prevents any chance of water from reservoir to move up in the draft tube to turbine.
- This increase in pressure also prevents any chances of serious problem of 'Cavitation'.


Authored by www.mekanizmalar.com
Francis Turbine
Water Head
© GDF Suez

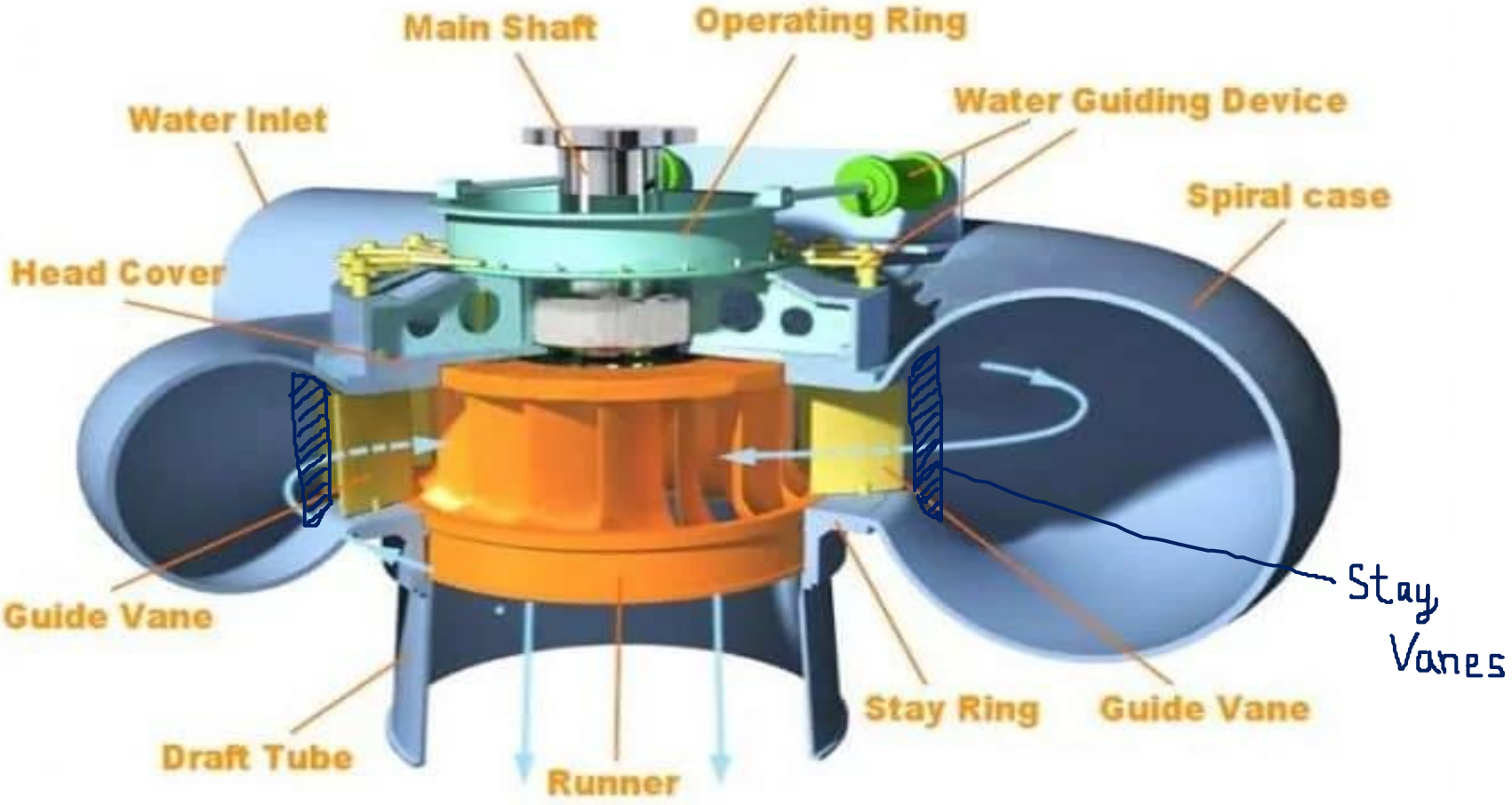
Spiral Casing of Francis Turbine




Spiral Case
Stay Vane
Guide Vane
Runner
Draft Tube
Z

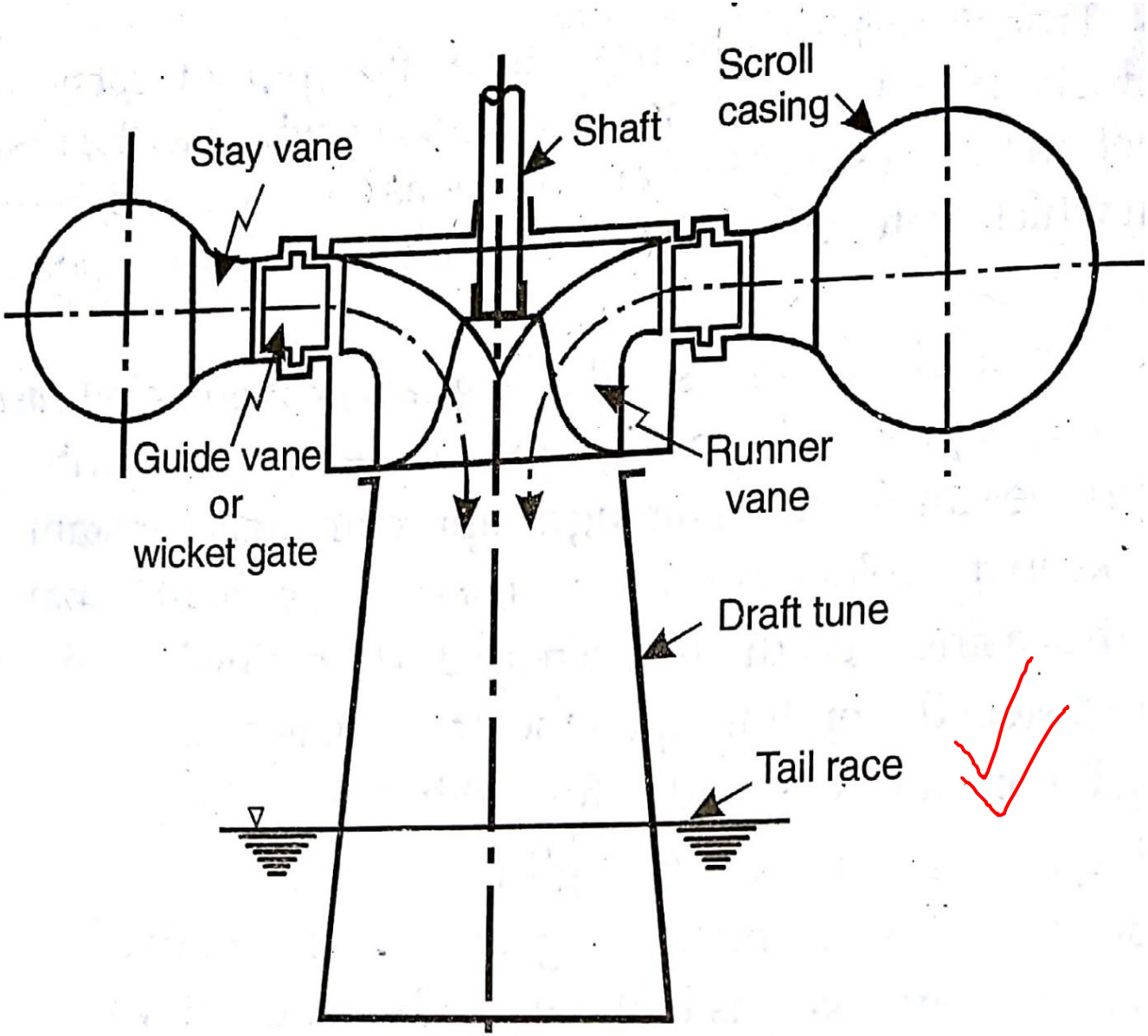
Francis Turbine:

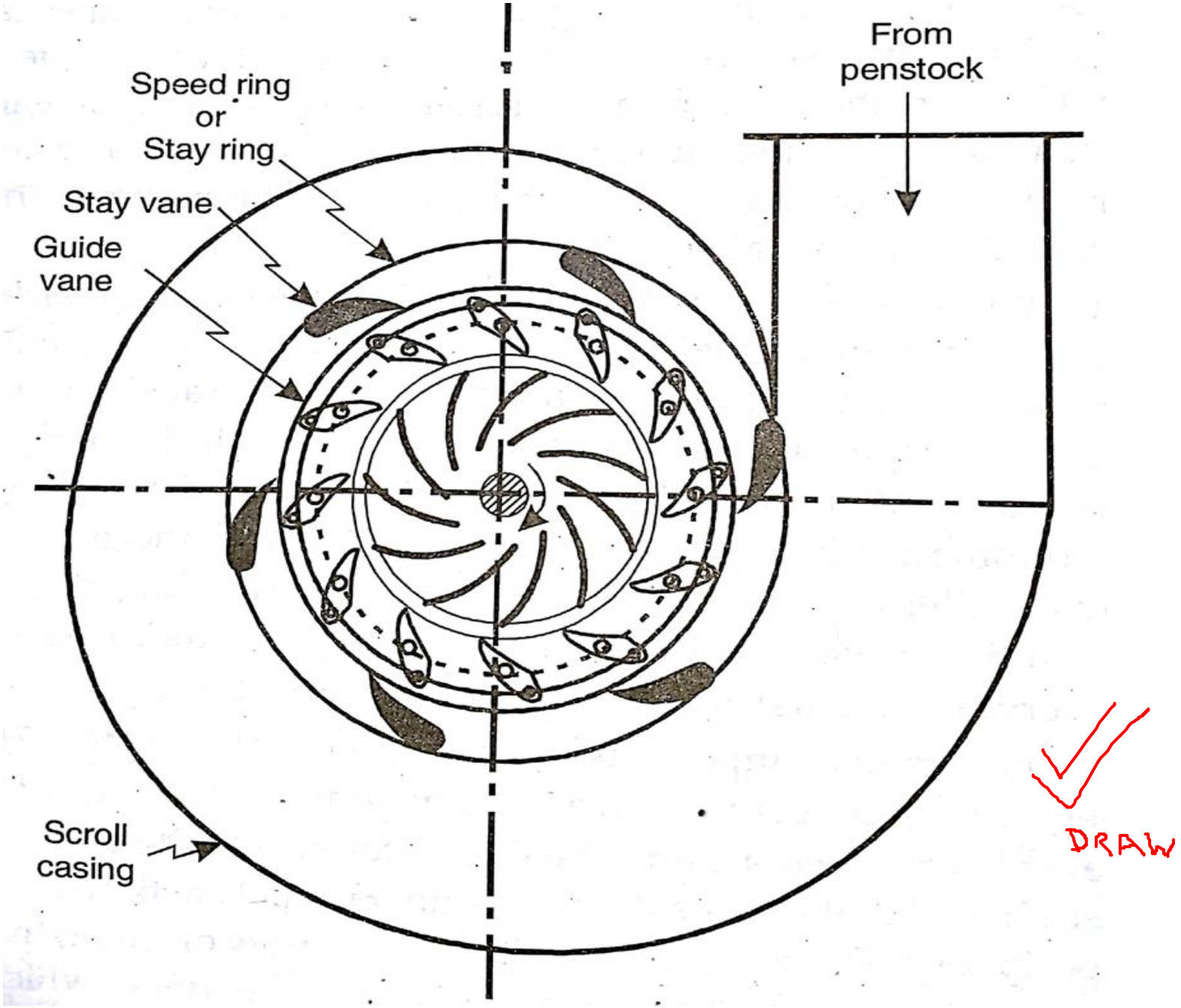
It’s a mixed flow type reaction turbine. In it water enters radially at its outer periphery and leaves axially at its center.

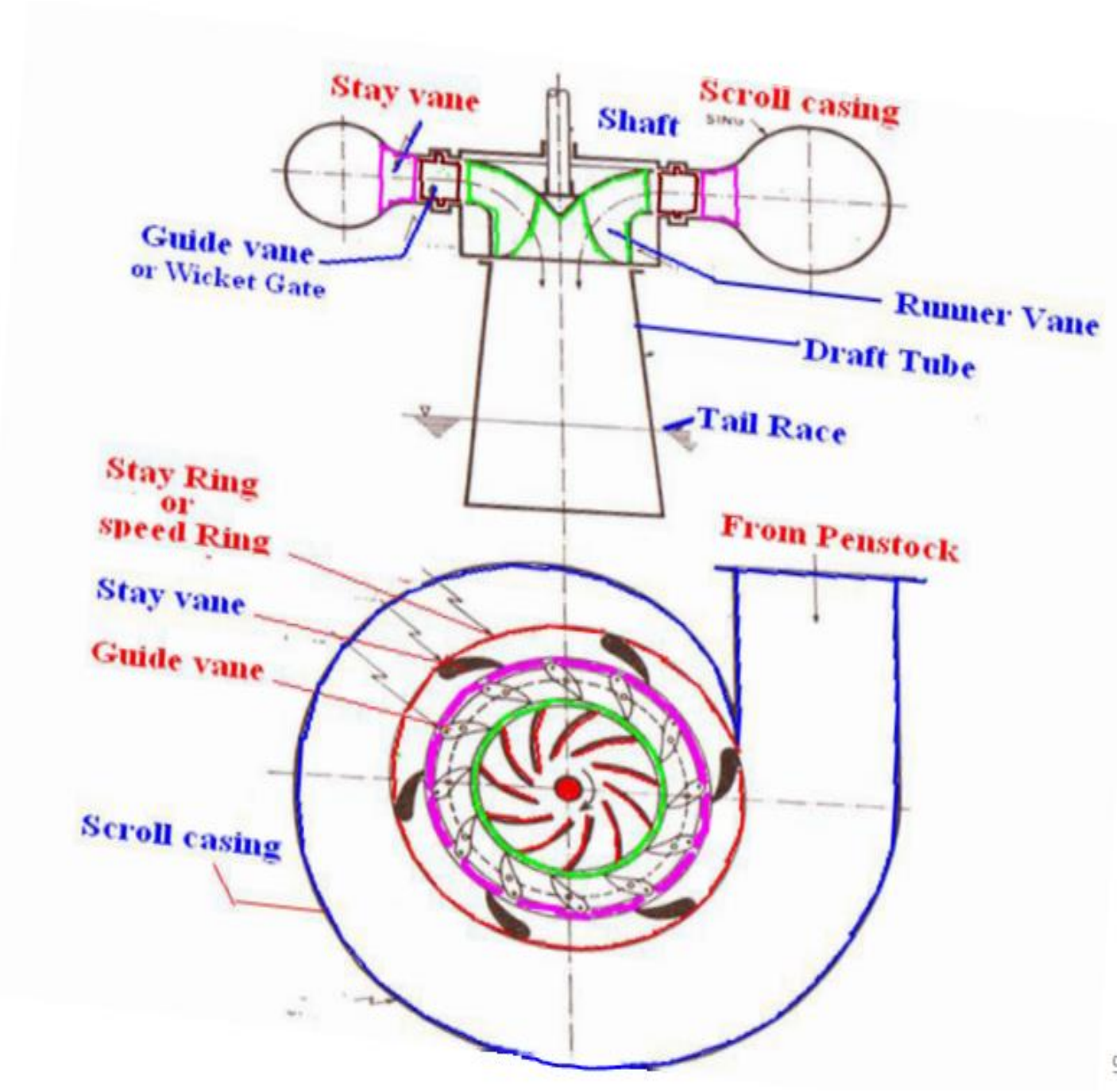


Francis Turbine

Main Components

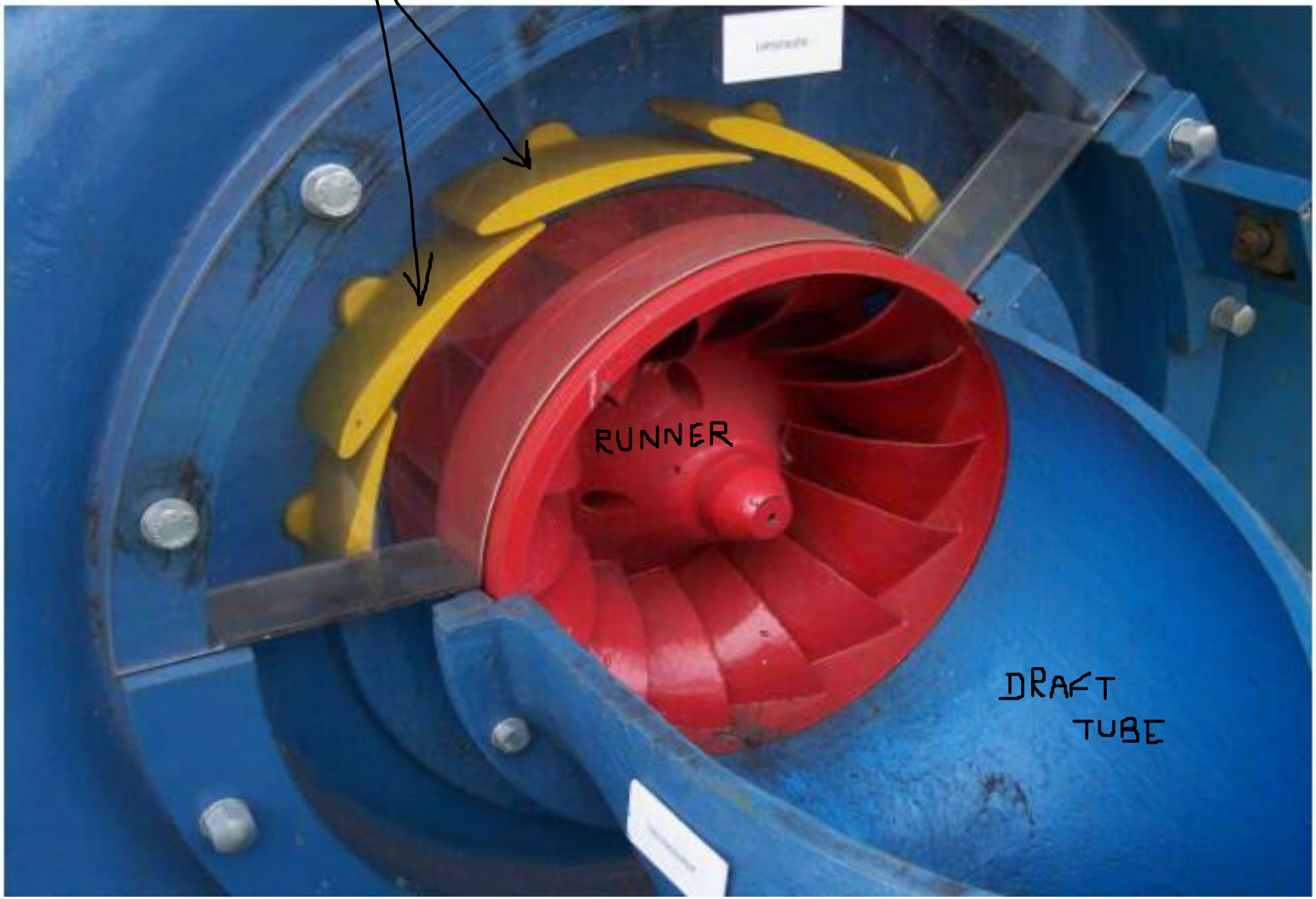



From
penstock
Speed ring
or
Stay ring
Stay vane
Guide
vane
Scroll
casing
DRAW


Stay vane
Shaft
Scroll casing
Guide vane
or Wicket Gate
Runner Vane
Draft Tube
Tail Race
Stay Ring
or
speed Ring
From Penstock
Stay vane
Guide vane
Scroll casing

Working of Guide vanes (Wicket gates)

Guide Vanes



Francis Turbine

- Head 45 – 400 m
- Flow rate : 10 to 700 m^3/sec
- Runner blades have thin airfoil type cross section causing a lift force. It is also have a special curved shape at exit point, so the water also cause impulsive force before leaving the runner.
- So Francis is not a pure reaction turbine, but partially impulse turbine also.
- These are mixed flow turbines.

Main Parts of Francis turbine

- Penstock
- Spiral casing (vortex casing) or scroll casing
- Stay ring
- Stay vanes
- Guide vanes
- Runner
- Draft tube

- Penstock : It is the large size pipeline through which the water comes from the head race reservoir side towards the turbine. Gates may be provided at the entrance to control the amount of water entering inside the penstock.

Casing – Scroll casing or spiral casing or vortex casing

- The purpose of the **casing** is to provide an even distribution of water around the circumference of the turbine runner
- In order to keep the velocity of the water constant throughout its path around the runner, the cross sectional area of the casing is gradually decreased.
- The casing is usually made up of cast iron.
- **Stay ring** : It is at the inner diameter circle of the vortex casing. Stay vanes are provided on stay rings.

Vanes

- **Stay Vanes:** It directs the water from casing to the guide vanes. Its number is usually taken as half the number of guide vanes. These are usually made of cast iron or cast steel.
- **Guide Vanes or Wicket Vanes (or Wicket gates):** Its function is to regulate the quantity of water supplied to the runner and to direct water onto the runner at an appropriate (optimum) angle.
  - Guide vanes are of *airfoil shape* to reduce friction losses and proper pressure variation.
  - Guide vanes are operated either by means of a wheel or automatically by a governor.

- **Runner blades:** The runner of Francis turbine consists of a series of curved blades(16 – 24 in no.) evenly arranged around the circumference of turbine shaft.

  •The blades are so shaped that the water enters the runner radially at the outer periphery and leaves it axially at the inner periphery.

  •The change in the direction of flow produces centrifugal action on the runner.

  •The blades have *airfoil shape*, so that the effect of reaction pressure could be used. It causes lower pressure at the inside of runner, whereas higher pressure on the outside of runner.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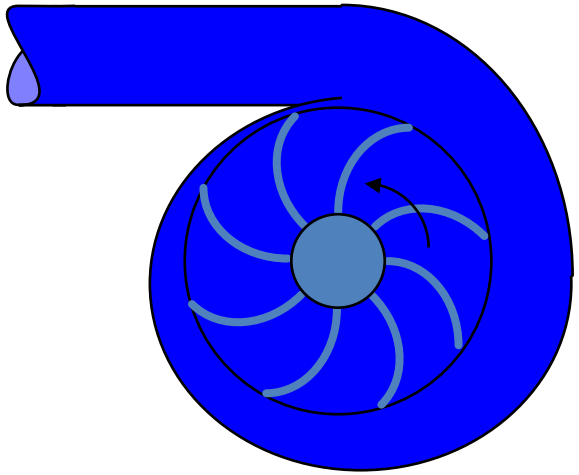
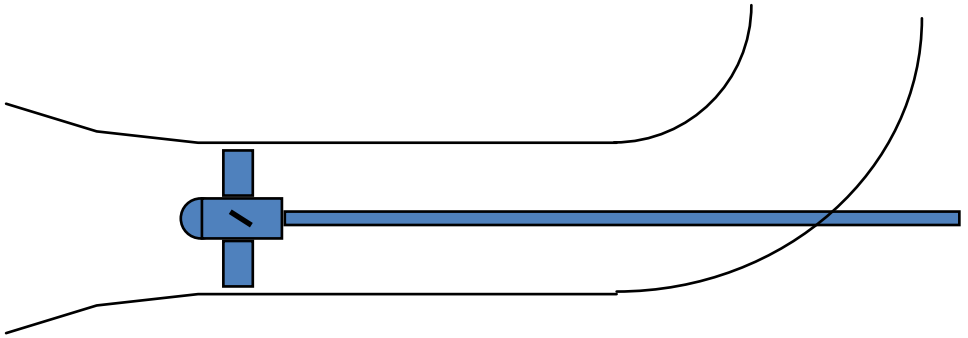
Impulse Vs Reaction Turbine

Impulse Turbine	Reaction Turbine
1. All the available energy of the fluid is converted into kinetic energy by an efficient nozzle that forms a free jet.	1. Only a portion of the fluid energy is transformed into kinetic energy before the fluid enters the turbine runner.
2. The jet is unconfined and at atmospheric pressure throughout the action of water on the runner, and during its subsequent flow to the tail race.	2. Water enters the runner with an excess pressure, and then both the velocity and pressure change as water passes through the runner.
3. Blades are only in action when they are in front of the nozzle.	3. Blades are in action all the time.
4. Water may be allowed to enter a part or whole of the wheel circumference.	4. Water is admitted over the circumference of the wheel.
5. The wheel does not run full and air has free access to the buckets.	5. Water completely fills the vane passages throughout the operation of the turbine.
6. Casing has no hydraulic function to perform; it only serves to prevent splashing and to guide the water to the tail race.	6. Pressure at inlet to the turbine is much higher than the pressure at outlet ; unit has to be sealed from atmospheric conditions and, therefore, casing is absolutely essential.
7. Unit is installed above the tail race.	7. Unit is kept entirely submerged in water below the tail race.
8. Flow regulation is possible without loss.	8. Flow regulation is always accompanied by loss.
9. When water glides over the moving blades, its relative velocity either remains constant or reduces slightly due to friction.	9. Since there is continuous drop in pressure during flow through the blade passages, the relative velocity does increase.
10. only moving Blades	10. Fixed Blades + Moving Blades, Both.

Hydraulic Pumps





Definition

- Water pumps are devices designed to convert mechanical energy to hydraulic energy.
- They are used to move water from lower points to higher points with a required discharge and pressure head.
- This chapter will deal with the basic hydraulic concepts of water pumps

Pump Classification

- **Based on working principle:**

- Centrifugal pumps
- Rotary Vane Pumps
- Piston pumps (reciprocating pumps)- single or double acting types
- Gear pumps
- Screw pumps

Pump Classification

- **Turbo-hydraulic (rotodynamic) pumps**

(based on LEAVING of fluid from the pump)

Centrifugal pumps (radial-flow pumps)

Propeller pumps (axial-flow pumps)

Jet pumps (mixed-flow pumps)

- **Positive-displacement pumps** **(enclosing a fixed volume of fluid and moving it mechanically by continuous pushing through the system. Here, the boundary of the fluid is displaced mechanically.)**

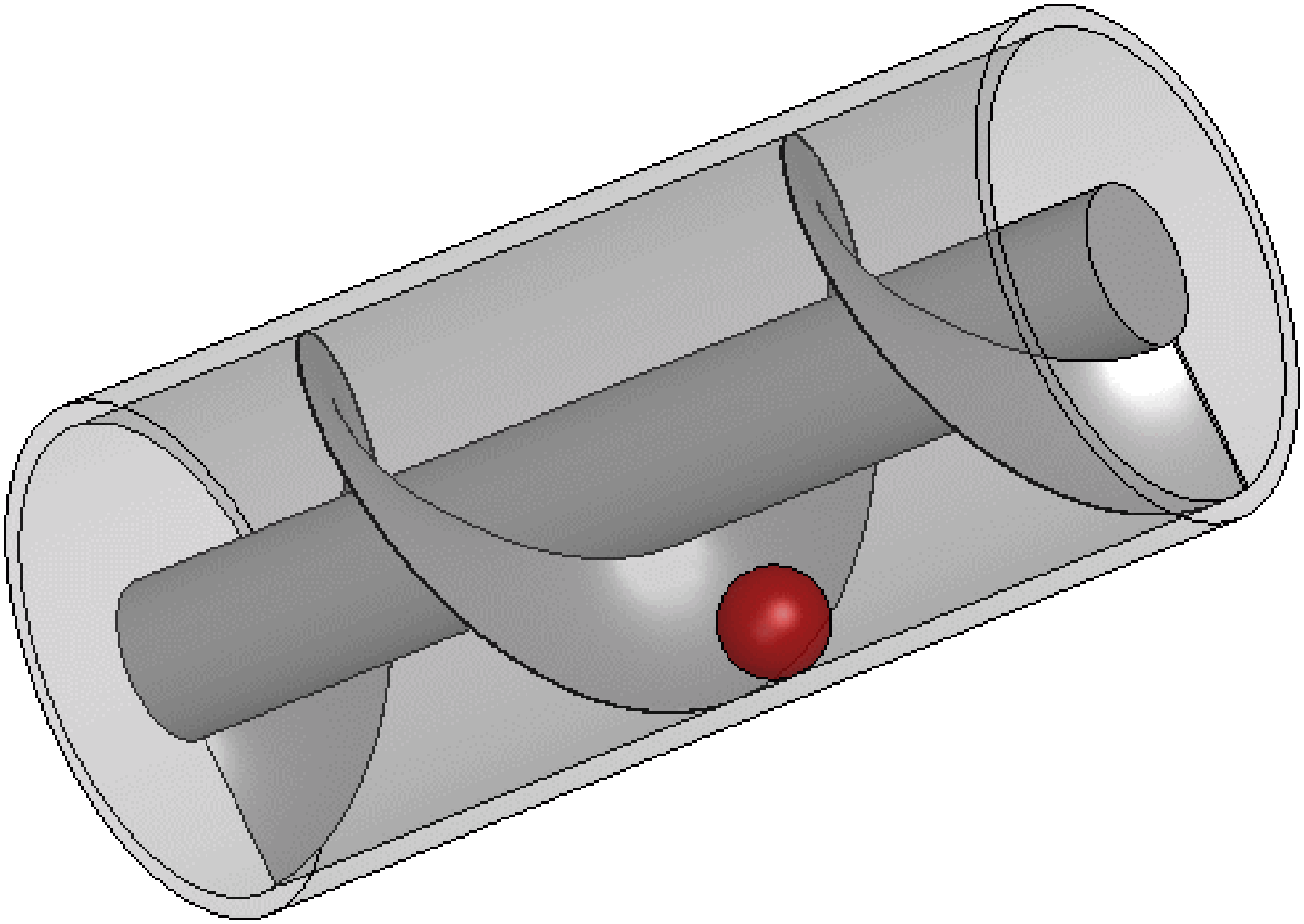
Screw pumps, Gear pump, Vane pump,
Reciprocating pumps

Turbo-hydraulic pumps :

This classification is based on the way by which the water leaves the rotating part of the pump.

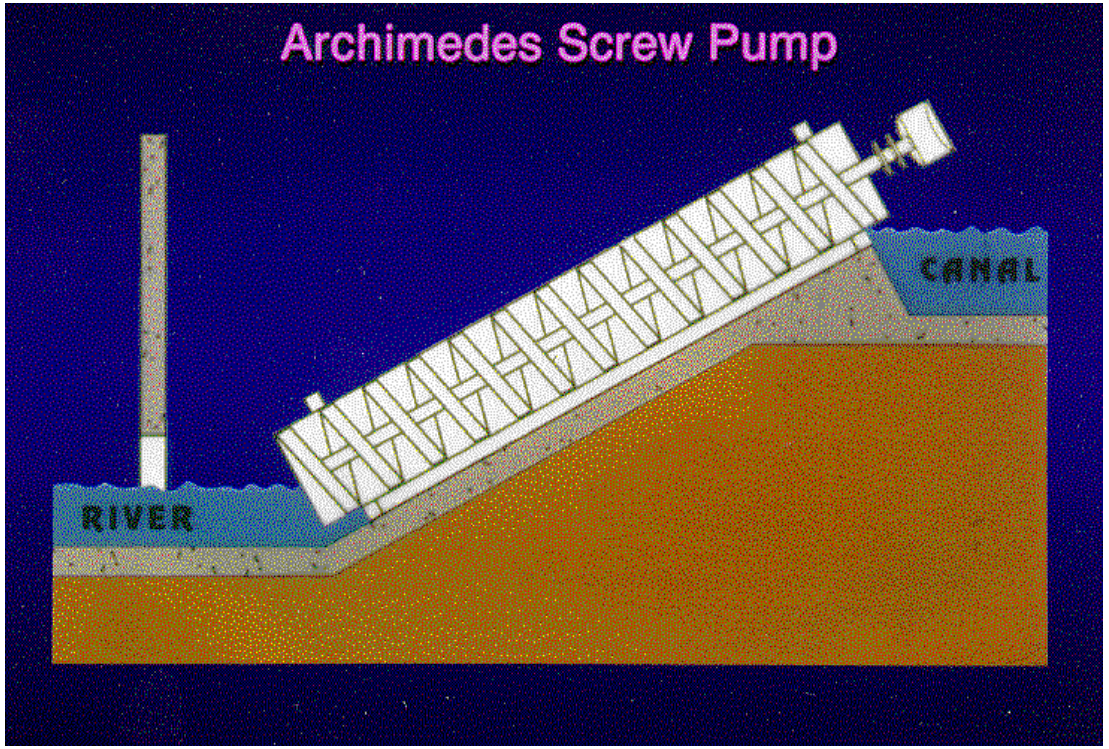
- In radial-flow pump the water leaves the impeller in radial direction,
- while in the axial-flow pump the water leaves the propeller in the axial direction.
- In the mixed-flow pump the water leaves the impeller in an inclined direction having both radial and axial components

Screw Pumps

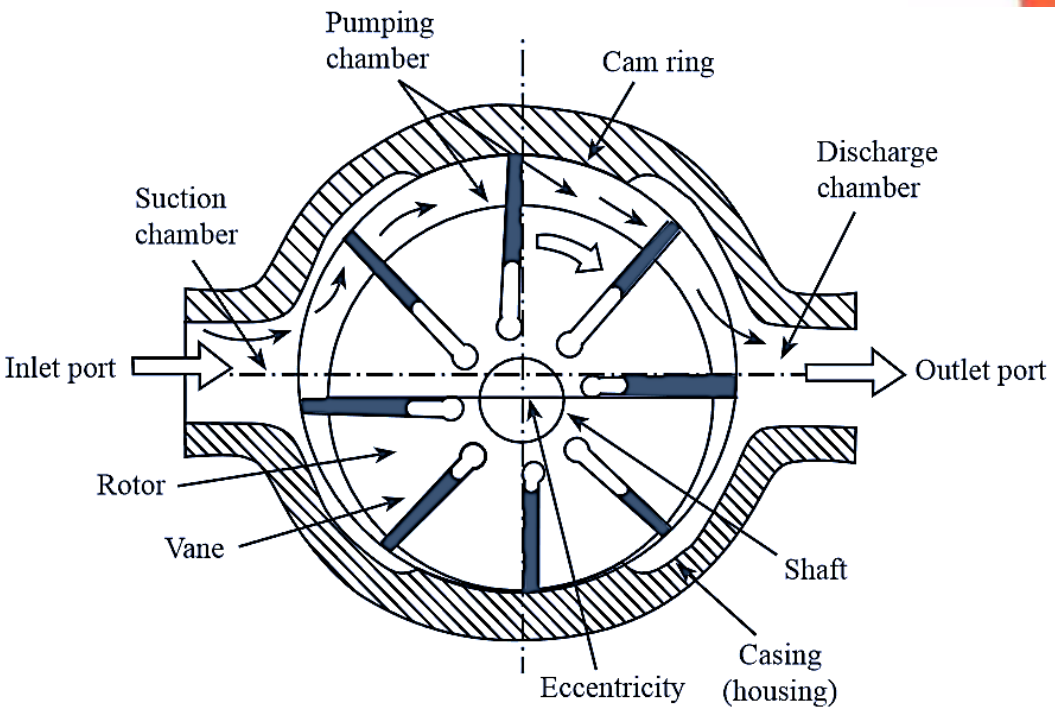


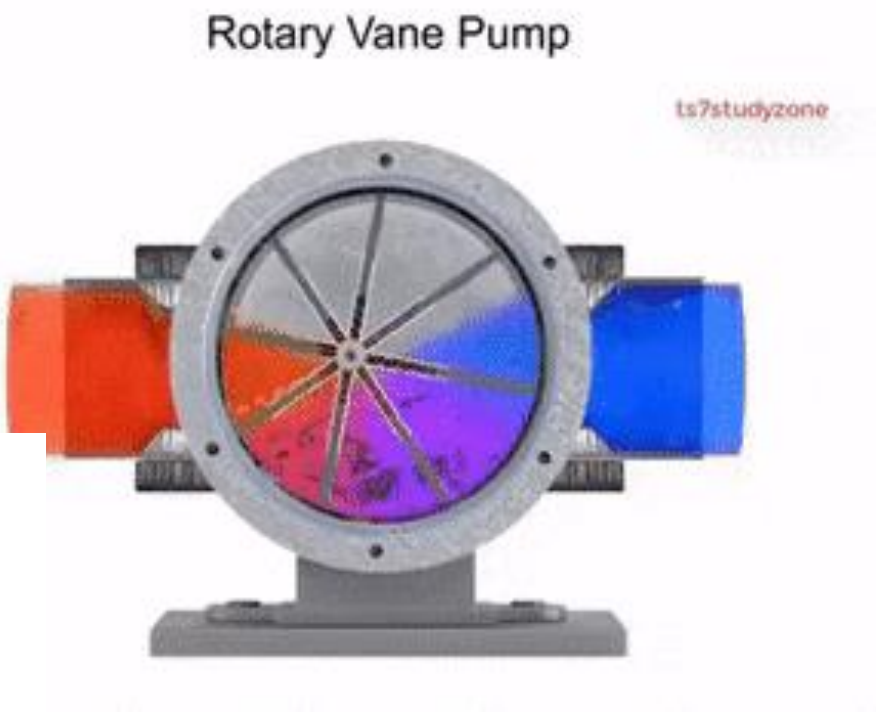
Screw Pumps

- In the screw pump a revolving shaft fitted with blades rotates in an inclined trough and pushes the water up the trough.

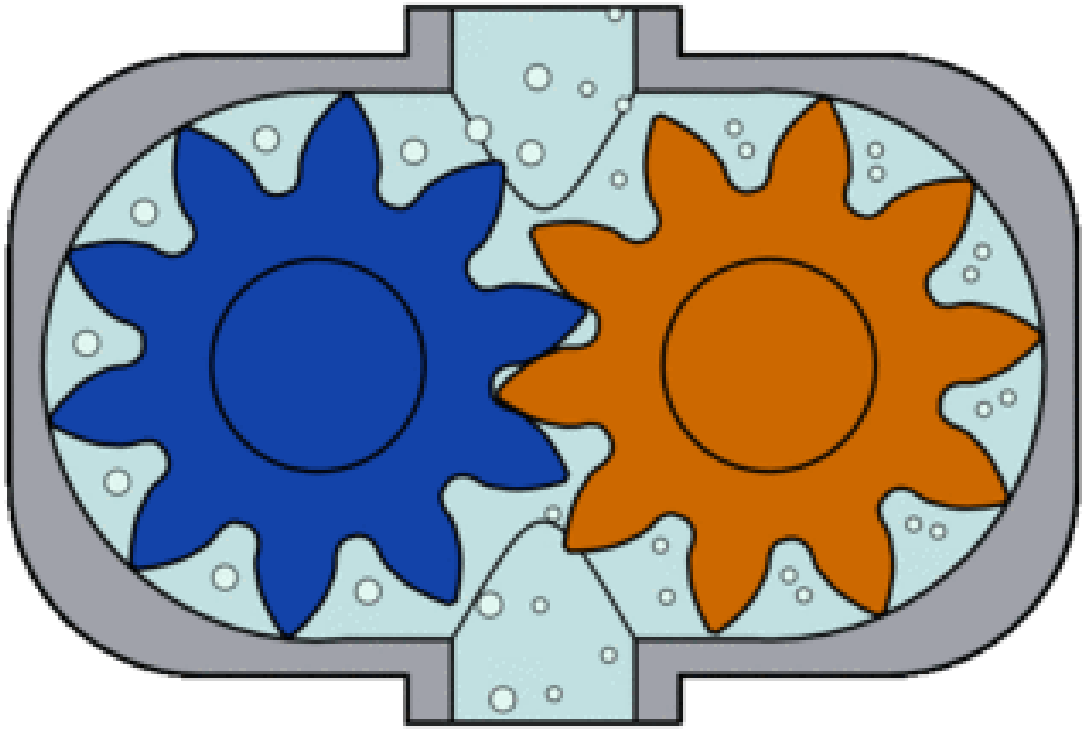


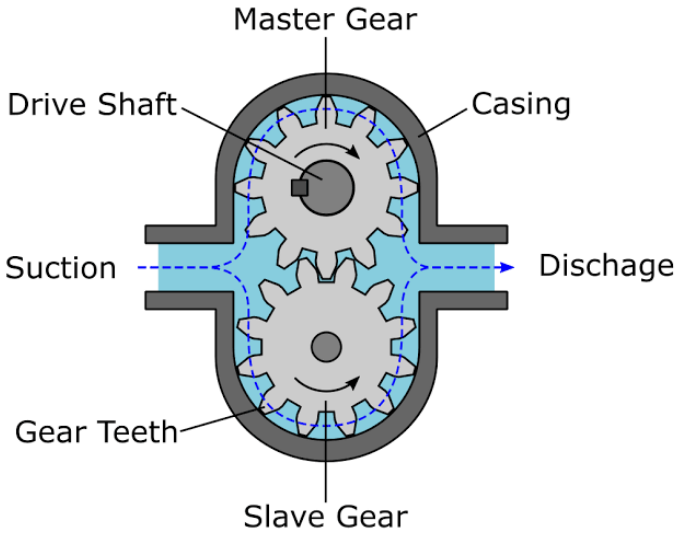
Rotary Vane pump





Gear pump




Master Gear
Drive Shaft
Casing
Suction
Dischage
Gear Teeth
Slave Gear

Piston pumps (reciprocating pumps)

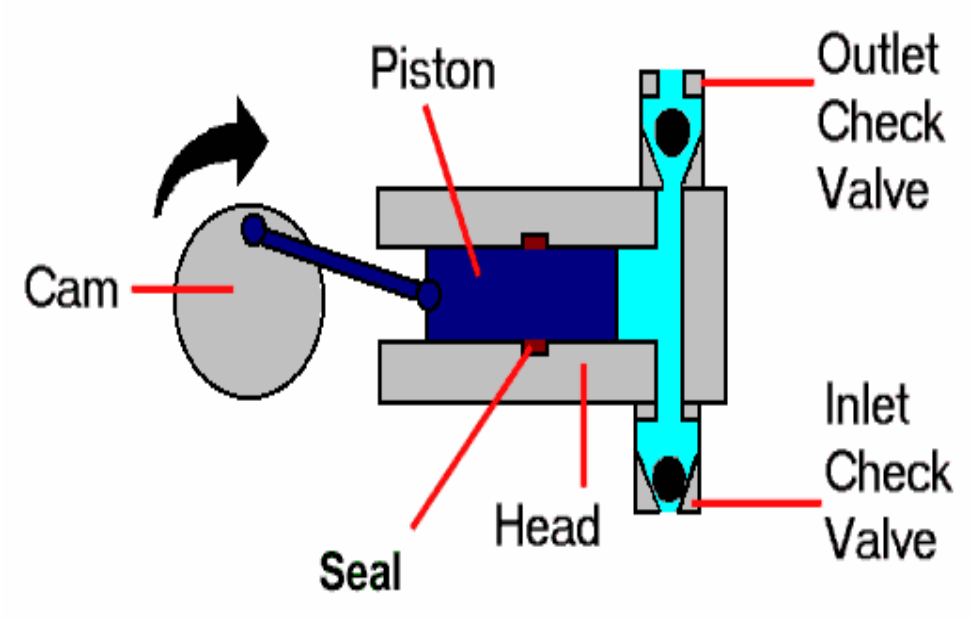
These pumps convert the rotating motion of a crank into reciprocating motion of a piston. The crank is rotated externally by a motor. Out of the two strokes of the piston, one creates suction of the fluid and the second stroke creates delivery of the fluid to a higher level. These pumps are of two types:

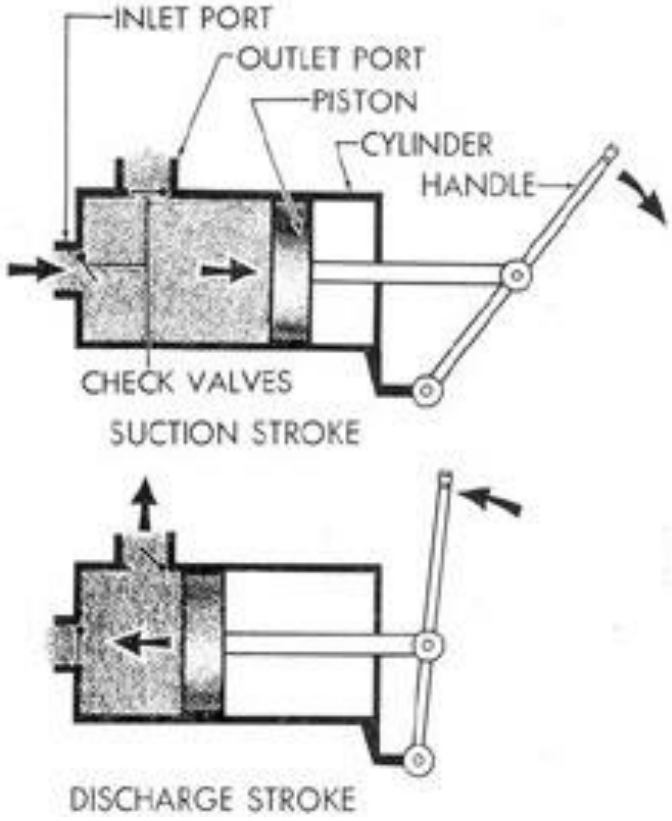
- Single acting reciprocating pumps
- Double acting reciprocating pumps

(for all theoretical details, plz refer notes).

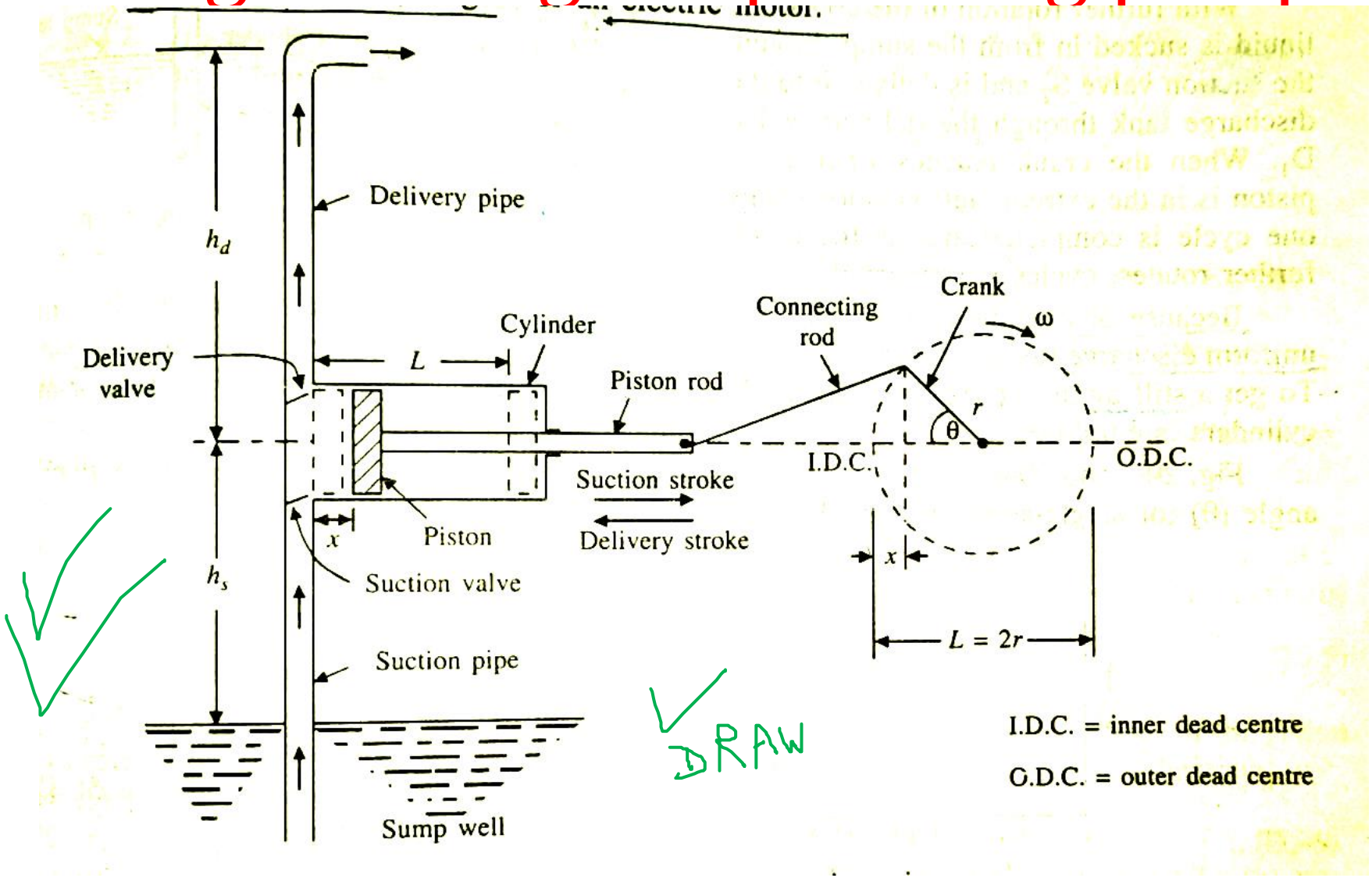
Reciprocating Pumps

- In the reciprocating pump a piston sucks the fluid into a cylinder then pushes it up causing the water to rise.

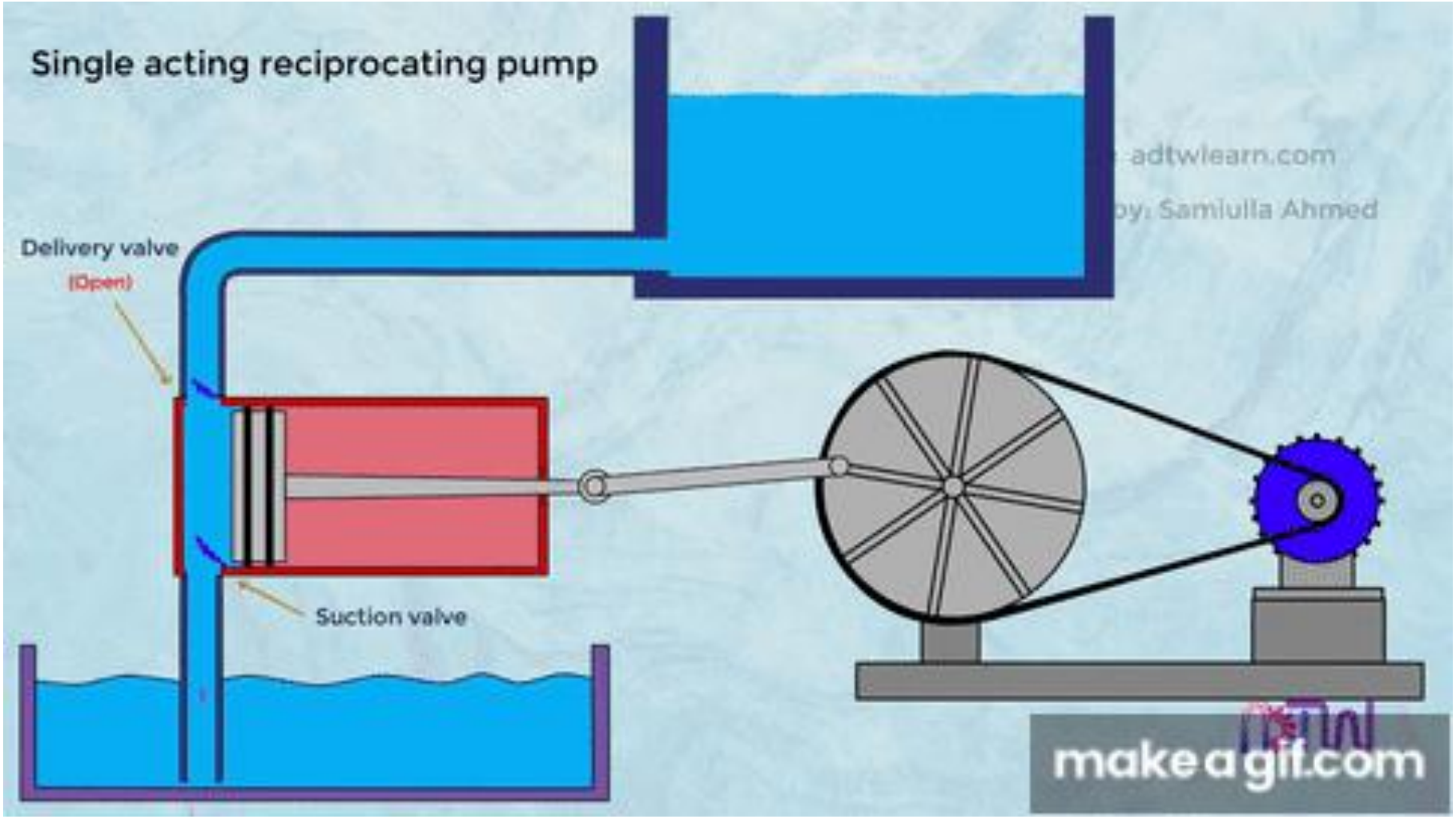




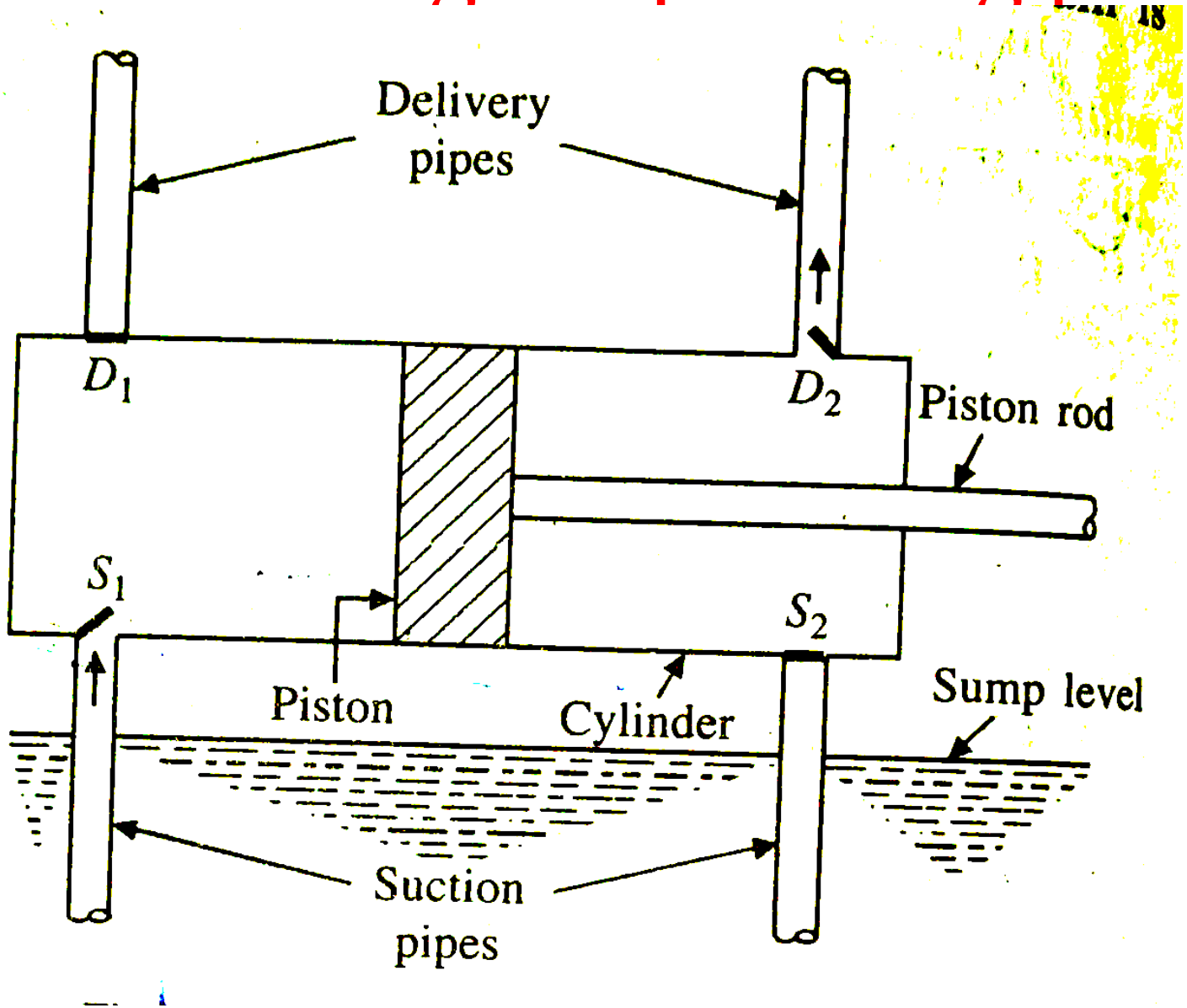
Single Acting reciprocating pump



Single Acting reciprocating pump

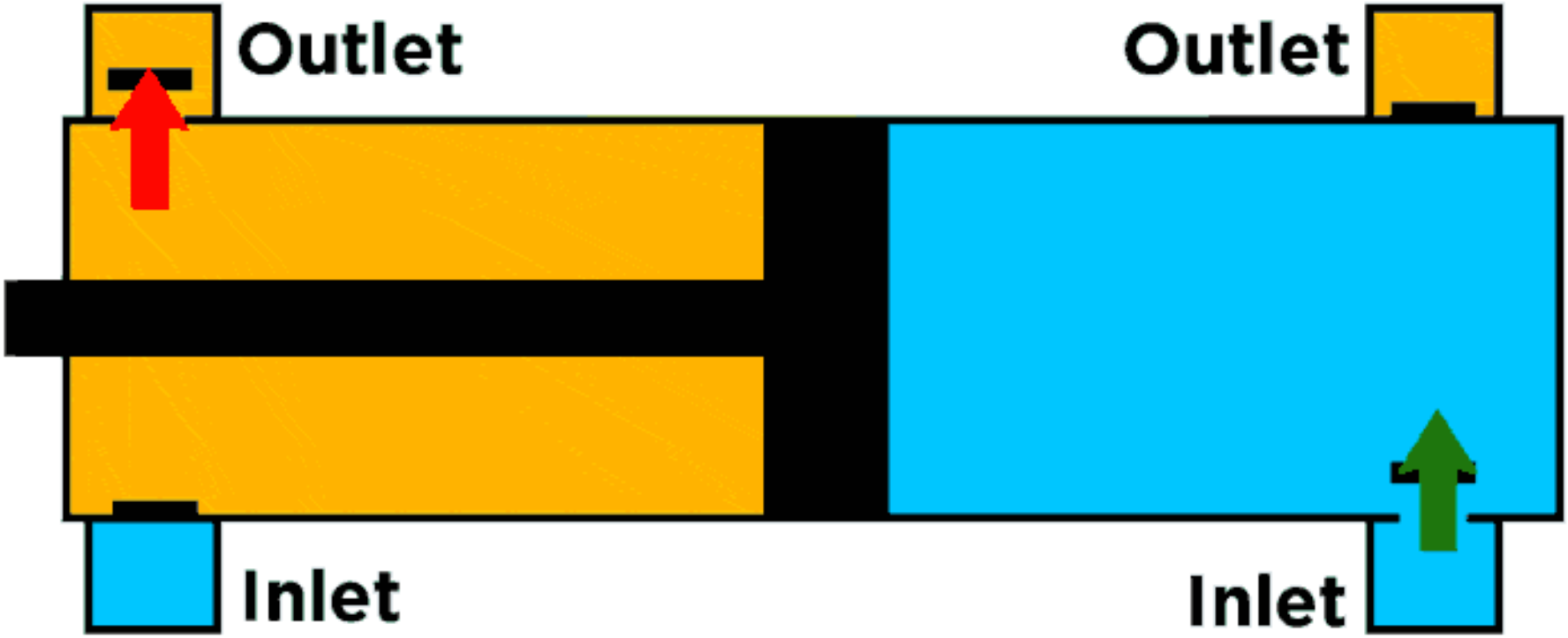


Double acting reciprocating pump



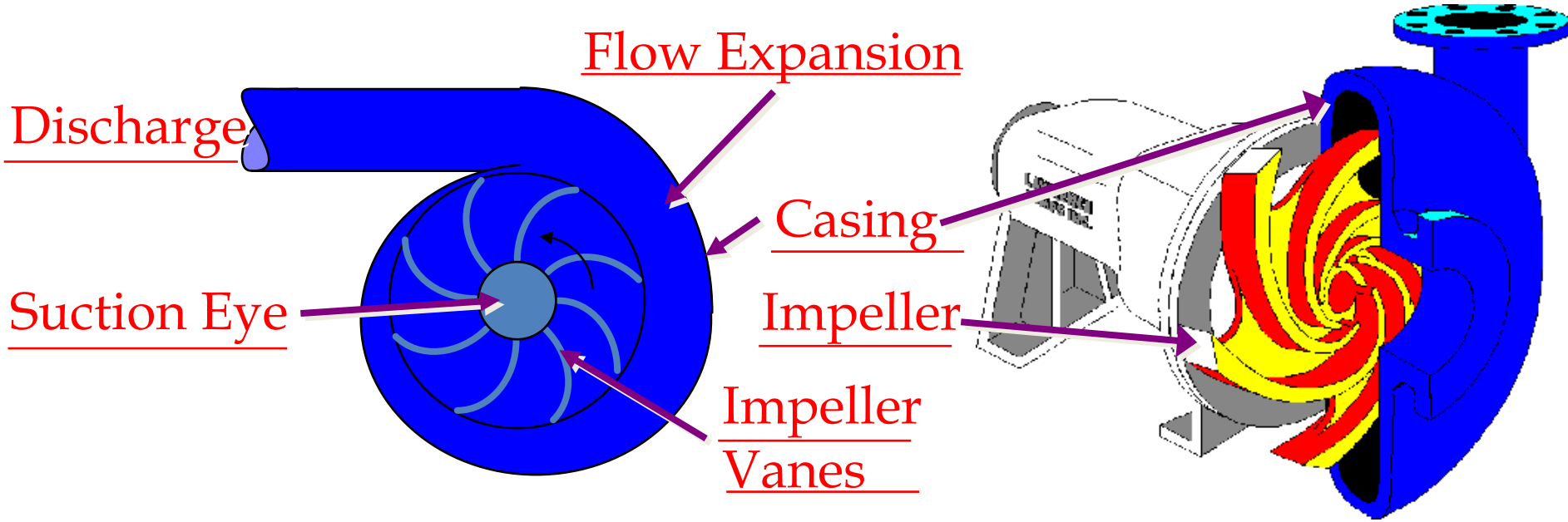
DRAW

Double acting reciprocating pump



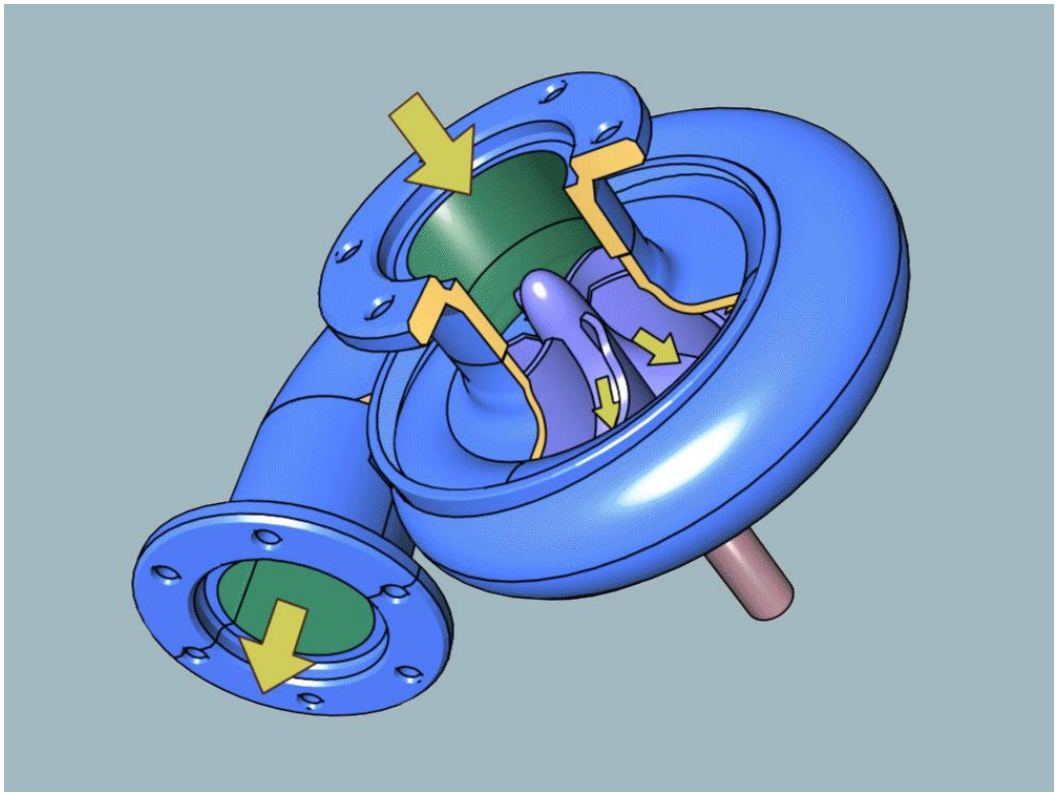
Centrifugal Pumps

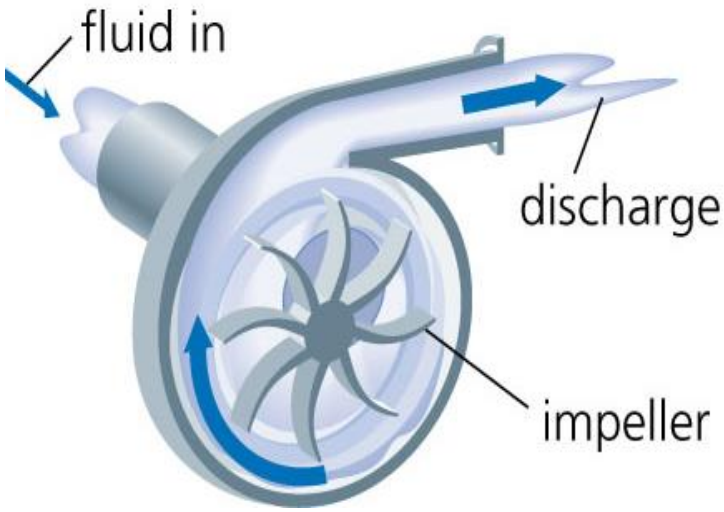
- Broad range of applicable flows and heads
- Higher heads can be achieved by increasing the diameter or the rotational speed of the impeller

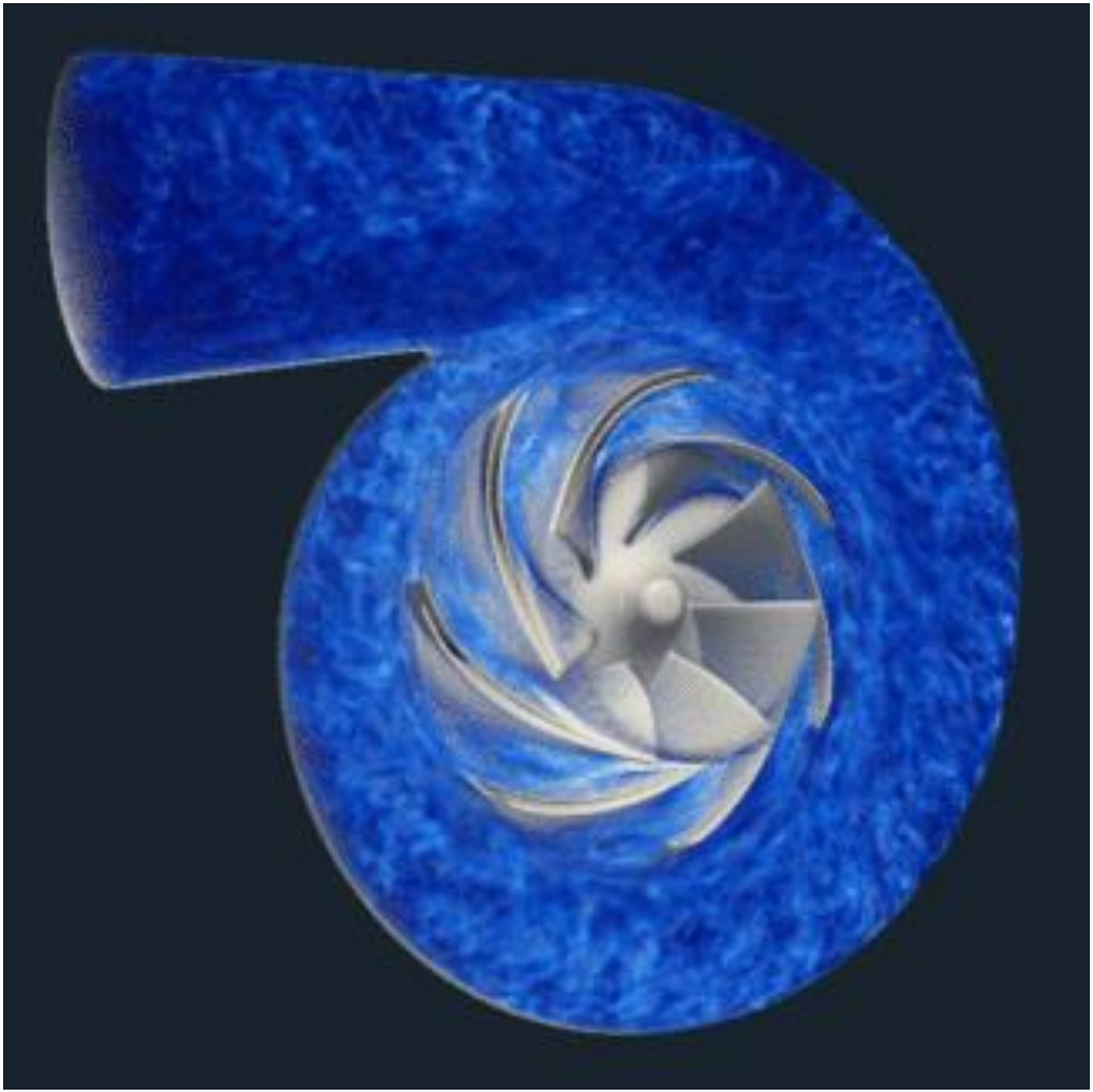


Centrifugal Pump:

- Centrifugal pumps (radial-flow pumps) are the most used pumps for hydraulic purposes. For this reason, their hydraulics will be studied in the following parts.



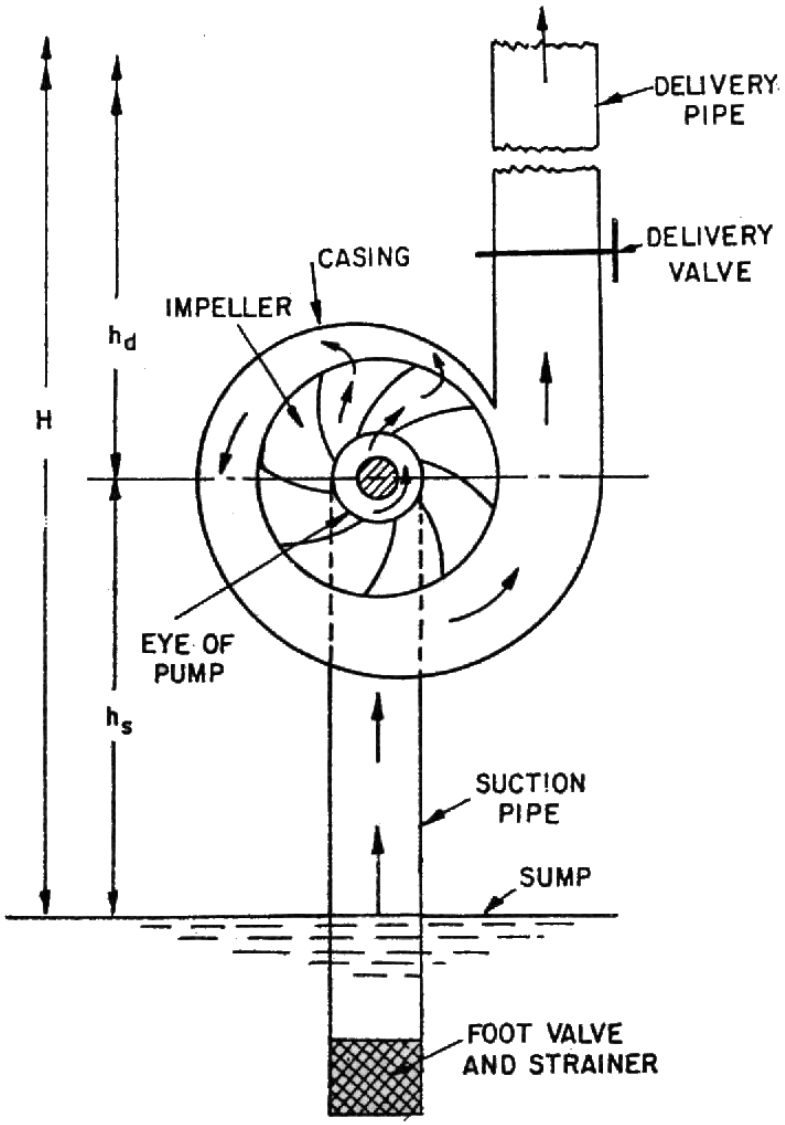




Main Parts of Centrifugal Pumps

1. Impeller:

- which is the rotating part of the centrifugal pump.
- It consists of a series of backward curved vanes (blades).
- The impeller is driven by a shaft which is connected to the shaft of an electric motor.

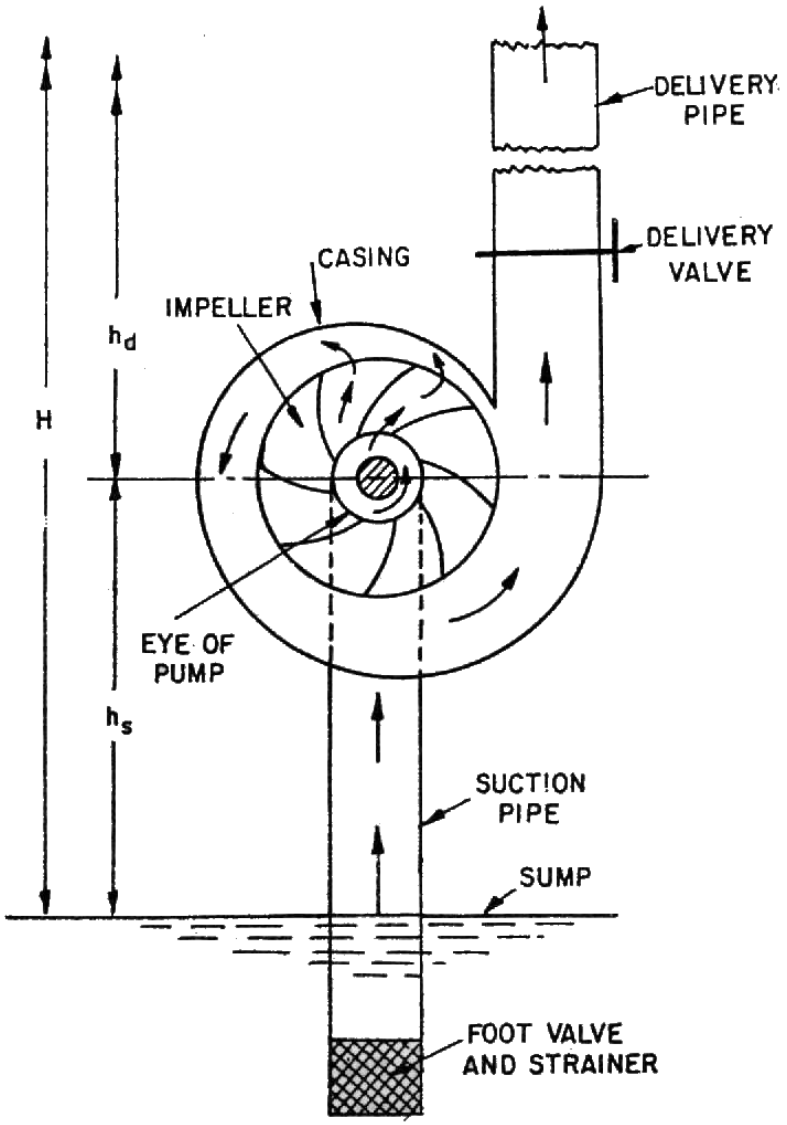


DRAW

Main Parts of Centrifugal Pumps

2. Casing

- Which is an air-tight passage surrounding the impeller
- designed to direct the liquid to the impeller and lead it away
- *Volute casing*. It is of spiral type in which the area of the flow increases gradually.



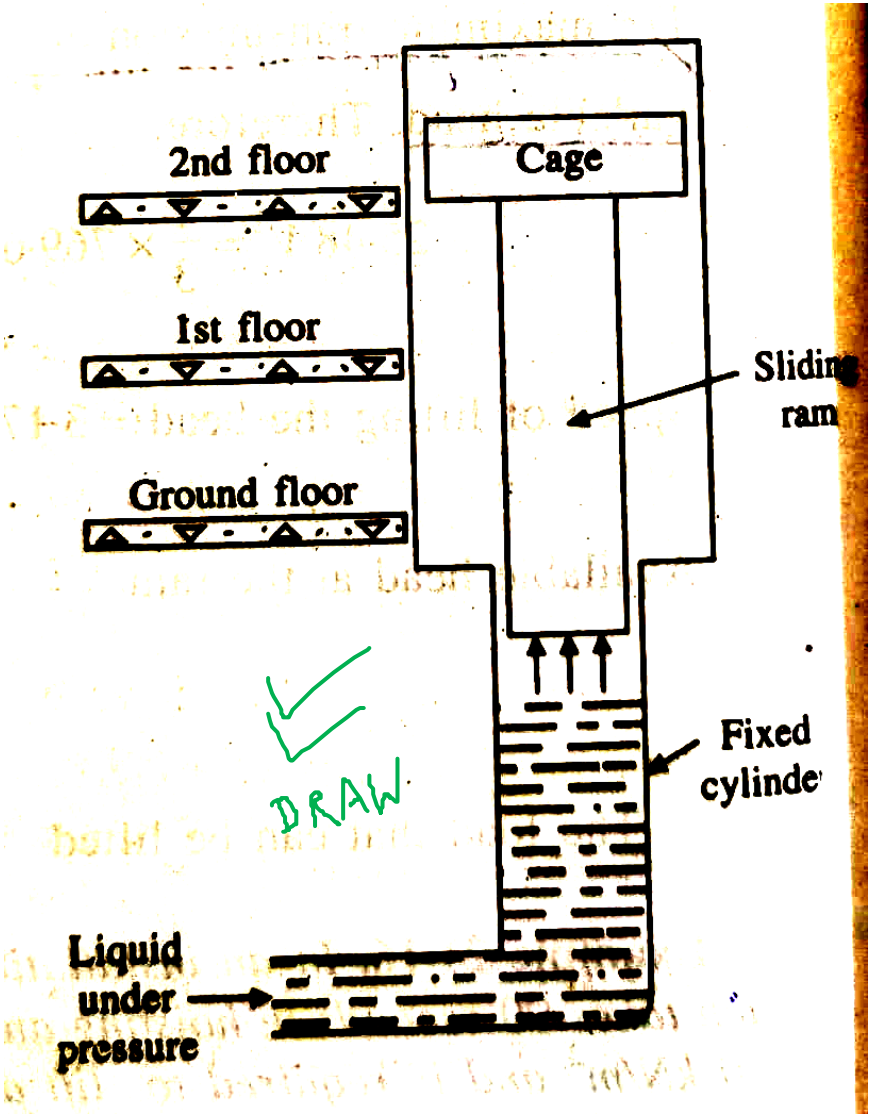
3. **Suction Pipe.**
4. **Delivery Pipe.**
5. **The Shaft**: which is the bar by which the power is transmitted from the motor drive to the impeller.
6. **The driving motor**: which is responsible for rotating the shaft. It can be mounted directly on the pump, above it, or adjacent to it.

Hydraulic Lifts

- A hydraulic device used for carrying persons and loads from one floor to another, in a multi-storeyed building

- These are mainly of two types:
  - Direct Acting hydraulic lift
  - Suspended hydraulic lift

Direct Acting hydraulic lift



Direct Acting hydraulic lift

- Principle of working: The functioning of a direct acting hydraulic lift is based on Pascal's law.

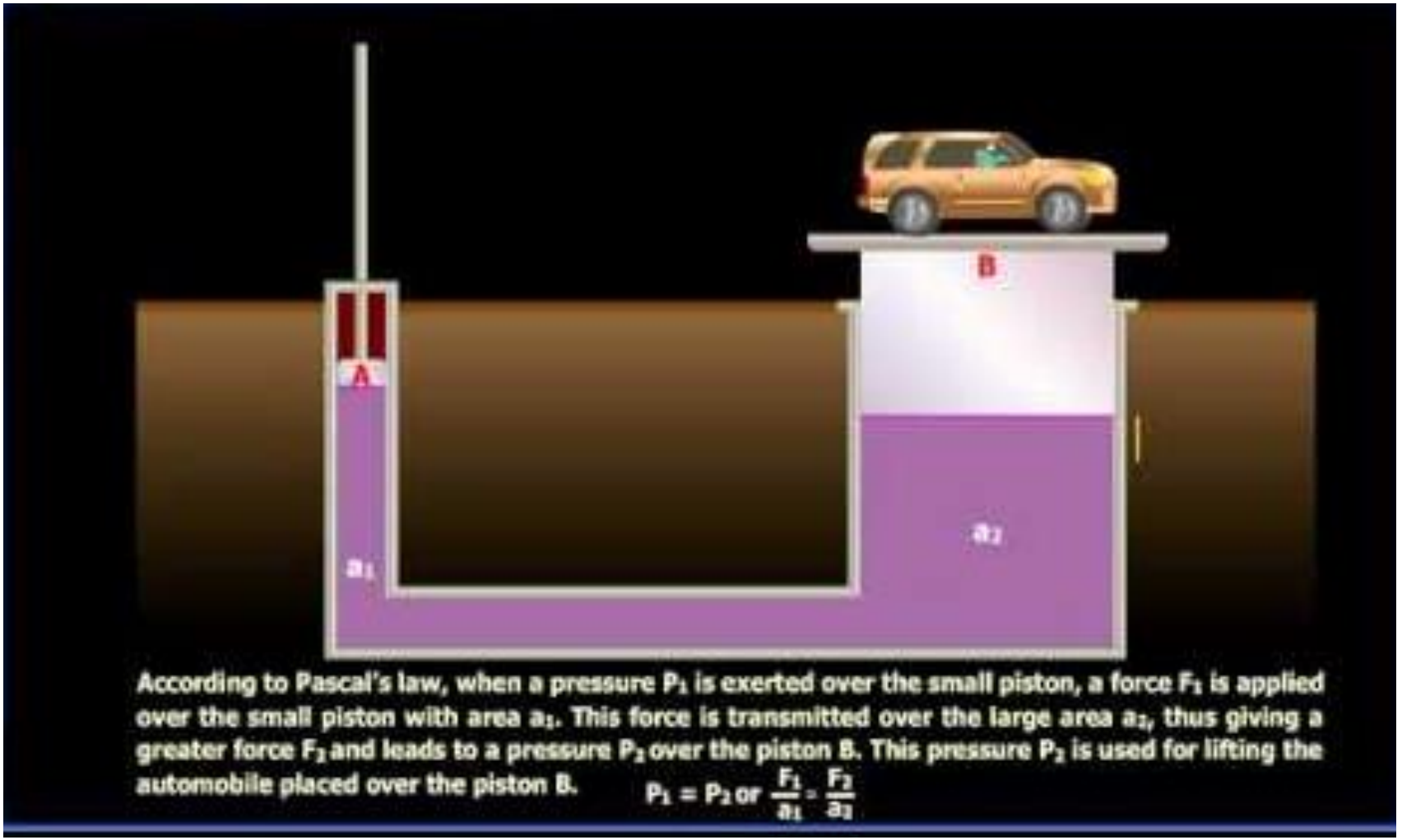
PARTs and Components:

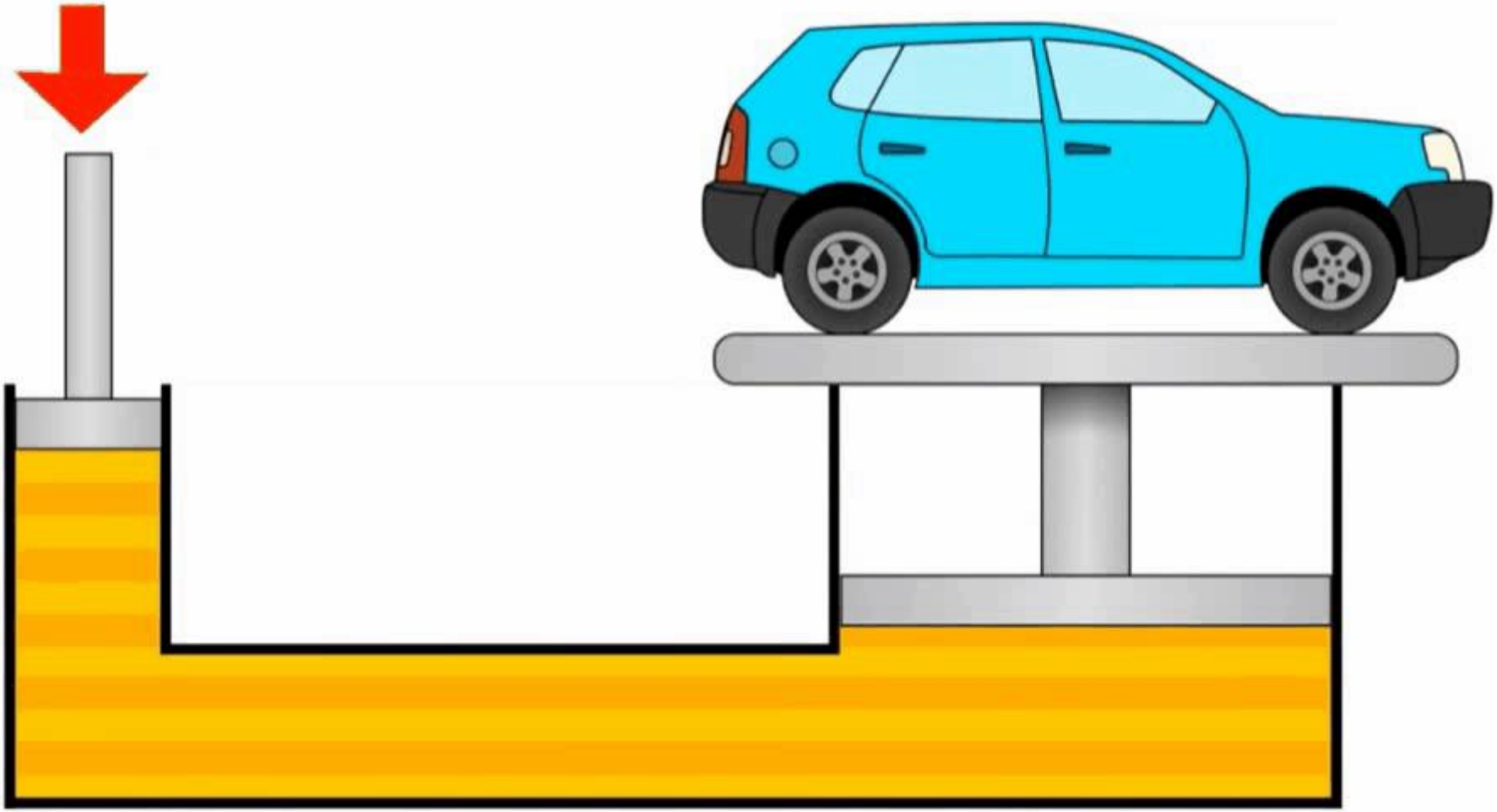
- It consists of a fixed hollow cylinder in which a suitable incompressible hydraulic oil is passed under pressure, through a pipeline. A rammer is fitted inside to slide into it, vertically upward/downward as required. The cage (Load) is fitted with this rammer, which is required to be moved up/down.
- Area of cross section of rammer is greater than that of the inlet pipeline, to ensure higher force to be transmitted, as per Pascal's law.

WORKING:

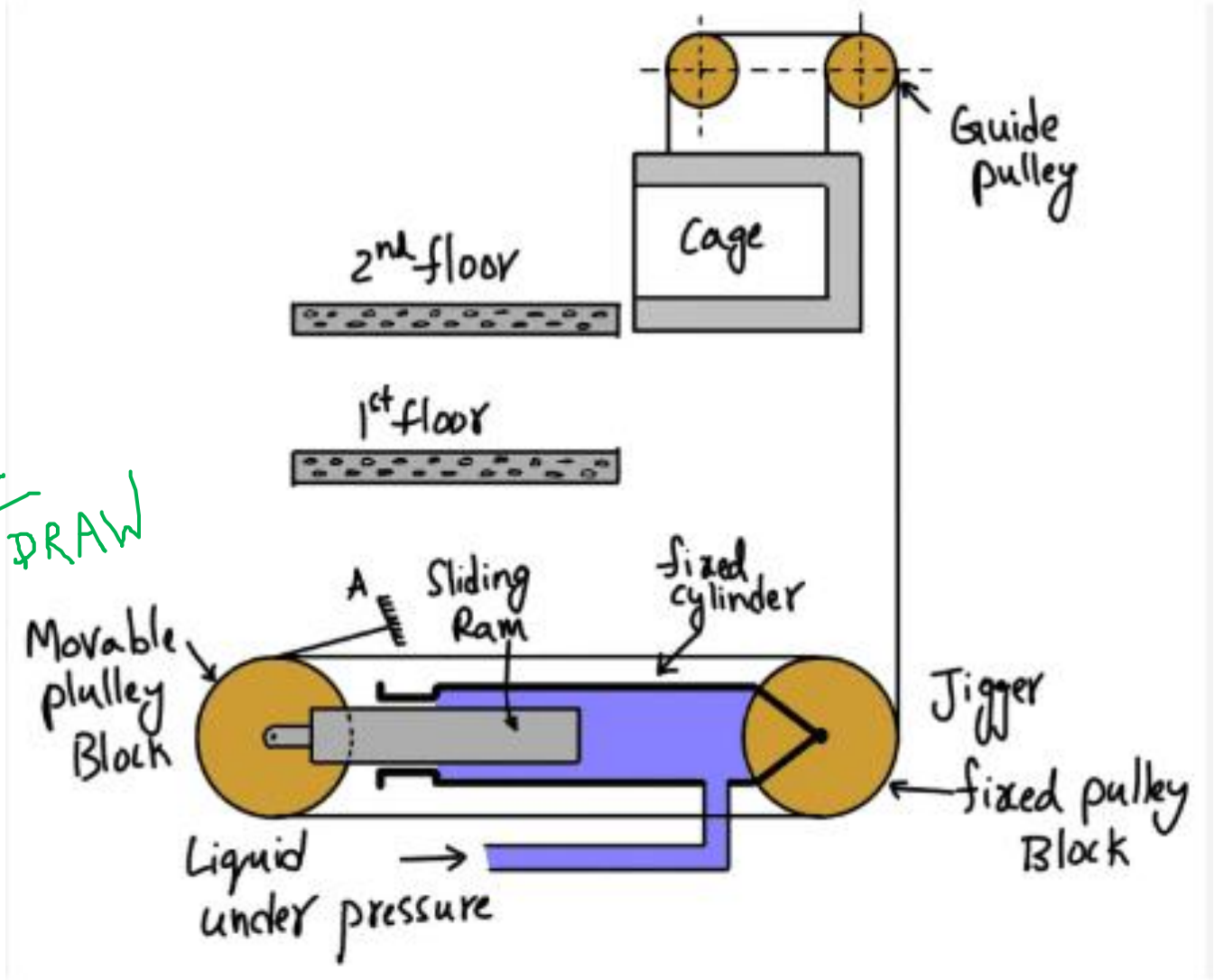
- When the cage is to be moved up to a higher level, oil is sent with high pressure inside the cylinder causing the rammer to slide up. It is done using a suitable hydraulic pump.
- When the cage is to be moved down to a lower level, excess oil inside the cylinder is drawn out of the cylinder so that the rammer could slide down.

Direct Acting hydraulic lift





Suspended Hydraulic Lift



Suspended Hydraulic Lift

- **Principle**: Here, the functioning is based on Pascal's law and a system of strong and inflexible cables is used. Reinforced cables are used to ensure **very high tensile strength**.

PARTS / COMPONENTS:

- Cage (which is to be shifted up/down) is connected with one end of the cable through guide pulleys, and its other end is wrapped on a member called '*Jigger*'
- There are a set of fixed pulleys and movable pulleys on opposite ends of the Jigger. The movable pulleys are connected to a sliding ram, which can slide inside a fixed cylinder. Hydraulic oil pipeline is connected to this fixed cylinder.

WORKING:

- When the cage is to be moved up, high pressurized oil is sent inside the fixed cylinder through a hydraulic pump discharge pipelines. It causes the sliding ram to slide out, which in-turn, causes additional cable to be wrapped on the Jigger as it gets wider. This causes the cage to be pulled up.
- When the cage is to be moved down, high pressurized oil is drawn out of the fixed cylinder. It causes the sliding ram to slide in, which in-turn, causes additionally wrapped cable on the Jigger to be un-wrapped, because it gets shorter. This causes the cage to be pulled down.