

* 4. BASICS OF TURBO MACHINERY *

Impact of jets:

when a fluid entering from a nozzle strikes a stationary or moving plate it exerts a force on the plate. This force is called impact of jet and is due to change in momentum of fluid.

$F = \text{Rate of change of momentum}$

$$= \frac{\text{Initial momentum} - \text{Final momentum}}{\text{time}}$$

$$= \frac{\text{mass}}{\text{time}} (\text{initial velocity} - \text{final velocity})$$

$$= \frac{\text{Volume} \times \text{Density}}{\text{time}} (\text{initial velocity} - \text{final velocity})$$

$$= \frac{\text{Area} \times \text{length} \times \text{Density}}{\text{time}} (\text{initial velocity} - \text{final velocity})$$

$$= \frac{a \times l \times \rho}{t} \times (v - 0)$$

$$= \rho a v (v - 0)$$

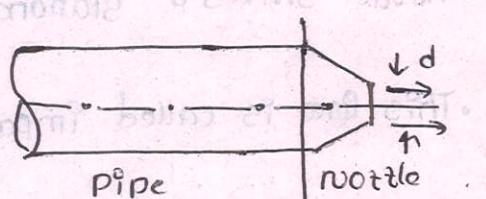
$$\boxed{\therefore F = \rho a v^2}$$

consider a jet of fluid strikes a plate held normal to it. Let the jet be

of cross sectional area 'a' and velocity 'v'. this jet after striking is divided into two parts of which one moves upwards and the other plate and other plate moves down along the plate.

Force exerted by the jet on a stationary vertical plate.

Consider a water jet, impinges on a flat vertical plate as shown in figure



let d - diameter of the jet of water (m)

a - area of the jet of water

$$= \frac{\pi}{4} d^2 (\text{m}^2)$$

v = velocity of jet (m/sec)

after striking the jet is deflected through 90°

according to newton's second law of motion

Force exerted by jet on a fixed plate = (-) Rate of change

of momentum in the force direction

(negative sign indicates opposite direction)

$$F = - \text{mass} \times (\text{Final velocity} - \text{Initial velocity})$$

$$= - \dot{m} (v - u)$$

$$= \dot{m} (u - v)$$

[\therefore mass flow rate = density \times discharge]

$$= \rho a v [v]$$

$$F = \rho a v^2 \text{ newtons}$$

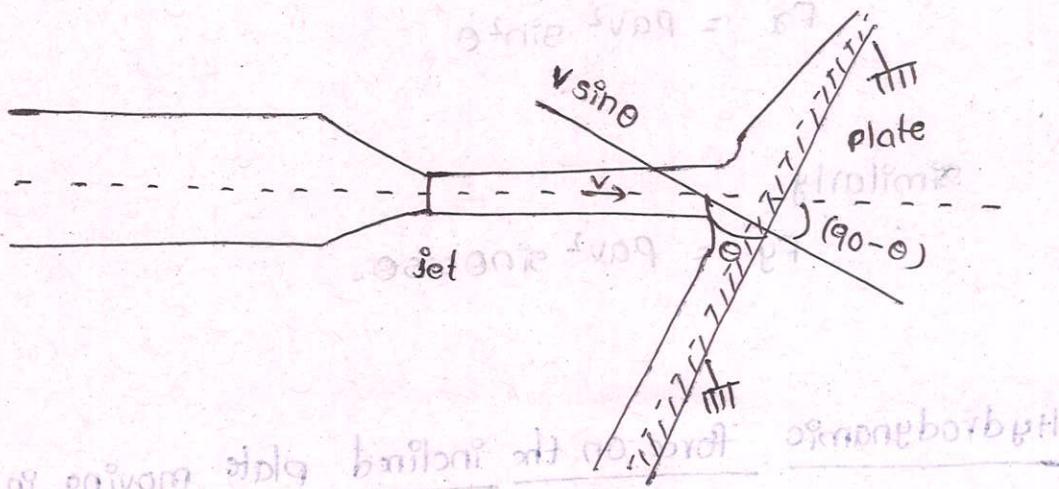
where

ρ - mass density of liquid, kg/m^3

a - area of jet m^2

v = velocity of jet m/sec

Force exerted by a jet on stationary inclined flat plate:



consider the jet of water, coming out from the nozzle strikes

as inclined plate inclined at an angle θ to be horizontal

v = velocity of the jet

θ - angle b/w jet and the plate

a - area of cross-section of jet

mass of water striking the plate per sec = $\rho a v$

Assuming no loss of energy, velocity of the jet due to

friction assuming it to be a smooth surface.

Force exerted to the normal surface of the jet plate

$F_n = \text{mass of jet striking per sec} \times [\text{initial - final velocity in the direction normal to plate surface}]$

$$= \rho av [v \sin \theta - 0]$$

$$= \rho av^2 \sin \theta$$

∴ The force exerted in the direction of jet is

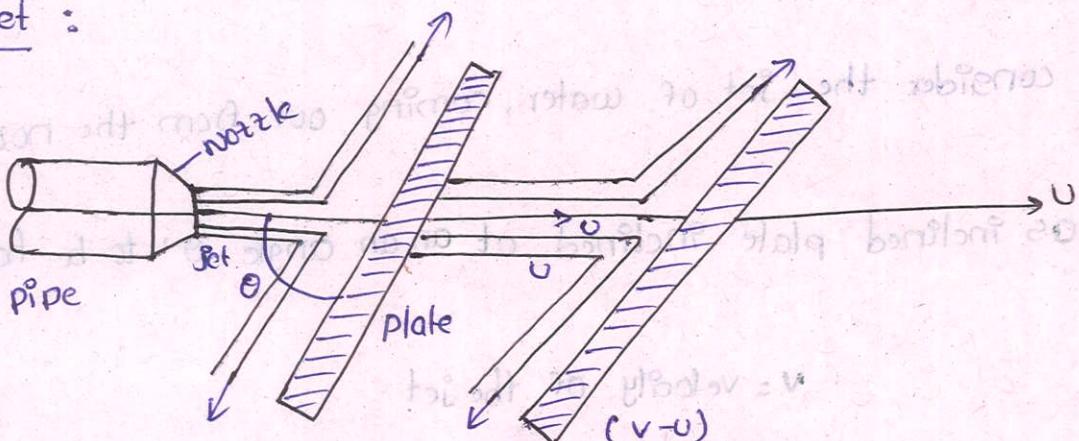
$$F_x = \rho av^2 \sin \theta \times \cos(90 - \theta)$$

$$F_x = \rho av^2 \sin^2 \theta$$

Similarly

$$F_y = \rho av^2 \sin \theta \cos \theta$$

Hydrodynamic force on the inclined plate moving in the direction of jet :



consider a jet of water striking an inclined plate which is

moving with uniform velocity in the direction of jet as shown

in figure.

Let

θ - Angle b/w jet and plate

v - Absolute velocity of jet of water

u - Velocity of the plate in the direction of jet

a - Cross sectional area of jet

$$Density = \rho = \frac{m}{V} = \frac{\rho A v t}{A u t} = \frac{\rho (v-u)}{u}$$

\therefore The velocity with which jet strikes

$$= v - u \text{ (that is relative velocity of water jet)}$$

Assume the plate is smooth and loss of energy due to impact

of jet is zero. Hence the jet of water will leave the inclined plate with a velocity $= v - u$

The force exerted by the jet of water on the plate is given as

$$F = \text{mass of water striking per second} \times (\text{initial velocity} - \text{final velocity})$$

$$= \rho a \times (v - u) [(v - u) \sin \theta - 0]$$

$$\therefore F = \rho a k (v - u)^2 \sin \theta$$

The components of normal force F_N in the direction of

α -and g are

$$F_N = F \sin \theta$$

$$= \rho a (v^2 - u^2) \sin^2 \theta$$

work done per second by the jet on the plate is

$w = F \times$ distance per second in the direction of a
stationary body to which vane is attached.

= $F_n \times$ velocity of the plate in the direction of jet

$$= F_n \times u$$

$$= \rho a (v-u)^2 \sin^2 \theta \times u$$

$$\therefore w = \rho a u (v-u)^2 \sin^2 \theta$$

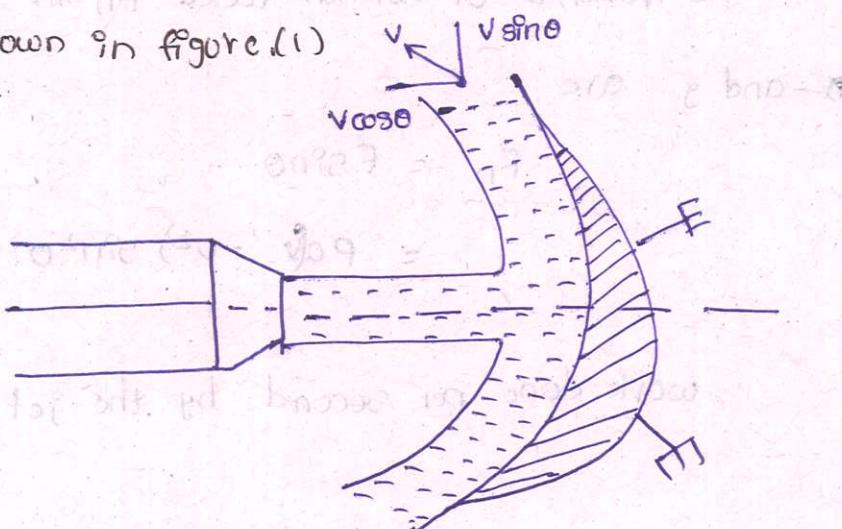
Force Exerted by jet on stationary curved vane:

The expression for the force exerted by the jet on the stationary curved vane for three cases is as follows.

Case(i): Jet strikes the curved vane at centre:

Consider a jet of fluid moving with a velocity v , strikes a smooth stationary curved vane at centre. As the vane is smooth there is no energy loss and the jet after striking comes out in tangential direction to the curved vane with same velocity. Let jet coming out after striking the curved vane make an angle θ with the horizontal as shown in figure (1).

Let the force exerted by the jet on the vane be F .



The component of velocity in the direction of jet = $-v - v$

$\cos\theta$ (since the direction is opposite to the inlet jet if it is negative)

total jet is not rotated by 90° so $v_{2x} = v \cos\theta$

The component velocity in the perpendicular direction of jet

$$F_x = m(v_{1x} - v_{2x})$$

where

v_{1x} - initial velocity in the direction of jet = v

v_{2x} - final velocity in the direction of jet = $v \cos\theta$

$$\therefore F_x = \rho av(v + v \cos\theta) (\because m = \rho av)$$

$$= \rho av^2(1 + \cos\theta) \quad (i)$$

where

a = area of jet

ρ = density of fluid

$$\rho \times F = A$$

Force exerted by the jet in perpendicular direction of jet

$$F_y = m \times (v_{1y} - v_{2y})$$

($v = v$) since $v_{1y} = 0$

where v_{1y} - initial velocity of jet in perpendicular direction of

$$[v = 0] \Rightarrow v_{1y} = 0$$

v_{2y} - final velocity in perpendicular direction of jet =

$$v \sin\theta$$

$$v \sin\theta$$

$$\therefore F_y = \rho av(0 - v \sin\theta)$$

$$= -\rho av^2 \sin\theta$$

Negative sign indicates that the force is acting in downward direction. Unit - N, Pg - 7/16

Problems

A jet of water 75 mm in diameter having velocity of 20 m/s strikes a series of flat plates arranged in a circle around the periphery of a wheel such that each plate appears successively before the jet. If the plates are moving at velocity of 5 m/s, compute the force exerted by the jet on the plate the work done per second on the plate and the efficiency of

Given that

Diameter of the jet $D = 75 \text{ mm}$

$$D = 0.075 \text{ m}$$

Velocity of jet $v = 20 \text{ m/s}$

Velocity of plates $U = 5 \text{ m/s}$

$$(v-u) = 20 - 5 = 15 \text{ m/s}$$

(i) Force exerted by the jet on the plates =

Cross sectional area of jet $A = \frac{\pi}{4} D^2$

$$A = \frac{\pi}{4} (0.075)^2$$

$$A = 4.417 \times 10^{-3} \text{ m}^2$$

Force exerted by the jet on the plate

$$F = \text{mass per second } [v-u]$$

$$F = 1000 \times 4.417 \times 10^{-3} \times 20 [20-5]$$

$$F = 1325.1 \text{ N}$$

∴ $F = 1.325 \text{ kN}$

Unit-4, Pg-8/16

Classification of turbines:

According to type of energy at inlet

(a) Impulse turbine: In an impulse turbine, all the available energy of water is converted into kinetic energy or velocity head by passing it through a contracting nozzle provided at the end of the penstock. Some of the impulse turbines are pelton wheel, turbo-impulse wheel, Girard turbine, Binki turbine, Sonval turbine etc.

(b) Reaction turbine:

In a reaction turbine at the entrance to the runner only a part of the available energy of water is converted into kinetic energy and a substantial part remains in the form of pressure energy. Some of the reaction turbines are Fourcroy, Thomson, Francis, propellers, Kaplan etc.

Direction of flow:

i) tangential flow turbine:

If the water flows along the tangent to the path of rotation of the runner then it is known as tangential flow turbine.

b) radial flow turbine:

If the water flows along the radial direction through the runner the turbine is known as radial flow turbine, In an inward flow radial turbine inward towards the centre of the runner.

→ old Francis turbine, Thomson turbine, Girard radial flow turbine.

outward flow turbines

semiturbine

In the outward flow radial turbine, water enters at the center and flows radially outwards towards the outer periphery of the runner.

(d) axial flow turbine:

If the water flows through the runner along the direction parallel to the axis of rotation of the runner, the turbine is called axial

flow turbines.

(e) mixed flow turbine:

If the water flows through the runner in the radial direction but leaves in the direction parallel to the axis of rotation of the runner,

the turbine is called mixed runner turbine.

3) Head at the inlet of the turbine:

(a) High head turbines:

Highest head about 1770 m

→ pelton wheel

(b) medium Head turbine:

→ ranging from 60 m - 250 m

→ modern Francis

(c) Low Head turbines:

→ Less than 60 m

→ Kaplan turbine.

specific speed of the turbines

(a) Low speed turbines

→ Specific speed varying from 8.5 to 30

→ Pelton wheel

(b) Medium speed turbines

Specific speed varying from 50 to 540

→ Francis turbine

(c) High speed turbines

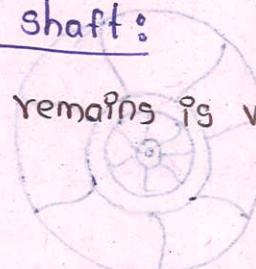
→ Specific speed varying from 285 to 860

→ Example Kaplan and other propeller turbines.

5) Oriposition of turbine shaft:

→ The shaft of turbine remains in vertical position.

→ Kaplan turbine



(b) Horizontal disposition of shaft:

→ The shaft of turbine will be in Horizontal direction

→ Pelton turbine

Types of flows:

(i) Radial flow:

→ The water flows in radial direction through the runner

→ Biogrid turbine example

→ the flow may be inward or outward

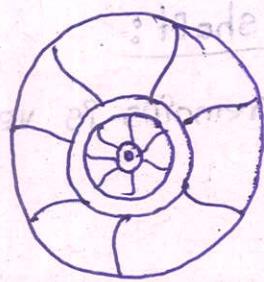
→ used for moderate medium heads (Head is 150m to 800m)

→ Speed control is easy and effective

→ Practically obsolete means outdated, due to technology advance

ment of other turbines.

- water hammer is more
- more chances of cavitation
- specific speed is moderate
- Runner shaft can be in any position
- number of blades are more (20-30)
- less efficiency
- A single governing method is used
- High frictional losses on account of more vanes
- less compact
- Generally draft tube is used



Radial flow turbine

Axial flow:

- The water flows through the runner in the direction parallel to the axis of the runner
- examples are Kaplan turbine, propeller turbines, Bulb turbines, to bulb turbines.
- The flow is unidirectional enters and leaves parallel to axis of shaft
- used for low heads (below 30 meters head)

→ The runner shaft is in vertical position in axial flow

→ number of blades n are less than (3-8)

→ high efficiency at low particle load

→ heavy duty governor is necessary

→ vanes of runners are adjusted

→ low frictional losses due to less surface area

→ more concept of same power

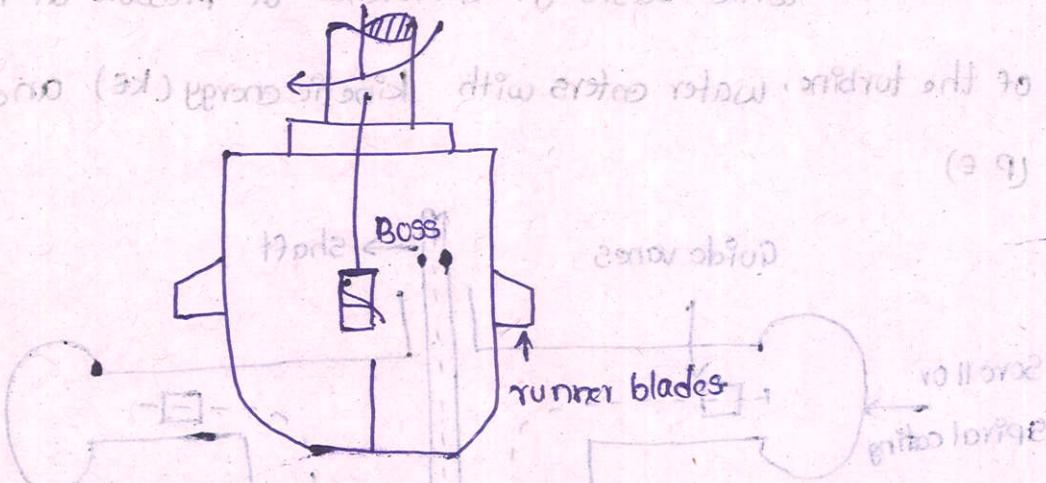


fig: Axial flow turbine.

Mixed flow:

→ The water flows through the runner in the radial direction

but leaves in the direction parallel to axis of the runner (i.e. radial and axial)

→ examples are Francis turbine

→ The flow enters radially and leaves axially through runner

→ used for medium heads (Head varies from 30 m to 150 m)

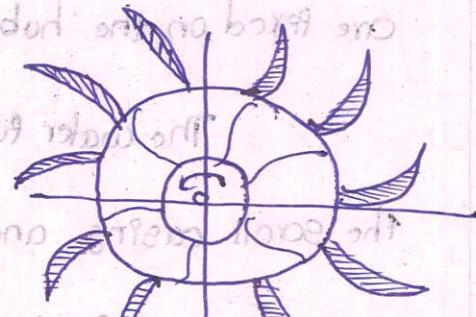
→ Speed control is difficult

→ For large power generation

→ moderate efficiency

→ ordinary governor is used.

unit - 4, Pg - 13 / 16



Mixed flow turbine.

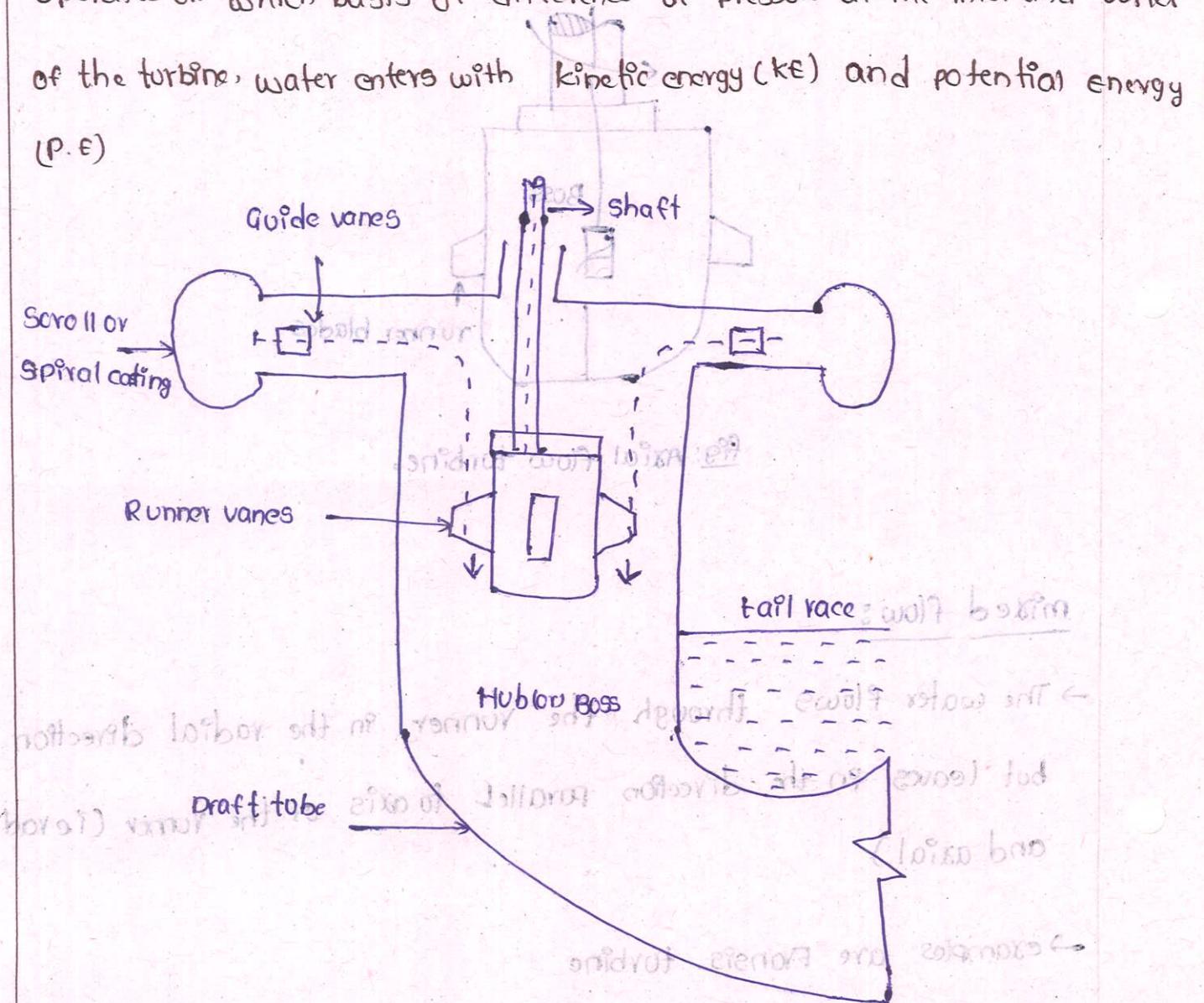
Axial flow turbine (Kaplan turbine) :

Axial flow turbines (B-8) will cost less in abode to advances.

Axial flow turbine is a reaction type hydraulic turbine.

The water enters and leaves the turbine runner in a direction parallel to the axis of turbine shaft.

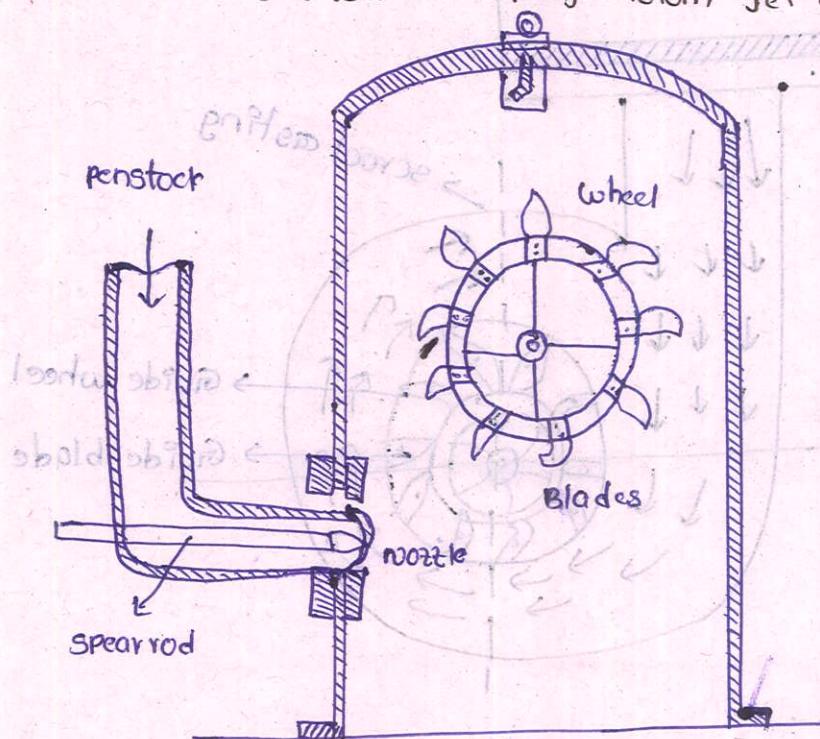
Kaplan turbine and propeller turbine, these turbines operates on which basis of difference of pressure at the inlet and outlet of the turbine, water enters with kinetic energy (KE) and potential energy (P.E)



→ The shaft of the turbine is in vertical position and lower end is made larger to accommodate vanes and is named as Hub boss. The vanes are fixed on the hub acts as runner.

The water from dam passes through penstock and enters the scroll casing and then passes through the right angle and flows axially through the runner after energy conversion; water is K.E discharge through tube.

Pelton wheel is incorporated in a casting to prevent splashing of water and safeguarded purpose. It consists of a circular disc with a number of double hemispherical cups i.e. buckets are spaced around the periphery of disc. Buckets each are divided into two symmetrical parts called as splitters. Water impinges from jet on splitters.



To illustrate various parts of Pelton wheel.

→ Cast iron is used as bucket material for low heads and cast steel or bronze or stainless steel is used as bucket material for higher heads.

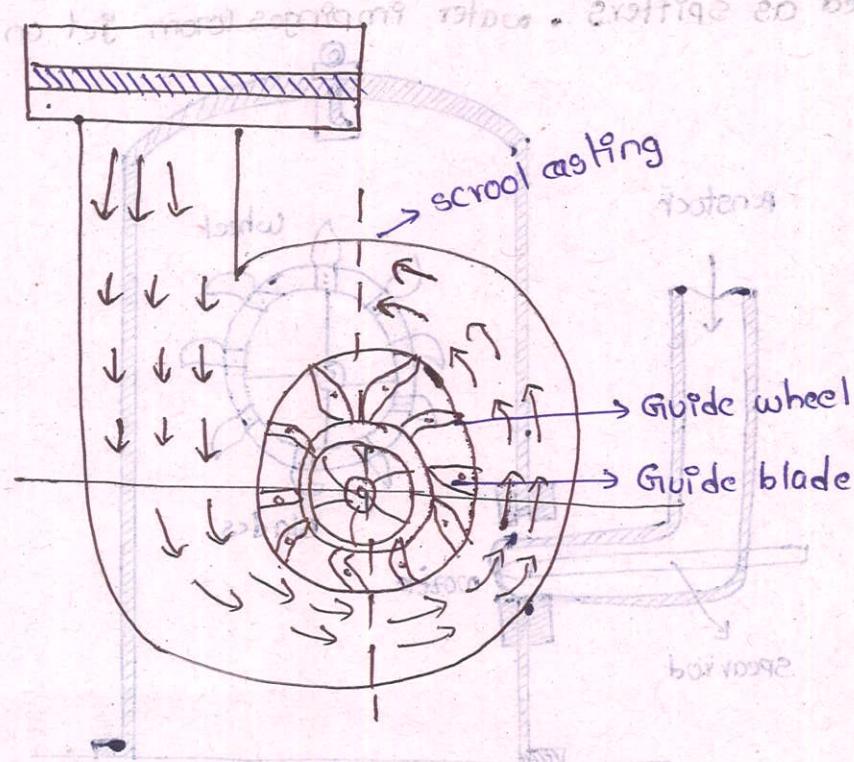
If the Pelton wheel is mounted on horizontal shaft then two jets are employed and if wheel is mounted on vertical shaft then upto six jets can be used.

→ Jet of water flows through smooth inner surface of bucket and outer edge of bucket. Nozzle is fitted at the end of penstock with spear rod to control the quantity of water impinges on runner.

Francis turbine :

In case of Francis turbine only a part of the total head available

at the inlet to the turbine is converted to velocity head before it reaches the runner. In Francis turbines, the working fluid instead of engaging only one or two blades, completely fills the passage in the runner.



The cross sectional area of this casting decreases uniformly along the circumference to keep the fluid's path in the volute decreases due to continuous entry of the fluid to the runner through the opening of guide vanes.