The Shirpur Education Society's

# R. C. Patel College of Engineering & Polytechnic, Shirpur

## QUESTION BANK OF CHAPTER – 4
## HYDRAULIC TURBINES

Program Name: Diploma in Mechanical Engineering
Name of Subject & Code : Fluid Mechanics and Machinery (313309)

Program Code: ME
Semester : THIRD

Instructions: (1) Illustrate your answers with neat sketches wherever necessary.

| Q.1. | Two marks questions. | Previous Exam | CO PO Mapping |
|---|---|---|---|
| 1. | State the function of draft tube & list any four types of draft tubes used in reaction turbine. | W24-1.d<br>W25-1.d<br>S25-3.a | CO4- TLO4.4 -R |
| 2. | State the need of surge tank in hydroelectric power plant | W24-1.e | CO4- TLO4.2 -R |
| 3. | Define : (i) Hydraulic efficiency (ii) Mechanical efficiency w.r.t. turbines | S25-1.b | CO4- TLO4.3 -R |
| 4. | Classify the water turbines | S25-1.e | CO4- TLO4.4-R |
| Q.2. | Four marks questions. | Previous Exam | CO PO Mapping |
| 1. | Draw the layout of hydroelectric power plant and classify the turbines used in it. | W25-3.d | CO4- TLO4.2-A |
| 2. | Discuss the factors considered for selection of turbine. | W24-4.e | CO4- TLO4.4 -U |
| 3. | Explain with neat sketch construction, working principle and velocity diagram of Kaplan turbine | W24-5.a | CO4- TLO4.3 -A |
| 4. | A single jet Pelton wheel runs at 280 rpm under a head of 510 meter. The jet diameter is 200 mm, its deflection inside the bucket is 165° and its relative velocity is reduced by 15% due to friction. Determine - i) Water power ii) Resultant force on the bucket and iii) Overall efficiency. Consider mechanical losses = 3%, Co-efficient of velocity = 0.98 and speed ratio = 0.46 | W24-5.c | CO4- TLO4.5 -A |
| 5. | Draw and explain performance characteristics curves for hydraulic turbine. | W24-6.a<br>W25-6.b | CO4- TLO4.5 -A |
| 6. | Explain concept of cavitation in the turbine. | S25-3.b | CO4- TLO4.5 -U |
| 7. | Find equation of force and work done for the impact of jet on moving vertical plate. | S25-3.c | CO4- TLO4.1 -U |
| 8. | A jet of water of diameter 35 mm moving with velocity of 30 m/s, strikes a curved fixed symmetrical plate at the centre. Find the force exerted by jet of water in the direction of jet, if jet is | S25-4.e | CO4- TLO4.1 -A |

| | | | |
|---|---|---|---|
| | deflected through an angles of 135° at outlet of curved plate. If the vane is moving with the velocity of 25 m/s in the direction of jet, find out force exerted. | | |
| 9. | A jet of water having velocity of 15 m/s strikes a curved vane which is moving with a velocity of 5 m/s in the same direction as that of jet at inlet. The vane is so shaped that the jet is deflected through 135°. The diameter of jet is 100 mm. Assume vane to be smooth. Find :– i) Force exerted by the jet on the vane in the direction of motion. ii) Output power of the vane iii) Efficiency of vane. | W25-5.c | CO4- TLO4.1 -A |
| 10. | A jet of water 80 mm diameter moving with a velocity 20 m/s, strikes a stationary flat plate. Find the normal force on the plate when – i) the plate is normal to the jet ii) the angle between jet and plate is 30°. | W25-4.b | CO4- TLO4.1 -A |
| 11. | A pelton wheel is designed for following specifications : Shaft power = 11772 kw, head = 380 m speed = 750 rpm, overall efficiency = 86%. If the jet diameter should not be exceed 1 6 th the wheel diameter, determine wheel diameter, number of jets required and diameter of jet. (Take speed ratio = 0.45) | W25-5.b | CO4- TLO4.3 -A |
| 12. | Compare Francis turbine with Kaplan turbine | S25-6.a | CO4- TLO4.4 -R |
| 13. | A Pelton wheel has a mean bucket speed of 15 m/s and is supplied with water at a rate of 0.8 m3/s under a head of 30 m. If the bucket deflects the jet through an angle of 165°, find the power developed by the turbine and its hydraulic efficiency. Take the coefficient of velocity as 0.98. Neglect friction in the bucket. Also determine the overall efficiency of the turbine, if its mechanical efficiency is 80% | S25-5.c | CO4- TLO4.3 -A |
| 14. | Explain with a neat sketch, the construction and working of pelton wheel. | | CO4- TLO4.3 -A |
| 15. | A jet of water of diameter 60 mm moving with a velocity of 18 m/s, strikes flat plate, moving with a velocity of 6 m/s in the direction of jet, at the center. Find - i) Thrust on plate in the direction of jet. If the flat plate is replaced by the symmetrical curved vane moving with the same velocity and the jet after striking is deflected through an angle of 165° at outlet of curved plate, find - ii) Thrust on plate in the direction of jet, and iii) Work done. | W24-5.b | CO4- TLO4.1 -A |
| | * * *Best of Luck* * * | | |

8/1/2026

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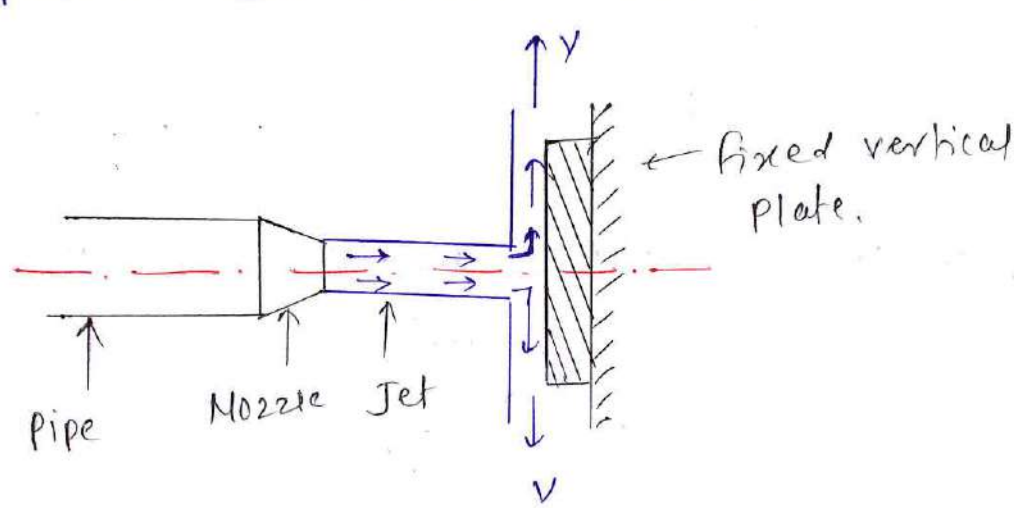
| Subject Teacher | HOD(ME) | Principal |

# * Fluid Mechanics & Machinery *

## Chapter 4 :- Hydraulic Turbines

4.1 Impact of Jet on fixed vertical plate, moving vertical plate, curved vanes with special reference to turbines & pumps, Numerical on above condn.

### * Impact of Jet on fixed Vertical Plate :-

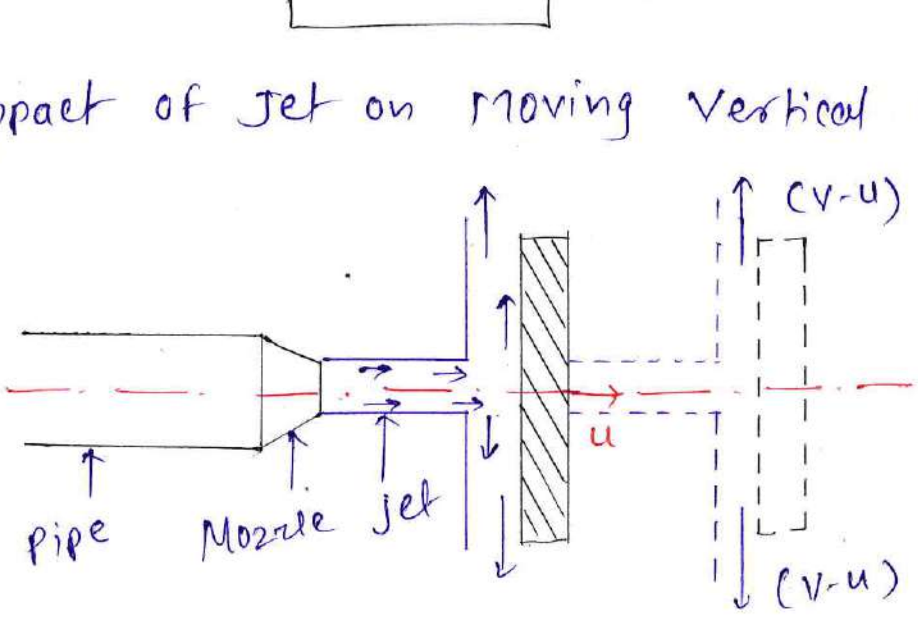



Force exerted by jet on a Plate = mass of water striking per sec × Change in velocity (Initial vel. - final vel.)

$$F = \rho a V . (V - 0)$$

$$\boxed{F = \rho a V^2} \quad --- \quad N$$

### * Impact of Jet on Moving Vertical Plate :-



Force exerted by jet = mass of water striking per sec. × Change in velocity. (Initial vel − final vel)

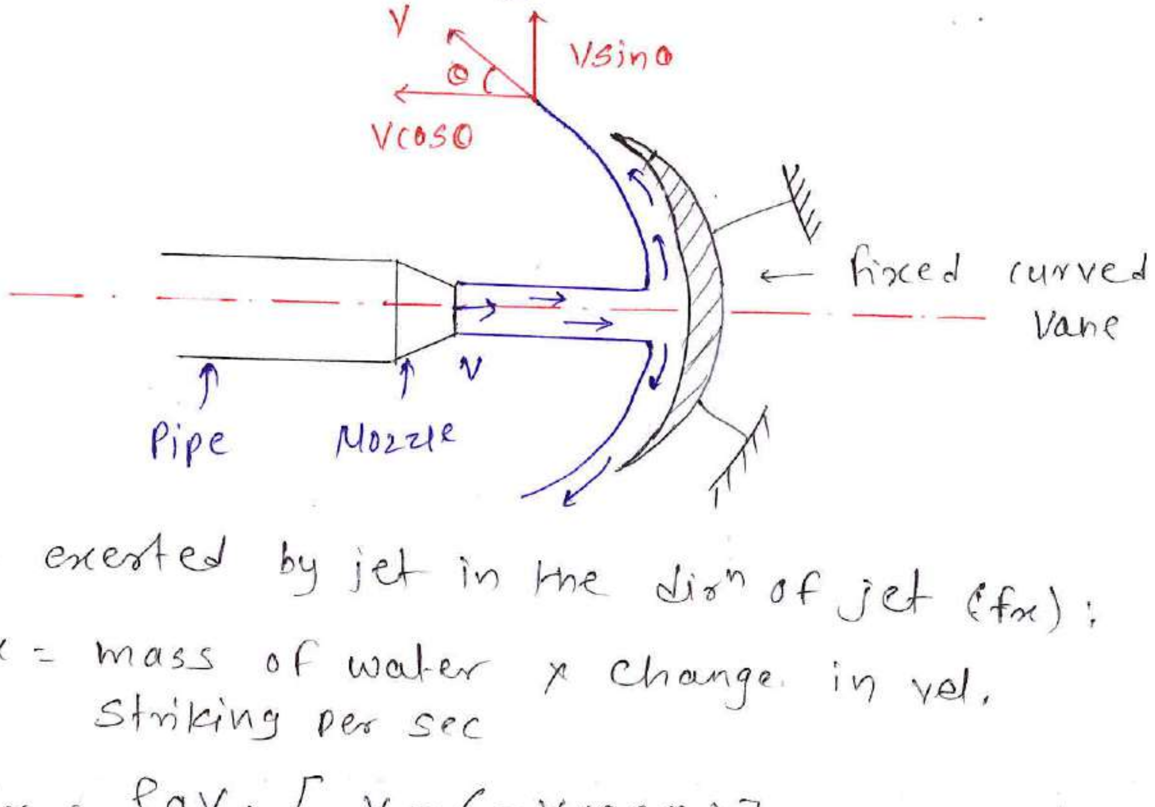
$$F = \rho a(V-u)\cdot[(V-u)-0]$$

$$\boxed{F = \rho a (V-u)^2} \quad \ldots N$$

work done by jet on plate:

$$\boxed{W = F\cdot u = \rho a (V-u)^2 \cdot u} \quad \ldots J/s$$

## * Impact of Jet striking fixed curved vane (Centrally):-




- force exerted by jet in the dirⁿ of jet ($F_x$):

$F_x$ = mass of water striking per sec × change in vel.

$$F_x = \rho a V\cdot[V-(-V\cos\theta)]$$

$$\boxed{F_x = \rho a V^2 (1+\cos\theta)}$$

- force exerted by jet in the dirⁿ ⊥er to dirⁿ of jet ($F_y$):

$$F_y = \rho a V\cdot(0 - V\sin\theta)$$

$$\boxed{F_y = -\rho a V^2 \sin\theta}$$

& for stationary plate

$$\boxed{\text{workdone } W = 0}$$

## * Impact of Jet on Moving Curved Vane (Centrally):-

Force excerted by jet in the dir$^n$ of flow ⇒

$$F_x = \rho a (V-u) \cdot [(V-u) - (-(V-u)\cos\theta)]$$

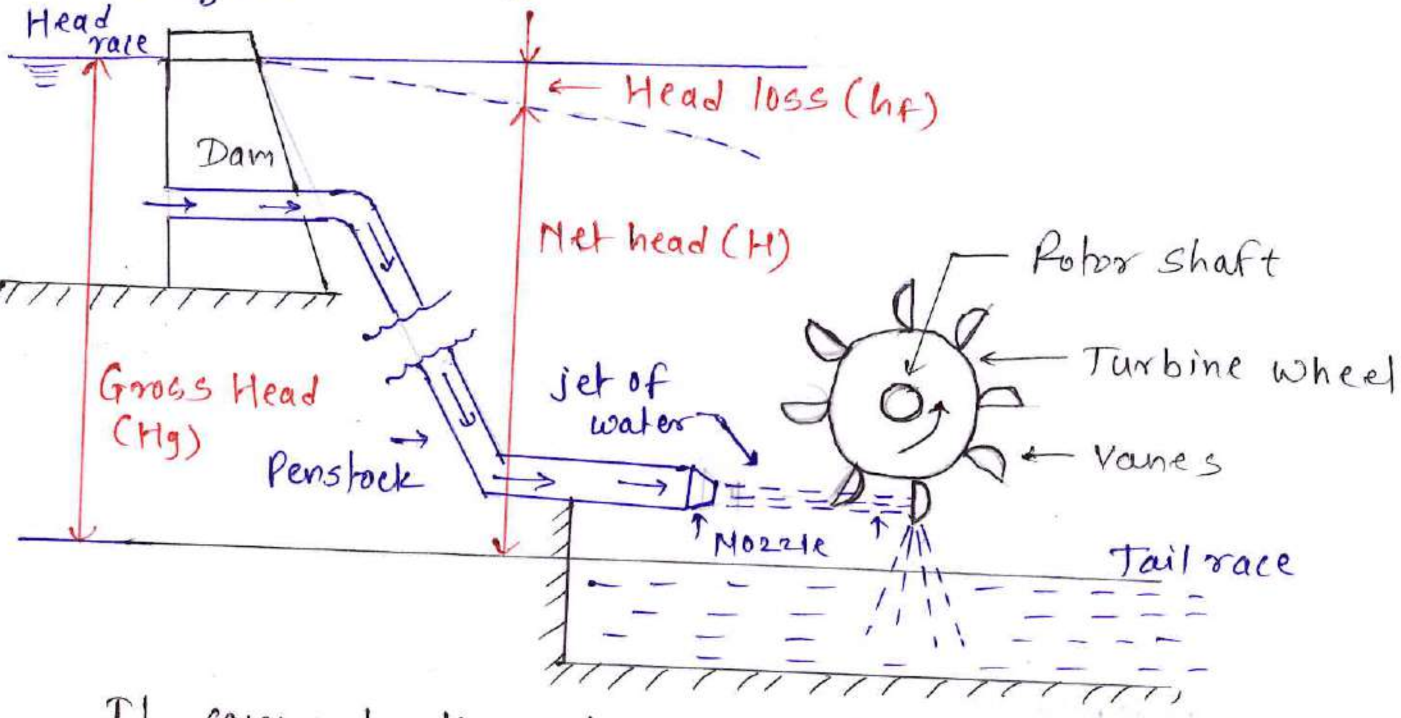
$$\boxed{F_x = \rho a (V-u)^2 (1+\cos\theta)} \quad -- \quad N$$

workdone $\boxed{W = \rho a (V-u)^2 (1+\cos\theta) \cdot u}$ ... ($\because W = F.u$)

-- J/s or Watt.

## 4.2 Layout of hydroelectric power plant & function of each component, Water storage systems used in Ancient India (IKS):

### * Layout of Hydroelectric Power Plant :-




It converts the potential energy stored in water into electrical energy. Water flows from a height through turbines, which drive generators.

- Main components & function :-
  - Dam - Stores water & creates head.
  - Reservoir - stores large quantity of water.
  - spillway - Releases excess water safely.

- Penstock - carries water to turbine.
- Surge tank - Controls pressure fluctuation,
- Turbine - Converts water energy → mechanical energy.
- Generator - converts mechanical → electric energy.
- Tail race - Returns water to river.

- Working :-
  1. Water stores in reservoir
  2. Flows through intake → penstock
  3. High-speed water rotates turbine
  4. Turbine drives generator → electricity.
  5. Water discharged through tailrace.

## * Water Storage systems in Ancient India (IKS) :-

Types :-

- Stepwells (Baoli / Vav) : Deep well with steps.
- Tanks (Talabs) : Artificial reservoirs for irrigation.
- Kunds : Underground rainwater storage
- Johads : Small earthen dams for groundwater recharge.
- Ahar - Pyne : Channel + storage system.
- Zing : Glacier water storage (Ladakh)
- Temple Tanks : Water storage near temples.

Importance :-

- Water conservation
- ~~Suitabl~~ Sustainable & eco-friendly
- Groundwater recharge.

## 4.3 Classification of hydraulic turbines

* Classification of hydraulic turbines :-

A) Based on Energy at inlet :

a) Impulse Turbine : (Uses kinetic energy only)

b) Reaction Turbine : (Uses kinetic + pressure energy)

e.g. Impulse Turbine - Pelton wheel

Reaction Turbine - Francis, Kaplan

B) Based on Direction of Flow :

a) Tangential Flow - water strikes tangentially - Pelton

b) Radial flow - water flows radially (inward/outward)

c) Axial flow - water flows $\parallel^{el}$ to shaft → Kaplan

d) Mixed flow - Combination of radial & axial → Francis

C) Based on Head :

a) High Head ( >250m) - Pelton Turbine

b) Medium Head ( 60-250 m) - Francis Turbine

c) Low Head ( <60m) - Kaplan Turbine.

D) Based on Specific Speed :

a) Low specific speed - Pelton

b) Medium Specific speed - Francis

c) High Specific speed - Kaplan

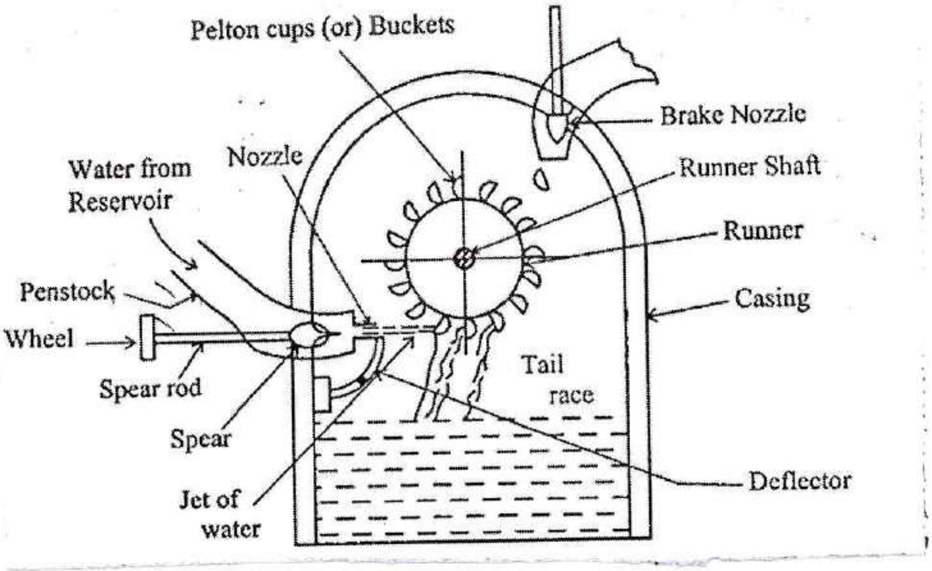
E) Based on Shaft Orientation :

a) Horizontal shaft Turbine

b) Vertical Shaft Turbine.

4.4 Construction, working principle, velocity diagram & appln of Pelton wheel, kaplan turbine & Francis Turbine:

## * Pelton Wheel *




Construction :

- Runner - Circular wheel with double hemispherical buckets mounted on rim.
- Buckets - Have a splitter to divide the jet into two equal parts.
- Nozzle - Converts pressure energy into velocity jet
- Spear & needle - Controls flow rate.
- Casing - Prevents water splashing & directs water to tailraces.

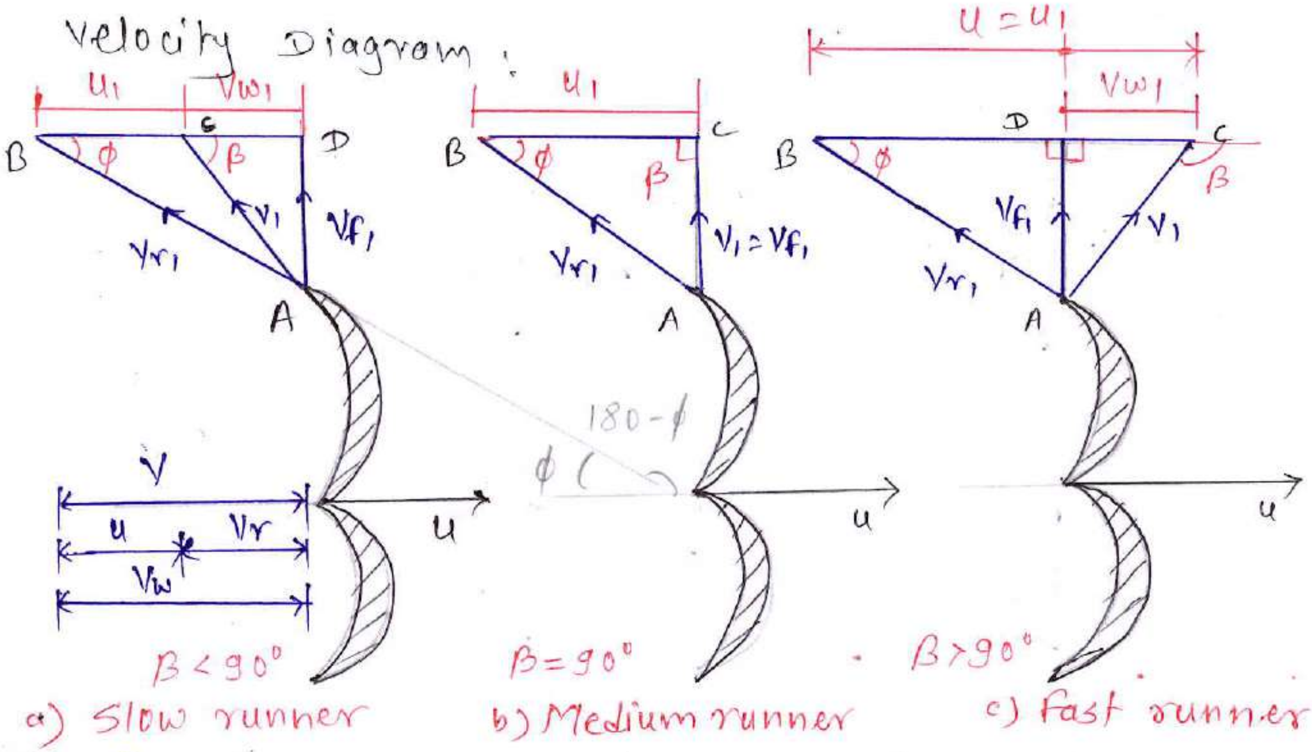
Working Principle :

- works on impulse principle (only kinetic energy)
- Water from high head passes through nozzle → forms high speed jet.
- Jet strikes bucket splitter - divides & flows over curved surface.
- Jet is deflected by 160° - 170°, producing force.
- This force rotates the runner → generator produces electricity.

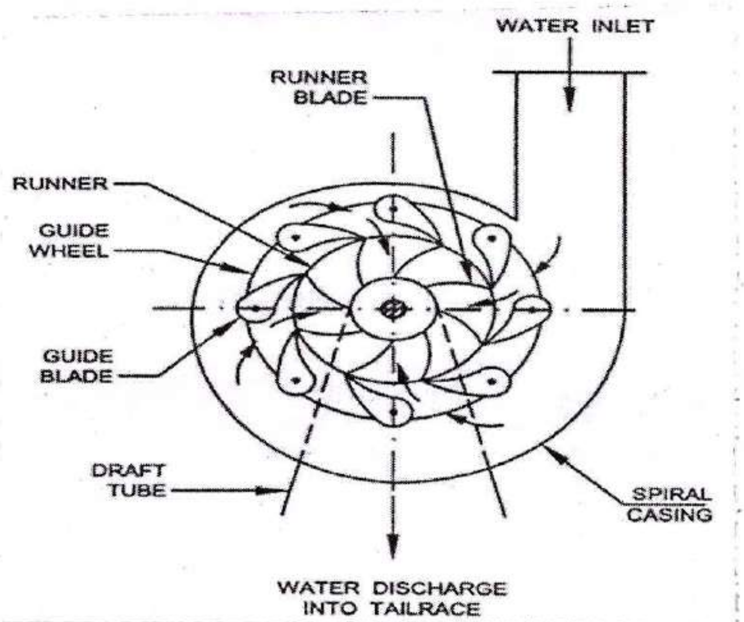
Applications :-

- High head (above 250m)
- Low discharge
- Used in mountainous hydroelectric plants.

Velocity Diagram :




## * Francis Turbine (Reaction Turbine) :



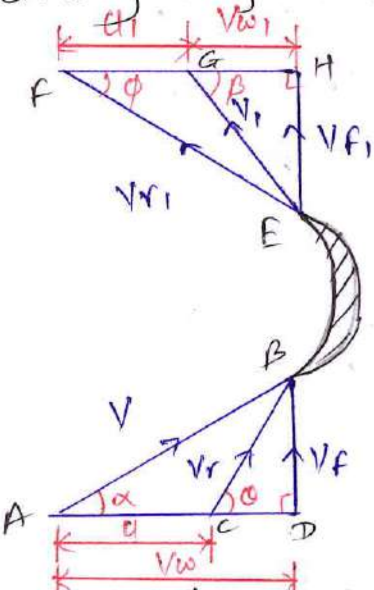

Construction :

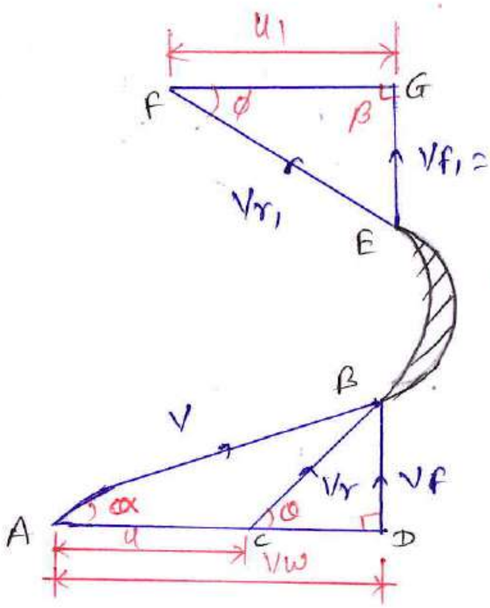
- Spiral (Scroll casing) :- Distributes water uniformly
- Guide vane (wicket gates) - Control flow direction & quantity.
- Runner - Curved blades mounted on shaft.
- Draft tube - Recovers pressure energy.

Working :

- Works on reaction principle (pressure + K.E.)
- water enters runner radially inward.
- Flows over blades & exits axially.
- Pressure decreases gradually → produces rotation.

velocity diagram :



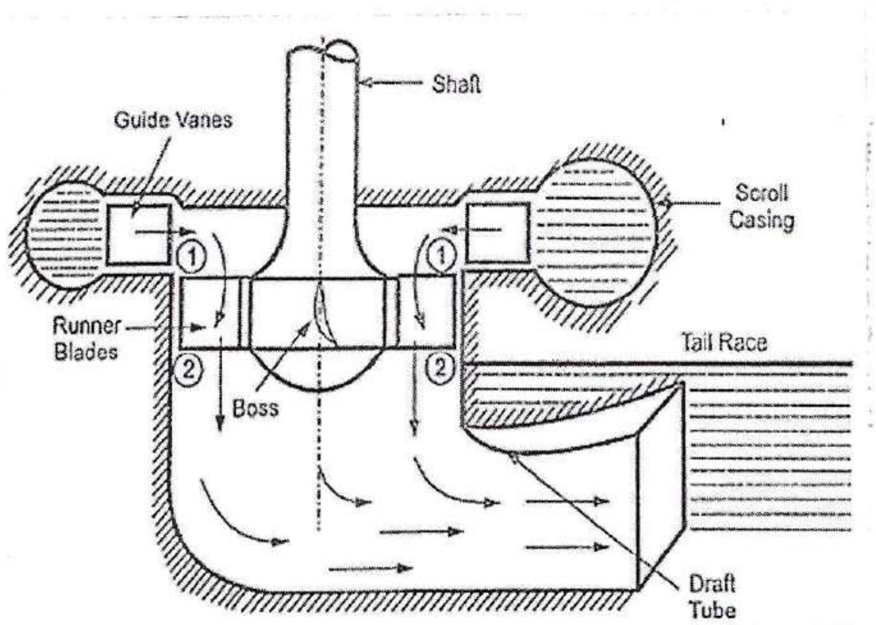




← vel. diagram for modern francis Turbine.

Applications :

- Medium Head (60 - 250 m
- Moderate discharge
- Most widely used turbine in hydroelectric plants.

## ✱ Kaplan Turbine (Reaction Turbine)



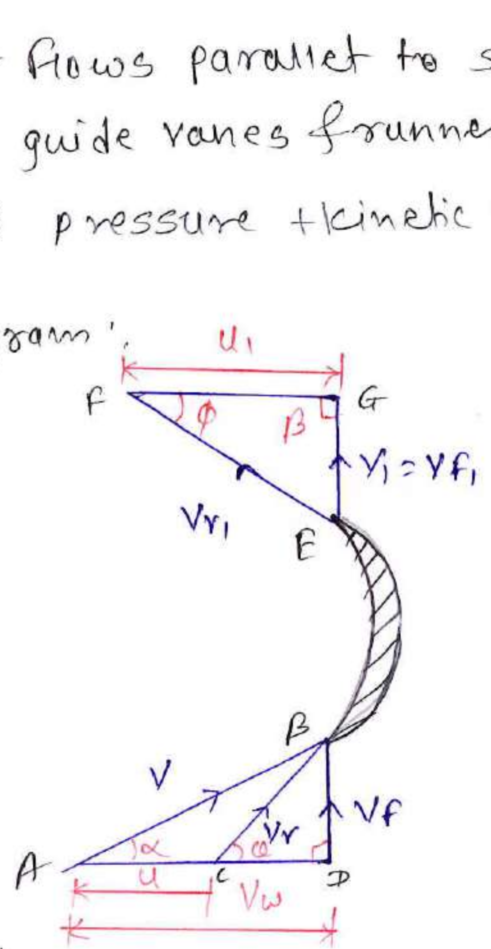
Construction :

- Runner - Propeller type with adjustable blades.
- Hub - Contains mechanism for blade pitch control
- Guide vanes - Regulate flow
- Draft tube - Improves efficiency.

Working :

- water flows parallel to shaft (axial flow)
- Both guide vanes & runner blades adjust → High effi.
- Uses pressure + kinetic energy.

Velocity diagram :




Application :

- low head (<60 m)
- High discharge
- Used in rivers, canals, dams with low height.

## 4.5 Draft tubes : Types, Concept of cavitation in turbine

### * Draft tube :

A draft tube is a gradually expanding (diverging) tube fitted at the outlet of a reaction turbine (francis/ kaplan) to connect the runner exit to the tailrace.

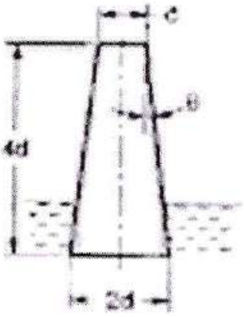
When water leaves the turbine runner:
- It still has high velocity (K.E.)
- If discharged directly → energy is wasted.

Draft tube recovers this energy by converting:

K.E. → Pressure Energy.

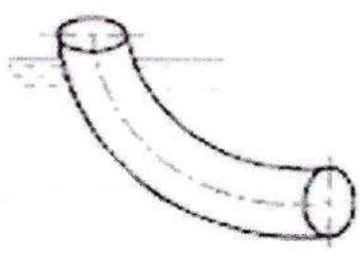
Functions :
- Improves overall efficiency (by 10-20%)
- converts velocity head into useful pressure head.
- Allows turbine installation above tailrace level.
- Reduces exit losses.

## * Types of draft tube :-

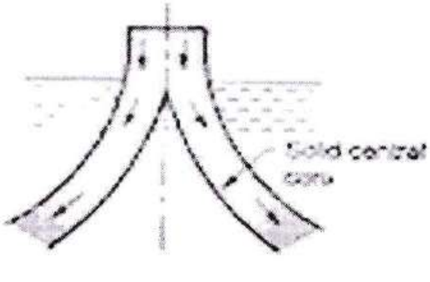



**(a) Conical Straight**


**(b) Elbow**



**(c) Simple Elbow**



**(d) Moody's Spreading Draft Tube**

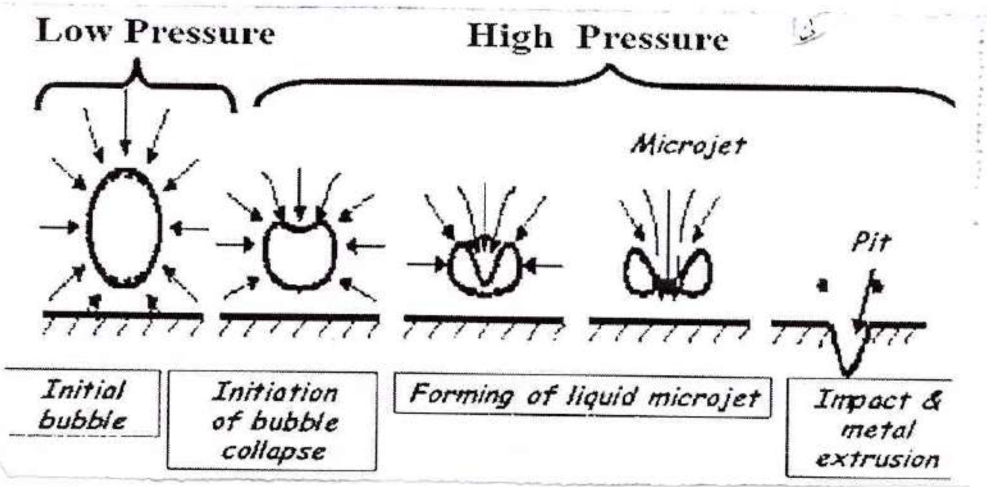
1. Straight Divergent Type -
   - Gradual expansion (cone shape)
   - Best theoretical efficiency.
   - large vertical space required.

- Simple Elbow Type -
  - Bent tube (L-shape)
  - Used where space is limited
  - Slightly lower efficiency.

8. Elbow Type (Circular inlet - Rectangular Outlet)
- Most commonly used in francis turbines.
- Provides better flow distribution
- Reduces eddies & losses.

- Moody Spreading Tube :
  - Specially designed with controlled expansion
  - Minimizes flow seperation.
  - Used in modern high-efficiency plants.

## * Cavitations in turbine




Cavitation is the formation & sudden collapse of vapour bubbles in a liquid due to low pressure.

It occurs when $P < P_{vapour}$. Also It occurs at turbine runner exit, inside draft tube & at regions of high velocity & low pressure.

Mechanism :

1. Pressure drops below vapour pressure → bubbles form
2. Bubbles move to high pressure region,
3. Sudden collapse (implosion)
4. Produces shock waves.

Effects of Cavitation:

- Pitting Corrosion on blades
- Surface erosion (metal removal)
- Noise & vibrations
- Loss of efficiency
- Shorter turbine life.

Types of cavitations:

- Runner cavitation
- Draft tube cavitation
- Tip cavitation (Kaplan turbine)

Methods to prevent cavitations:

- Proper draft tube design
- Keep turbine at optimum height
- Maintain sufficient Pressure.
- Use polished / smooth blades.
- Use cavitation resistant materials (stainless steel)
- Proper operation (avoid overloads).

## 4.6 Calculation of workdone, output power, efficiency of Pelton turbine only:

- Workdone or runner power (R.P.)

$$R.P = \frac{W}{g}(V-u)(1+\cos\phi).u \quad \dots W$$

- Absolute velocity of water

$$V = C_v.\sqrt{2gH} \quad \& \quad H = H_g - h_f$$

Also velocity of whirl, $V_w = V$

- K.E. of water (K.E.) $= W.\frac{V^2}{2g}$
- Speed of pelton wheel $u = \frac{\pi D N}{60}$
- Speed ratio $k_u = \frac{u}{V} = \frac{\text{Runner speed}}{\text{Velocity of jet.}}$

  $k_u = 0.43$ to $0.48$

- Jet ratio $\Rightarrow m = \frac{D}{d} = \frac{\text{Mean or pitch diam of wheel}}{\text{Diam of jet}}$

  $m \Rightarrow$ betn 11 to 16

- Water Power $\Rightarrow \rho.g.Q.H$
- Value of side clearance angle $(\phi)$:

  For semicircular wheel, $\phi = 0°$

  In another cases, valve of $\phi$ varies from $10°$ to $20°$

- Power developed $\Rightarrow P = \eta_o.(\rho.g.Q.H)$.

## * Efficiencies related to Pelton wheel Turbine:

- Hydraulic efficiency $(\eta_{hyd})$:

  It is ratio of power developed by runner to the power supplied by water at entrance of turbine.

$$\eta_{hyd} = \frac{2(V-u)(1+\cos\phi).u}{V^2}$$

or

$$\eta_{hyd} = \frac{2(V_w + V_{w1})\,u}{V^2}$$

- Mechanical efficiency $(\eta_{mech})$:

  It is the ratio of power available at the turbine shaft to the power developed by runner,

$$\eta_{mech} = \frac{P}{\frac{W}{g}\cdot(V-u)(1+\cos\phi)u}$$

- Overall efficiency ($\eta_{over}$):

It is the ratio of shaft Power to the water power.

$$\eta_{over} = \frac{P}{\rho g Q H}$$

or

$$\eta_o = \eta_{hyd} \times \eta_{\cancel{hyd}mech}$$

* Cond$^n$ for maximum hydraulic efficiency:

$$V = 2u \quad \text{or} \quad u = \frac{V}{2}$$

& $k_u = 0.5$

∴ By solving we get

$$\eta_{hyd\,max} = \frac{1+\cos\phi}{2} \quad \text{— (1)}$$

Put $\phi = 0°$ in eq$^n$ (1)

$$\therefore \quad \eta_{hyd\,max} = \frac{1+\cos(0°)}{2} = 1 \times 100\,\%$$

$$\eta_{hyd\,max} = 100\,\%$$

In actual practice, jet gets deflected through 160° to 170°, ∴ value of max. hydraulic efficiency lies bet$^n$ 90 % to 94 %.

## * Specific speed of turbine ($N_s$):

It is the speed of geometrically similar turbine that would produce unit power (1 kW) under unit head (1 m).

It is used to compare turbines & select the suitable type.

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

where

$N$ = Speed of wheel

$H$ = Head

$P$ = Power

* Range of specific speed → Type of useful Turbine

More than 400 → Kaplan turbine

Between 60 to 400 → Francis turbine

less than 60 → Pelton wheel

## 4.7 Criteria for selection of hydraulic turbines & performance criteria (characteristics):

### * Selection criteria for hydraulic turbines:

1. Head of water (most imp.)
   - High head (>250 m) → Pelton turbine
   - Medium head (60-250 m) → Francis turbine
   - Low head (<60 m) → Kaplan turbine.

2. Discharge (flow rate)
- Low discharge → Pelton
- Medium discharge → Francis
- High discharge → Kaplan

3. Specific Speed ($N_s$)
- Low $N_s$ → Pelton
- Medium $N_s$ → Francis
- High $N_s$ → Kaplan

4. Efficiency requirement -
Choose turbine with max$^m$ efficiency at operating condition.

5. Cost & Installation -
Initial cost, maintanance cost, space availability

6. Load variation -
Kaplan turbine is best for varying load cond$^n$ (adjustable blades).

7. Cavitation consideration
- Turbine should operate without cavitation
- Proper installation height is important.

8. Type of water source
- Mountain regions → Pelton
- river / dams → Francis / Kaplan

## * Performance characteristics of Hydraulic Turbines:

1. Main characteristics (constant Head):

Cond$^n$ ⇒ Head (H) = constant
& speed varies by changing load.

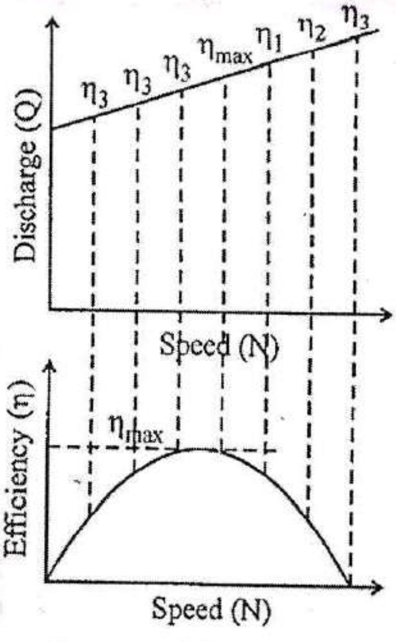



*Figure (a) N Vs $\eta$ & Q*

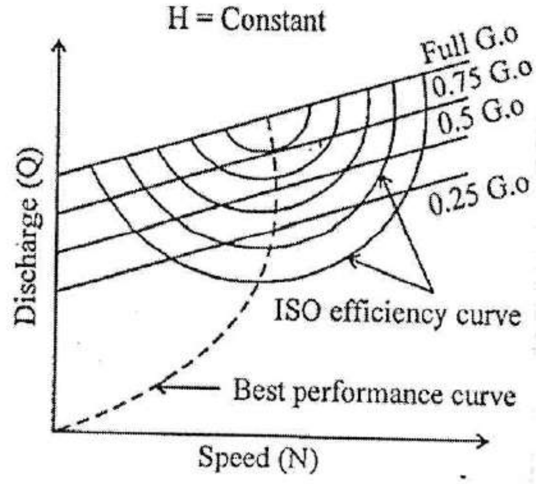


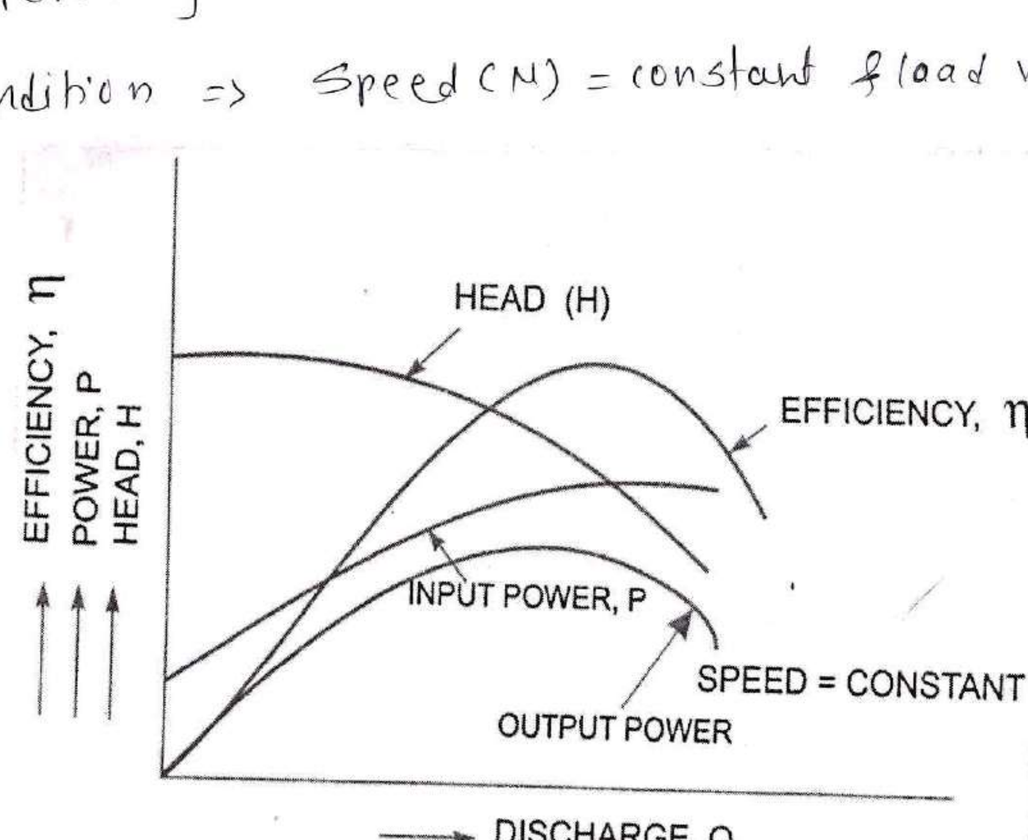

*Figure (b) N Vs Q*

Observations :

- efficiency increases → reaches max^m → decreases
- Max^m efficiency occurs at optimum speed.
- Power increases with speed up to a limit.
- Discharge increases with speed.

2. Operating Characteristics (Constant Speed) :

Condition => Speed (N) = constant & load varies.



Observations :

- efficiency is max$^m$ at rated load
- At low load → efficiency is low
- At overload → efficiency decreases
- Discharge increases with load.

## * Numericals on Impact of Jet *

1. A jet of water of diam. 35 mm moving with velocity of 30 m/s, strikes a curved fixed symmetrical plate at the centre. Find the force excerted by jet of water in the dir$^n$ of jet, if jet is deflected through an angle of 135° at outlet of curved plate. If the ~~valve~~ vane is moving with the velocity of 25 m/s in the direction of jet, find out force exerted. (S-25)

→ Given data

$d = 35\ mm = 0.035\ m$

$\theta = 180° - 135° = 45°$

$u = 25\ m/s$

$V = 30\ m/s$

Area $a = \frac{\pi}{4} d^2 = \frac{\pi}{4} (0.035)^2 = 9.62 \times 10^{-4}\ m^2$

i) Force exerted when plate is stationary.

$F_x = \rho . a . V^2 (1 + \cos\theta)$

$= 1000 \times 9.62 \times 10^{-4} \times (30)^2 \times (1 + \cos 45°)$

$\boxed{F_x = 1478.013\ N}$

ii) Force exerted by jet when plate is moving $u = 25$ m/s

$$F_x = \rho . a . (V-u)^2 (1+\cos\theta)$$

$$= 1000 \times 9.62 \times 10^{-4} (30-25)^2 (1+\cos 45^\circ)$$

$$\boxed{F_x = 41.0559 \text{ N}}$$

2. A jet of water having velocity of 15 m/s strikes a curved vane which is moving with a velocity of 5 m/s in the same direction as that of jet at inlet. The vane is so shaped that the jet is deflected through 135°. The diam. of jet is 100 mm. Assume vane to be smooth.
Find : i) Force exerted by jet on the vane in the dir$^n$ of motion
(CW-25)
ii) Output power of the vane
iii) Efficiency of vane.

→ Given data:

$V = 15$ m/s

$u = 5$ m/s

$\theta = 180^\circ - 135^\circ = 45^\circ$

$d = 100$ mm $= 0.1$ m

area $a = \frac{\pi}{4} . d^2 = \frac{\pi}{4} . (0.1)^2 = 0.00785 \text{ m}^2$

i) Force exerted by jet on moving plate.

$$F_x = \rho . a . (V-u)^2 (1+\cos\theta)$$

$$= 1000 \times 0.00785 (15-5)^2 (1+\cos 45^\circ)$$

$$\boxed{F_x = 5360.315 \text{ N}}$$

ii) Power output / workdone (W)

$P = F_x \cdot u$

$= 5360.315 \times 5$

$$\boxed{P = 26801.57 \text{ W}}$$

iii) input power (Pin) ⇒

$P_{in} = \frac{1}{2} \cdot \rho \cdot a \cdot V^3$

$= \frac{1}{2} \times 1000 \times 0.00785 \times 15^3$

$$\boxed{P_{in} = 13246.875 \text{ W}}$$

iv) Efficiency ⇒ $\eta = \frac{\text{output Power}}{\text{input Power}} = \frac{13246.875}{26801.57} \times 100\%$

$$\boxed{\eta = 49.42\%}$$

3) A jet of water 80 mm diam. moving with a velocity 20 m/s strikes a stationary plate. find the normal force on the plate when i) the plate is normal to the jet (W-25)
ii) the angle betn jet & plate is 30°.

→ Given data;

$d = 80 \text{ mm} = 0.08 \text{ m}$

$V = 20 \text{ m/s}$

area of jet $a = \frac{\pi}{4} \cdot d^2 = \frac{\pi}{4} (0.08)^2 = 0.00503 \text{ m}^2$

i) when plate is normal to jet ($\theta = 90°$)

$F = \rho a V^2 = 1000 \times 0.00503 \times \cancel{40} (20)^2$

$$\boxed{F = 2012 \text{ N}}$$

ii) When plate is inclined at 30° to jet.

$F_n = \rho a V^2 \cdot \sin^2\theta$

$= 1000 \times 0.00503 \times (20)^2 \times (\sin 30^\circ)^2$

$\boxed{F_n = 503\ N}$

4. A jet of water of diam, 60 mm moving with a velocity of 18 m/s, strikes flat plate, moving with a velocity of 6 m/s in the dir$^n$ of jet, at the center. find i) Thrust on plate in the dir$^n$ of jet. If the flat plate is replaced by symmetrical carved vane moving with the same velocity & jet after striking is deflected through an angle of 165° at outlet of carved plate, find - ii) Thrust on plate in the direction of jet, & iii) work done. (W-24)

→ Given data:

$d = 60\ mm = 0.06\ m$

$V = 18\ m/s$

$u = 6\ m/s$

$\rho = 1000\ m/s$

area $a = \frac{\pi}{4} \cdot d^2 = \frac{\pi}{4} \times (0.06)^2 = 0.002827\ m^2$

∴ mass flow rate $\dot{m} = \rho A V = 1000 \times 0.002827 \times 18$

$\boxed{\dot{m} = 50.89\ kg/s}$

i) Thrust on Moving flat plate

$F = \dot{m}\,(V-u)$

$= 50.89\,(18-6)$

$\boxed{F = 610.7\ N}$

ii) Thrust on Moving Carved Vane

$\theta = 180^\circ - 165^\circ = 15^\circ$

Relative velocity ⇒ $V_r = V - u = 18 - 6 = 12\ m/s$

for smooth vane → $V_{r_2} = V_{r_1}$

outlet whirl velocity

$V_{w_2} = u - V_r \cos 15^\circ$

$\cos 15^\circ = 0.966$

$V_{w_2} = 6 - (12 \times 0.966) = 6 - 11.59$

$V_{w_2} = -5.59$ m/s

Thrust $F = \dot{m}(V_{w_1} - V_{w_2})$ & $V_{w_1} = 18$

$= 50.89\ (18 - (-5.59))$

$\boxed{F = 1200\ N}$

work done (W) $= F.u = 1200 \times 6$

$\boxed{W = 7200\ W}$

* Numericals on Pelton wheel *

5. A single jet pelton wheel runs at 280 rpm under a head of 510 m. The jet diam is 200 mm, its deflection inside the bucket is 165° & its relative velocity is reduced by 15% due to friction. Determine
i) water power ii) Resultant force on the bucket &
iii) overall efficiency. Consider mechanical losses = 3%, coeff. of velocity = 0.98 & speed ratio = 0.46 (W-24)

→ Given data:

$N = 280$ rpm

$H = 510$ m

$d = 0.2$ m

reduction in relative vel. = 15%

$K_u = 0.46$

$\theta = 180^\circ - 165^\circ = 15^\circ$

mechanical losses = 3%

velocity of Jet ($V_1$). => $V_1 = C_v . \sqrt{2gH}$

$= 0.98 \times \sqrt{2 \times 9.81 \times 510}$

$\boxed{V_1 = 98.03 \text{ m/s}}$

Bucket speed ($k_u$) => $u = k_u . \sqrt{2gH}$

$u = 0.46 . \sqrt{2 \times 9.81 \times 510}$

$\boxed{u = 46.01 \text{ m/s}}$

discharge (Q) => $Q = \frac{\pi}{4} d^2 V_1 = \frac{\pi}{4} . (0.2)^2 \times 98.03$

$\boxed{Q = 3.08 \text{ m}^3/\text{s}}$

Water power => $P_{water} = \rho . g . Q . H$

$= 1000 \times 9.81 \times 3.08 \times 510$

$\boxed{P_{water} = 15.41 \times 10^6 \text{ W}}$

velocity component => inlet $= V_{w_1} = V_1 = 98.03$ m/s

Relative velocity at inlet $V_{r_1} = V_1 - u = 98.03 - 46.01$

$V_{r_1} = 52.02$ m/s

Relative velocity at outlet $V_{r_2} = 0.85 \times V_{r_1} = 0.85 \times 52.02$

$V_{r_2} = 44.22$ m/s

outlet velocity triangle => $V_{w_2} = V_{r_2} \cos(15°) - u$

$= 44.22 \times \cos(15°) - 46.01$

$V_{w_2} = -3.29$ m/s

Force on Bucket => $F = \rho . Q . (V_{w_1} - V_{w_2})$

$= 1000 \times 3.08 (98.03 - (-3.29))$

$\boxed{F = 3.12 \times 10^5 \text{ N}}$

Power developed $\Rightarrow$ $P = F \cdot u = 3.12 \times 10^5 \times 46.01$

$$\boxed{P = 14.35 \text{ MW}}$$

Overall efficiency $\Rightarrow$ considering mechanical losses = 3%

$P_{output} = 0.97 \times 14.35 = 13.92$ MW

$$\eta_o = \frac{\text{output}}{\text{water power}} = \frac{13.92}{15.41} \times 100\%$$

$$\boxed{\eta_o = 90.3\%}$$

6. A pelton wheel is designed for following specifications: shaft power = 11772 kW, head = 380 m, speed = 750 rpm, overall efficiency = 86 %. If the jet diam. should not be $1/16^{th}$ of the wheel diam. Determine the wheel diam, no. of jets reqd & diam of jet. (Take speed ratio = 0.45).
(1N-25)

→ Given data:

Shaft Power $P_o = 11772$ kW $\qquad$ $k_u = 0.45$

$H = 380$ m $\qquad$ Condn = $d \leq \frac{D}{6}$

$N = 750$ rpm

$\eta_o = 0.86$

Jet velocity $\Rightarrow$ $V = \sqrt{2gH} = \sqrt{2 \times 9.81 \times 380}$

$$\boxed{V = 86.36 \text{ m/s}}$$

Bucket speed $\Rightarrow$ $u = k_u \cdot \sqrt{2gH} = 0.45 \times 86.36$

$$\boxed{u = 38.86 \text{ m/s}}$$

Wheel diam (D) $\Rightarrow$ $u = \frac{\pi D N}{60}$ $\Rightarrow$ $38.86 = \frac{\pi D \times 750}{60}$

$$\boxed{D = 0.99 \text{ m}}$$

Discharge (Q) $\Rightarrow$ $P_{shaft} = \eta_o \cdot \rho \cdot g \cdot QH$

$$Q = \frac{P}{\eta_o \cdot \rho \cdot g \cdot QH} = \frac{11.772 \times 10^6}{0.86 \times 10^3 \times 9.81 \times 380}$$

$$\boxed{Q = 3.67\ m^3/s}$$

Jet diam (for one jet) =>

$$Q = \frac{\pi}{4} \cdot d^2 \cdot V$$

$$d = \sqrt{\frac{4Q}{\pi \cdot V}} = \sqrt{\frac{4 \times 3.67}{\pi \times 86.36}}$$

$$\boxed{d = 0.232\ m}$$

Now check cond$^n$ => $d = \frac{D}{6} = \frac{0.99}{6} = 0.165\ m$

but $d = 0.232 > 0.165$

Not acceptable → Need multiple jets.

No. of Jets => let no. of jets = $n$ Try $n = 2$

$$Q_{per\,jet} = \frac{Q}{n} = \frac{3.67}{n} = \frac{3.67}{2} = 1.835$$

$$\therefore d = \sqrt{\frac{4Q}{\pi \cdot V}} = \sqrt{\frac{4 \times 1.835}{\pi \times 86.36}} = 0.164\ m/s$$

Check $d = 0.164 \approx 0.165\ m$ ✓

Hence. Wheel diam = $D = 0.99\ m$

No. of Jet = $n = 2$

Jet diam = $d = 0.164\ m$

7. A pelton wheel has mean bucket speed of 15 m/s & is supplied with water at a rate of 0.8 $m^3/s$ under a head of 30m. If the bucket deflects the jet through an angle of 165°, find the power developed by the turbine. Neglect friction in the bucket. Also determine the overall efficiency of the turbine, if its mechanical efficiency is 80%.
(S-25)

→

Given data :

$u = 15\ m/s$ $\phi = 180 - 165^\circ = 15^\circ$

$Q = 0.8\ m^3/s$ $C_v = 0.98$

$H = 30m$ $\eta_m = 0.8$

Jet velocity => $V_1 = C_v.\sqrt{2gH} = 0.98 \times \sqrt{2 \times 9.81 \times 30}$

$\boxed{V_1 = 23.79\ m/s}$

Relative velocity at inlet => $V_{r_1} = V_{w_1} - u = 23.79 - 15$

$V_{r_1} = 8.79\ m/s$

(smooth bucket → no loss) $V_{r_2} = V_{r_1} = 8.79\ m/s$

outlet velocity component => $V_{w_2} = u - V_{r_2} \cos 15^\circ$

$= 15 - 8.79 \times \cos 15^\circ$

$V_{w_2} = 6.51\ m/s$

Force => $F = \rho . Q. (V_{w_1} - V_{w_2})$

$= 1000 \times 0.8 \times (23.79 - 6.51)$ -- ($\because V_{w_1} = V_1 = 23.79\ m/s$)

$\boxed{F = 13,824\ N}$

Power developed => $P = F.u = 13824 \times 15$

$\boxed{P = 207360\ W}$

Hydraulic efficiency ($\eta_{hyd}$) :

water power $= \rho g Q H = 1000 \times 9.81 \times 0.8 \times 30$

$P_{water} = 235,440\ W$

$\therefore \eta_{hyd} = \frac{\text{Power developed}}{\text{water power}} = \frac{207360}{235440} \times 100\% = \boxed{\eta_{hyd} = 88.1\%}$

Overall efficiency ($\eta_{over}$) => $= \eta_{hyd} \times \eta_{mech}$ => $\boxed{70.5\%}$