MODULE 4: IMPACT OF JETS AND HYDRAULIC TURBINES

IMPACT OF JET

When the jet impinges on plates or vanes, its momentum is changed and a hydrodynamic force is exerted, this exerted force is known as impact of jet.

JET

The jet is a stream of liquid comes out from nozzle with a high velocity under constant pressure.

INTRODUCTION

The impulse momentum principle is used to calculate the hydrodynamic force of jet on the vane. This principle is derived from the Newton's IInd Law of motion. The hydrodynamic force is due to the change in the momentum of the jet as a consequence of the impact. This force is equal to the rate of change of momentum. i.e., the force is equal to (mass striking the plate per second) x (Change in velocity).

From Newton's 2nd law, $F = ma = \underline{m (V_1 - V_2)/} t$

Impulse of a force is given by the change in momentum caused by the force on the body.

$Ft = mV_1 - mV_2$ = Initial Momentum - Final Momentum

Force exerted by jet on the plate in the direction of jet, $F = m (V_1 - V_2)/t$

= (Mass/Time) (Initial Velocity - Final Velocity)

$= ƒQ (V_1 - V_2)$

$F = ƒa V (V_1 - V_2)$

1) Force exerted by the jet on a stationary plate.

a) Plate is vertical to the jet.

b) Plate is inclined to the jet.

c) Plate is curved.

2) Force exerted by the jet on a moving plate.

a) Plate is vertical to the jet.

b) Plate is inclined to the jet.

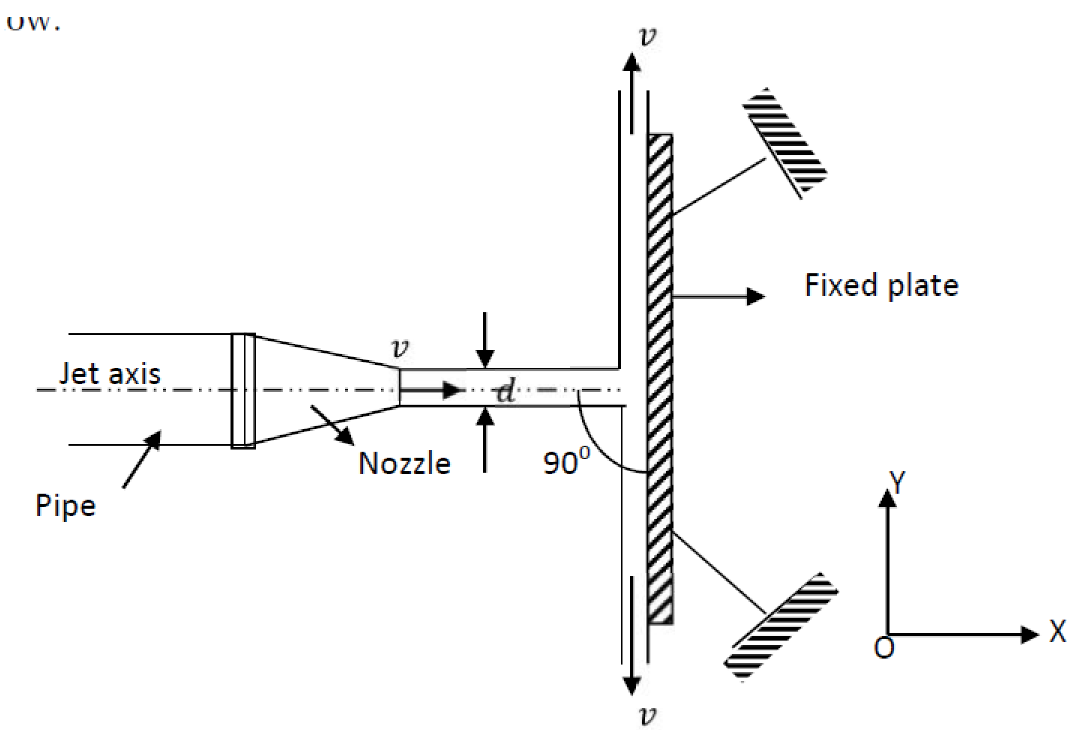
c) Plate is curved.

Assumptions were made while analyzing impact of jet

- ❖ Plate is smooth.
- ❖ No loss of energy due to impact of jet.
- ❖ Jet will move over the plate after striking with a velocity equal to initial velocity.
- ❖ Uniform distribution of velocity.
- ❖ Pressure everywhere is atmosphere.

a) Force exerted by the jet on a stationary vertical plate

Consider jet of water coming out from the nozzle strikes the vertical plate,



Let,

V = velocity of jet, d = diameter of the jet in meters,

a = area of cross-section of the jet, in m^2

ρ - is the density of the fluid, kg/m^3

The force exerted by the jet on the plate in the direction of jet.

F_x = Rate of change of momentum in the direction of force.

Rate of change of momentum in the direction of force,

= (initial momentum – final momentum)/time

= (mass x initial velocity – mass x final velocity) / time

= mass/time (initial velocity – final velocity)

= mass/ sec x (velocity of jet before striking - velocity of jet after striking)

= m (V-0)

= ρaV (V-0)

$\mathbf{F_x = \rho a V^2}$

b) Force exerted by the jet on a stationary inclined plate

If the surface is inclined at an angle to the jet, as shown in Fig, the jet velocity can be resolved into two components, one normal to the surface and other parallel to it. Since, water leaves the surface tangentially; there is no component of force in that direction after impinging.

Applying impulse momentum equation in the direction normal to the plate, then normal force on the plate,

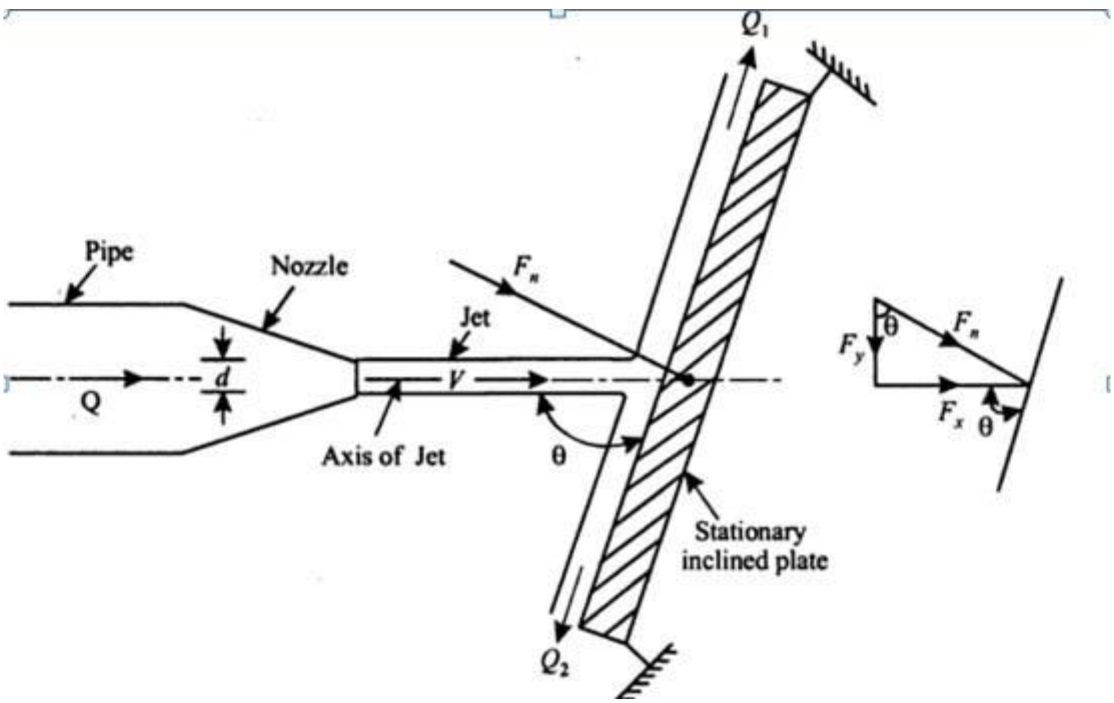
F_n = Mass of jet striking per second (initial velocity of the jet before striking - final velocity of the jet after striking)

$= m (V_{1n} - V_{2n})$

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

$$\mathbf{F_n = \rho a V^2 \sin\theta}$$

This force can be resolved into two components, one in the direction of the jet and other normal to the direction of flow.



Then Force exerted by the jet in the direction of flow,

F_x **= F_n Cos (90-θ)**

= F_n Sin θ

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

Force exerted by the jet in the direction normal to the flow,

F_y **= F_n Sin (90-θ)**

= F_n Cos θ

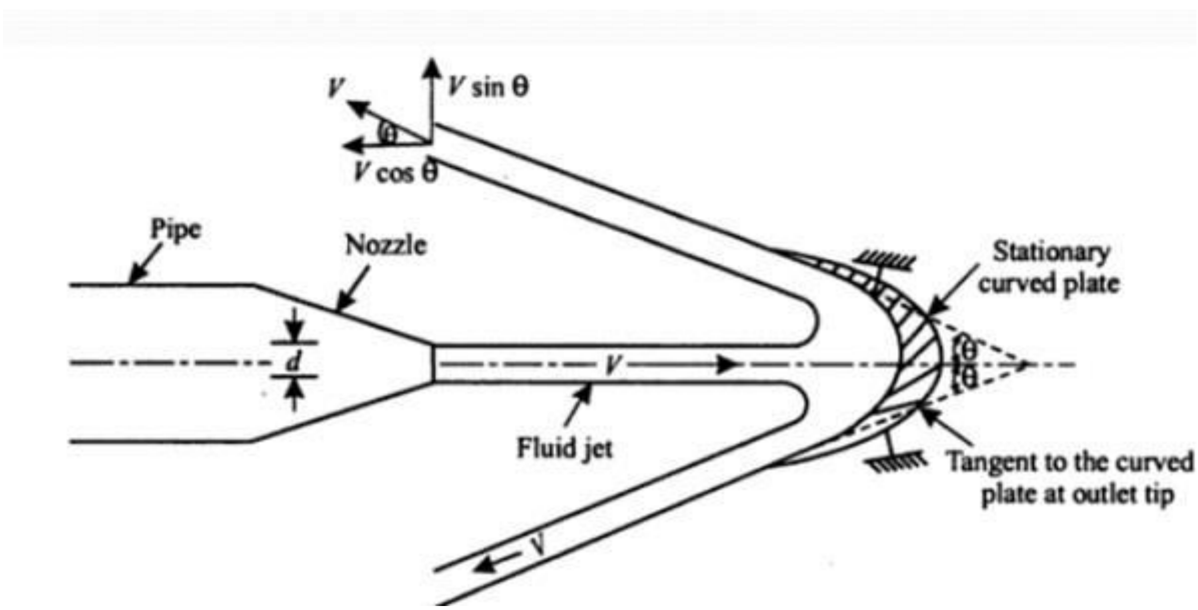
= $\rho a V^2$ Sin θ Cos θ

c) Force exerted by the jet on a stationary cuved plate

(i) **Impact of jets on stationary curved plates at the center**

The impact of jet on the curved surface is of much practical significance. The jet of water can be introduced tangentially, whereas in other case it can strikes at some angle to the entrance portion of the surface. Here, both such cases deserve individual consideration.

Consider the case when the jet strikes horizontally at the centre of the vane on the concave side as shown in figure below.



After it strikes, it gets divided, glides over the surface and leaves the vane tangentially with same velocity 'v'. The velocity at outlet of the plate can be resolved into two components, one in the direction of the jet and the other perpendicular to the direction of the jet.

Component of velocity in the direction of the jet is given by, $-(V\cos\theta)$ here -ve sign has been considered because; outlet velocity is in the opposite direction of the jet of water coming out of from nozzle. Component of velocity perpendicular to the jet is given by, $V\sin\theta$

V_{1X} is the initial velocity of the jet before striking in the direction of the jet,

ie in the X direction = V

V_{2X} =is the final velocity of the jet after striking in the direction of jet, ie in the X - direction = $-V\cos\theta$

V_{1Y} = is the initial velocity of the jet striking in the direction of Y = 0

V_{2Y} = is the final velocity of the jet after striking in the direction of Y = V Sinθ

Applying impulse-momentum equation in the direction normal to the plate, then normal force on the plate,

Force exerted by the jet in the direction of the jet,

F_X = Mass of jet striking per second (Initial velocity of the jet before striking - Final velocity of the jet after striking)

$= m (V_{1x} - V_{2x})$

$= \rho aV [V- (-V \cos\theta)]$

$= \rho aV [V + V \cos\theta]$

$$\mathbf{F_x = \rho a V^2 [1+ \cos\theta]}$$

Similarly, Force exerted by the jet normal to the direction of the jet,

F_y = Mass of jet striking per second (initial velocity of the jet before striking - Final velocity of the jet after striking)

$= m (V_{1y} - V_{2y})$

$= \rho aV [0 -V \sin\theta]$

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

Negative sign means the force is acting in the downward direction.

In this case angle of deflection of the jet = 180-θ

Problem: A jet of water of diameter 0.10m moving with a velocity of 20m/s, strikes acurved fixed symmetrical plate at the centre. Find the force exerted by the jet of water inthe direction of the jet, if the jet is deflected through an angle of 120^0at the outlet of thecurved plate.

Solution: Given data,

Diameter of the jet, d= 0.10m;

Area of the jet, a= 0.00785m2;

Velocity of the jet, v=20m/s;

Angle of deflection = 120^0; $\theta=60^0$(because, angle of deflection=(180^0 - θ)

Using the relation, for force exerted by the jet on the curved plate in the direction of the

jet,

$$\mathbf{F_x = \rho a V^2 \left[1 + Cos\theta \right]}$$

= 1000 x 0.00785 x 20 {1 + cos 60} = **4710 N**

(ii) <u>FORCE EXERTED BY THE JET ON A STATIONARY CURVED PLATE AT ONE END TANGENTIALLY</u>

Consider a jet of fluid strikes a fixed curved vane at one end glides over the vane and then leaves it tangentially. The velocity of the jet at the outlet will be same as that of inlet end.

Case I: When the plate is symmetrical.

Let the jet strikes the curved fixed plate symmetrical about X-axis at one end tangentially as shown in Fig. The plate is symmetrical, and then the angle made by the tangents at the two ends of the plate will be same.

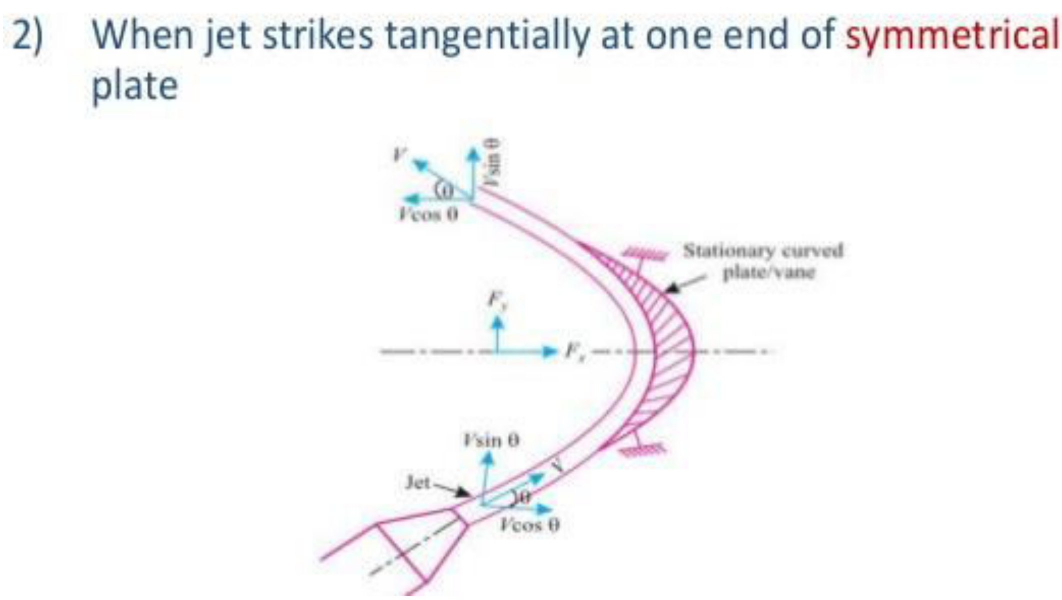


Fig. Jet strikes on a stationary symmetrical curved plate/vane at one end tangentially.

Let,

V = velocity of jet, d = diameter of the jet in meters,

a = area of cross-section of the jet, in m^2

ρ - is the density of the fluid, kg/m^3

θ - is the angle made by the jet with X-axis at inlet tip of the curved plate.

m - is the mass flow rate in kg/sec

V_{1X} - is the initial velocity of the jet before striking in the direction of the jet,

ie in the X direction = $V\cos\theta$

V_{2X} - is the final velocity of the jet after striking in the direction of jet,

ie in the X - direction = $-V\cos\theta$

V_{1Y} - is the initial velocity of the jet striking in the direction of Y = $V\sin\theta$

V_{2Y} - is the final velocity of the jet after striking in the direction of Y = $V\sin\theta$

Applying impulse-momentum equation in the direction normal to the plate, then normal force on the plate,

Force exerted by the jet in the direction of X,

F_x = Mass of jet striking per second (Initial velocity of the jet before striking - Final velocity of the jet after striking)

$= m(V_{1x} - V_{2x})$

$= \rho aV [V\cos\theta - (-V\cos\theta)]$

$= \rho aV [V\cos\theta + V\cos\theta)]$

$F_x = 2\rho aV^2 \cos\theta$

Similarly, Force exerted by the jet in the direction of Y,

F_y = Mass of jet striking per second (initial velocity of the jet before striking - Final velocity of the jet after striking)

$= m(V_{1y} - V_{2y})$

$= \rho aV [V\sin\theta - V\sin\theta]$

$= 0$

Case II: When the plate is unsymmetrical

Let the jet strikes the curved fixed plate unsymmetrical about X-axis at one end tangentially, then the angle made by the tangents drawn at the inlet and outlet tips of the plate with X-axis will be different.

Let,

V = velocity of jet, d = diameter of the jet in meters,

a = area of cross-section of the jet, in m^2

ρ - is the density of the fluid, kg/m^3

θ - is the angle made by the jet with X-axis at inlet tip of the curved plate.

Φ - is the angle made by the jet with X-axis at outlet tip of the curved plate.

m - is the mass flow rate in kg/sec

V_{1X} is the initial velocity of the jet before striking in the direction of the jet,

ie in the X direction, $V_{1X} = V \cos\theta$

V_{2X} - is the final velocity of the jet after striking in the direction of jet,

ie in the X - direction , $V_{2X} = -V \cos\Phi$

V_{1Y} - is the initial velocity of the jet striking in the direction of Y = $V \sin\theta$

V_{2Y} - is the final velocity of the jet after striking in the direction of Y = $V \sin\Phi$

Applying impulse-momentum equation in the direction normal to the plate, then normal force on the plate,

Force exerted by the jet in the direction of X,

F_x = Mass of jet striking per second (Initial velocity of the jet before striking - Final velocity of the jet after striking)

$= m\,(V_{1x} - V_{2x})$

$= \rho aV\,[\,V\,Cos\theta - (-V\,Cos\Phi)\,]$

$= \rho aV\,[\,V\,Cos\theta + V\,Cos\Phi)\,]$

$\mathbf{F_x = \rho aV^2\,[Cos\theta + Cos\Phi]}$

Similarly, Force exerted by the jet in the direction of Y,

F_y = Mass of jet striking per second (initial velocity of the jet before striking - Final velocity of the jet after striking)

$= m\,(V_{1y} - V_{2y}\,)$

$= \rho aV\,[\,V\,Sin\theta - V\,Sin\Phi\,]$

$\mathbf{F_y = \rho aV^2\,[\,Sin\theta - Sin\Phi\,]}$

[Total angle of deflection of the jet = 180-(θ+Φ)]

FORCE EXERTED BY THE JET ON MOVING PLATES

Consider a jet of fluid strikes on a smooth vertical plate at the centre which is moving in the same direction as of jet, say with a velocity of u.

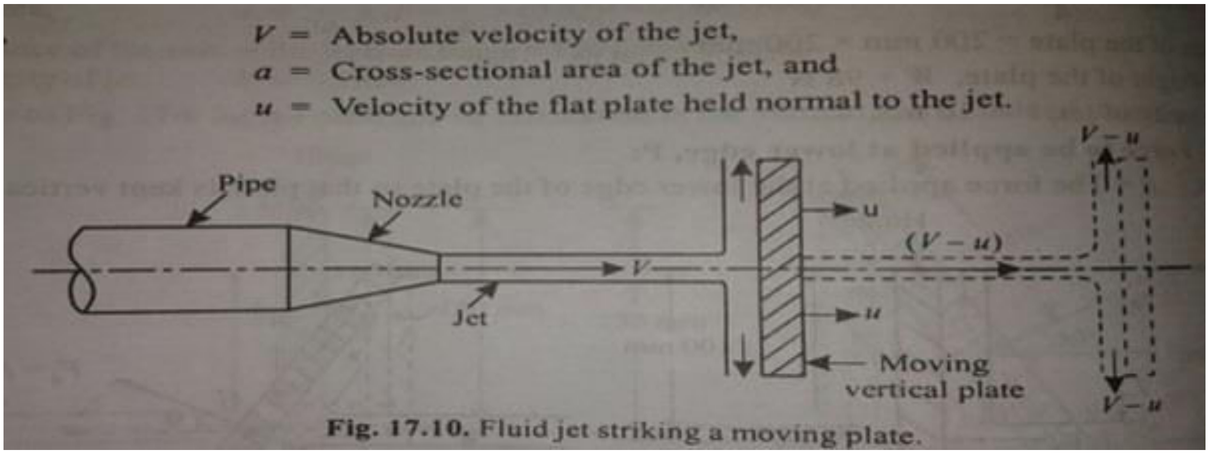


Fig. Fluid jet striking on a moving vertical plate

Let,

V - is the velocity of the jet measured in m/s

a - is the cross sectional area of the jet

u - is the velocity of the flat plate as a result of impact of jet

In this case jet strikes with a relative velocity, $V_r = (V-u)$

m - Mass of fluid striking the plate per second is given by = $\rho a(V-u)$

Force exerted by the jet on the moving plate in the direction of the jet, X-direction,

F_x = Mass of fluid striking per second (Initial velocity with which fluid strikes - Final velocity)

$= m\,[(V-u) - 0]$

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

$F_x = \rho a\,(V-u)^2$

In case of moving plate, work is done on the plate by the jet,

$W = $ Force x Distance moved by the plate in the direction of force per second

$= F_x \times u$

$= \rho a(V-u)^2 \times u$ Nm/s

But Work done per second is the power developed.

$P = \rho a(V-u)^2 \times u$ watts

Energy supplied by jet = Kinetic energy of issuing jet

$= 1/2\ mV^2$

$= 1/2\ \rho aV \times V^2$

$= 1/2\ \rho aV^3$

Efficiency of the jet, $\eta = \dfrac{\text{Output of the jet per second}}{\text{Input of the jet per second}}$

$= \dfrac{\text{Work done per second}}{\text{Energy supplied per second}}$

$= \dfrac{\rho a(V-u)^2 \times u}{1/2\ \rho aV^3}$

$$\boldsymbol{\eta = \frac{2\,(V-u)^2\,u}{V^3}}$$

Problem: A jet of water of diameter 50mm strikes a flat plate normally with a velocity of 26 m/s. The plate is moving with a velocity of 10 m/s in the direction of the jet and away from the jet. Find i) the force exerted by the jet on the plate. ii) Work done by the jet on the plate per second. iii) Power of the jet. iv) Efficiency of the jet.

Solution:- Given data,

Diameter of the jet, d = 50 mm = 50×10^{-3} m

Velocity of the jet , v = 26 m/s

Velocity of the plate, u = 10 m/s

Force exerted by the jet on the flat moving plate,

$F_x = \rho a(V-u)^2$

$= 1000 \times \Pi/4 \times (50 \times 10^{-3}) \times (26 - 10)^2$

= 502.65 N

Work done by the jet on the plate per second,

$W = F_x \times u$

$= 502.65 \times 10$

= **5026.5 Nm/s**

Power of the jet, P = Work done by the jet on the plate per second

P = 5026.5 W

Efficiency of the jet, $\eta = \frac{2\,(V-u)^2\,u}{V^3}$

$\eta = \frac{2\,(26 - 10)^2 \times 10}{26^3}$ = **29.13 %**

FORCE EXERTED BY THE JET ON A FLAT INCLINED PLATE MOVING IN THE DIRECTION OF JET

Consider a jet of fluid strikes on a smooth inclined flat plate at the centre which is moving in the same direction as of jet, say with a velocity of u.

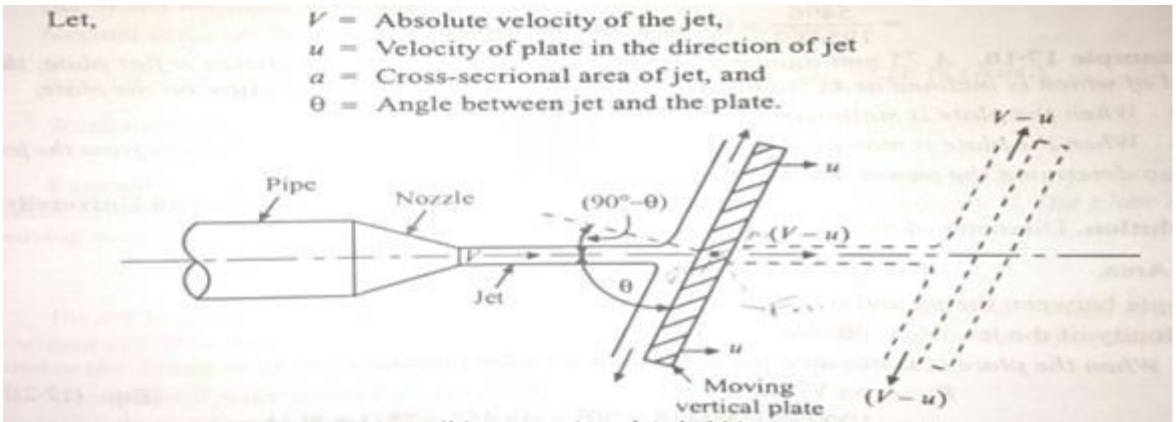


Fig. Fluid jet striking on a moving inclined plate

Let,

V - is the velocity of the jet measured in m/s

a - is the cross sectional area of the jet

u - is the velocity of the flat plate as a result of impact of jet

In this case jet strikes with a relative velocity, $V_r = (V\text{-}u)$

m - mass of fluid striking the plate per second is given by = $\rho a(V\text{-}u)$

Force exerted by the jet of fluid on the moving plate in the direction normal to the plate,

F_n = Mass of fluid striking per second **(** Initial velocity in the normal direction with which fluid strike - Final velocity in the direction normal to the plate**)**

$= m[\,(V\text{-}u)\sin\theta - 0]$

$= \rho a(V\text{-}u)\,[\,(V\text{-}u)\,\mathrm{Sin}\theta - 0]$

$= \rho a(V\text{-}u)^2 \sin\theta$

The normal force F_n can be resolved into two components F_x and F_y in the direction of jet and perpendicular to the direction of the jet respectively.

F_x = Component of the normal force F_n parallel to the jet

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

$= \boldsymbol{\rho a(V-u)^2 \sin^2\theta}$

F_y = Component of the normal force F_n perpendicular to the jet

$= F_n \cos\theta = \rho a(V-u)^2 \sin\theta \times \cos\theta$

$= \boldsymbol{\rho a(V-u)^2 \sin\theta \cos\theta}$

Work done by the jet on the plate per unit time, $W = F_x \times u$

$$= \boldsymbol{\rho a(V-u)^2 \sin^2\theta \times u} \quad \textbf{Nm/s}$$

Power developed, P = **$\rho a(V-u)^2 \sin^2\theta \times u$ watts**

Energy supplied per second $= \frac{1}{2} m V^2$

$$= \frac{1}{2} \rho aV \times V^2 = \frac{1}{2} \rho aV^3$$

Efficiency of the jet is the ratio of output of the jet per second to the input of the jet per second.

Efficiency, $\eta = \dfrac{\text{Output of the jet per second}}{\text{Input of the jet per second}}$

$$= \frac{\text{Work done per second}}{\text{Energy supplied per second}}$$

$$= \frac{\rho a(V-u)^2 \sin^2\theta \times u}{\frac{1}{2} \rho aV^3}$$

$$\boldsymbol{\eta = 2(V-u)^2 \sin^2\theta \; u / V^3}$$

Problem: A 75 mm diameter water jet having a velocity of 30 m/s strikes a flat plate, the normal of which is inclined at 45^o to the axis of the jet. Find the normal pressure on the plate (i) When the plate is stationary (ii) When the plate is moving with a velocity of 15 m/s and away from the jet. Also determine the power and efficiency of the jet when the plate is moving.

Given data,

Diameter of the jet, d = 75 mm = 0.075 m

Absolute velocity of the jet, V = 30 m/s

Angle between jet and plate, $\theta = 45^0$

Velocity of the plate, u = 15 m/s

(i) When the plate is stationary, normal force on the plate,

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

$$= 1000 \times \Pi/4 \times (0.075)^2 \times 30^2 \times \sin 45$$

$$= 2811.51 \text{ N}$$

(ii) When the plate is moving with a velocity 15 m/s and away from the jet, the normal force on the plate,

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

$$= 1000 \times \Pi/4 \times (0.075)^2 \times (30 - 15)^2 \times \sin 45$$

$$= \mathbf{702.88 \text{ N}}$$

Force in the direction of the jet, $F_x = F_n \sin\theta$

$$= 702.88 \times \sin 45$$

$$= \mathbf{497 \text{ N}}$$

Workdone per second, W = F_x x u = 497 x 15 = **7455 Nm/s**

Power, P = 7455 W = **7.5 kW**

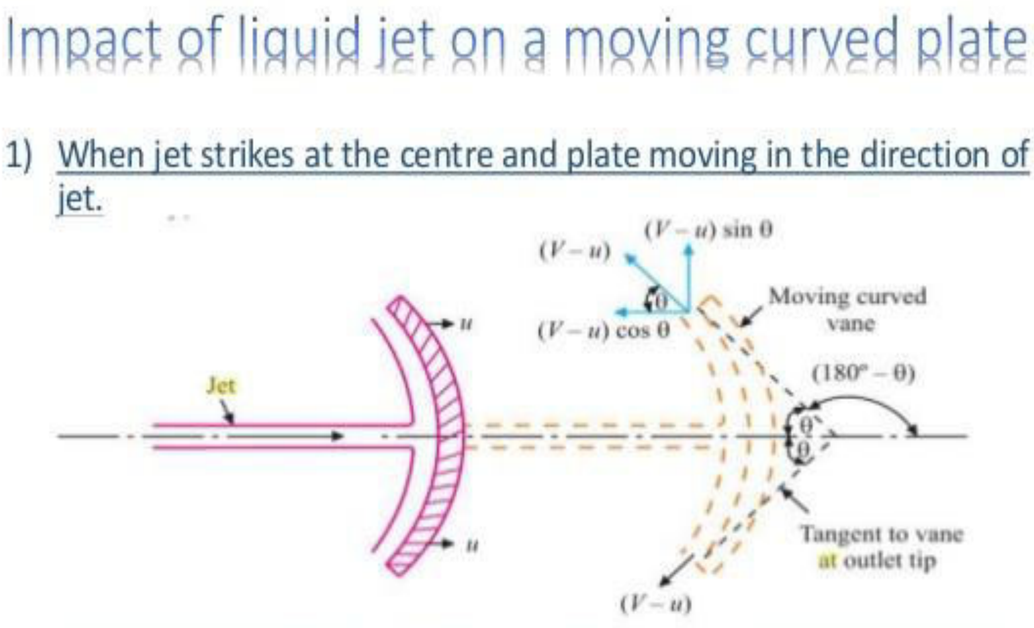
$$\text{Efficiency, } \eta = \frac{2\ (V-u)^2 \sin^2\theta\ u}{V^3}$$

$$= \frac{2 \times (300-15)^2 \sin^2 45 \times 15}{30^3}$$

$$= \mathbf{12.5\ \%}$$

FORCE EXERTED BY THE JET STRIKING AT CENTRE 0N A CUVED PLATE / VANE WHEN THE PLATE IS MOVING IN THE DIRECTION OF THE JET.

Consider a jet of fluid strikes at the centre of a symmetrical smooth curved plate moving with a uniform velocity in the direction of jet as shown in diagram.



Let,

V = velocity of jet, d = diameter of the jet in meters,

a = area of cross-section of the jet, in m^2

ρ- is the density of the fluid, kg/m^3

θ- is the angle made by the jet with X-axis at inlet tip of the curved plate.

m - is the mass flow rate in kg/sec

V_{1X} is the initial velocity of the jet before striking in the direction of the jet,

ie in the X direction = (V- u) cosθ

V_{2X} =is the final velocity of the jet after striking in the direction of jet, ie in the X - direction = $-(V- u) \cos\theta$

V_{1Y} = is the initial velocity of the jet striking in the direction of Y = $(V- u) \sin\theta$

V_{2Y} = is the final velocity of the jet after striking in the direction of Y = $(V-u) \sin\theta$

Applying impulse-momentum equation in the direction normal to the plate, then normal force on the plate,

Force exerted by the jet in the direction of X,

F_X= Mass of jet striking per second (Initial velocity of the jet before striking - Final velocity of the jet after striking)

$= m(V_{1x} - V_{2x})$

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

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

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

Similarly, Force exerted by the jet in the direction of Y,

F_y = Mass of jet striking per second (initial velocity of the jet before striking - Final velocity of the jet after striking)

$= m (V_{1y} - V_{2y})$

$= \rho a(V- u) [(V- u) \sin\theta - (V- u) \sin\theta]$

$= 0$

Workdone by the jet on the curved plate per second, $W = F_x \times u$

$$\mathbf{W = \rho a(V- u)^2 [1 + \cos \theta] u}$$

Power developed, $\mathbf{P = \rho a (V- u)^2 [1 + \cos \theta] u}$ **watts**

Efficiency, $\eta = \frac{\text{Output of the jet per second}}{\text{Input of the jet per second}}$

$= \frac{\text{Work done per second}}{\text{Energy supplied per sec,}}$

$$= \frac{\rho a(V-u)^2 [1 + \cos\theta]\, u}{\frac{1}{2} \rho a V^3}$$

$$\boldsymbol{\eta = \frac{2u(V-u)^2[1+\cos\theta]}{V^3}}$$

Problem: A jet of water of diameter 75 mm strikes curved plate at its centre with a velocity of 23 m/s. The curved plate moving with a velocity of 8 m/s in the direction of jet. The jet is deflected through an angle of 165^0. Assume the plate to be smooth. Find i) Force exerted on the plate in the direction of the jet. ii) Power of the jet iii) Efficiency of the jet.

Given data,

Diameter of the jet, d = 75 mm = 0.075 m

Absolute velocity of the jet, V = 23 m/s

Angle of deflection of the jet, $(180-\theta) = 165^0$, $\theta = 180 - 165 = 15^0$

Velocity of the plate, u = 8 m/s

(i) Force exerted by the jet on the plate in the direction of jet,

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

$= 1000 \times \Pi/4 \times (0.075)^2 \times (23 - 8)^2 (1 + \cos 15)$

= 1954.17 N

(ii) Workdone by the jet on the plate per second,

$W = F_x \times u = 1954.17 \times 8 =$ **15633.36 Nm/s**

Power of the jet, P = Workdone by the jet per second

= 15633.36 Watts

$$= \mathbf{15.63\ kW}$$

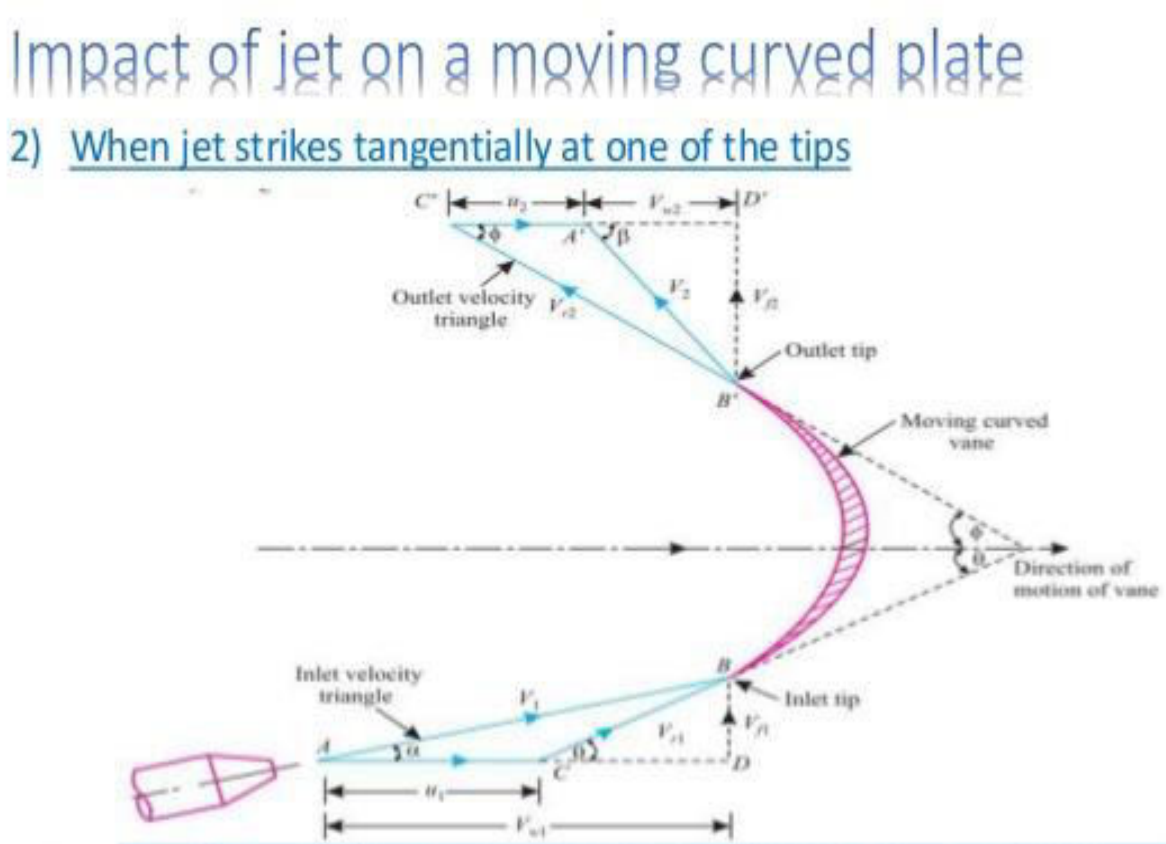
(iii) Efficiency of the jet, $\eta = \dfrac{\text{Work done per second}}{\text{Energy supplied per sec}}$

$$= \frac{15633.6}{\frac{1}{2} \times 1000 \times \frac{\Pi}{4} \times (0.075)^2 \times 23^2}$$

$$\boldsymbol{\eta = 0.5817 = 58.17\ \%}$$

FORCE EXERTED BY THE JET ON A MOVING CURVED PLATE AT ONE END TANGENTIALLY

Consider a jet of fluid strikes on a curved plate tangentially at one of its tips as shown in fig. As the jet strikes tangentially, the loss of energy due to impact of jet will be zero.



HYDRAULIC TURBINES - INTRODUCTION

Turbines are the hydraulic machine which converts hydraulic energy to mechanical energy where as pumps are hydraulic machine which convert mechanical energy to hydraulic energy.

Classification of Turbines

Based on Energy Exchange between the water and the Machine

Impulse Turbines

If the turbine wheel is driven by the kinetic energy of the fluid that strikes the turbine blades through the nozzle or otherwise, the turbine is known as an impulse turbine. In these types of turbines, a set of rotating machinery operates at atmospheric pressure. Impulse turbines are usually suitable for high head and low flow rates.

Pelton, Turgo, and Cross-flow turbines are three types of impulse turbines. The construction of the Pelton and Turgo turbines is similar. However, the Cross-flow turbine is a modified type of impulse turbines that is classified as an impulse turbine due to the rotation of the runner at atmospheric pressure and not as a submerged turbine.

Reaction Turbines

If the sum of potential energy and kinetic energy of water which are due to the pressure and velocity, respectively cause the turbine blades to rotate, the turbine is classified as a reaction turbine. In these types of turbines, the entire turbine is immersed in water and changes in water pressure along with the kinetic energy of the water cause power exchange. Applications of reaction turbines are usually at lower heads and higher flow rates than impulse turbines.

Based on Fluid Direction Through the Machine

f the flow in the runner moves radially, the turbine is radial flow. These turbines are divided into two types: **Inward radial flow** and **outward radial flow**. Francis turbines can be in the form of radial flow turbines.

Inward Radial Flow Turbines

In these turbines, water enters the turbine casing through the Penstock, and travels through the fixed guide vanes to the rotor, and exits from there. Therefore, the inner and outer diameters are as the outlet and the inlet, respectively.

Tangential or Peripheral Flow Turbines

In these turbines, water flows in a tangential direction to the runner. Pelton belongs to this category of turbines.

Axial Flow Turbines

In this type of turbine, the fluid flows parallel to the turbine shaft (turbine axis). Kaplan is one of these turbines.

Mixed Flow Turbines

A turbine in which the flow enters the turbine radially and leaves it axially is a mixed flow turbine, like modern Francis turbines.

Based on the hydraulic operating range

Accordingly, water turbines are of three categories:

Low Head Turbines

Hydraulic turbines operating in the head range of fewer than 45 meters are considered low-head turbines. Kaplan turbine is one of these turbines. If the head is less than 3 meters, it is considered an ultra-low head.

Medium Head Turbines

The working range for heads of 45 to 250 meters is known as medium heads. Francis turbines generally operate in such conditions.

High Head Turbines

Turbines with heads higher than 250 meters are known as high-head turbines, Like the Pelton Turbine.

Based on Specific Speed

The specific speed of a turbine (denoted by N_s) is defined as the speed of a turbine with a geometric similarity that can generate a unit of power under a head unit. Based on this parameter, water turbines are classified into three classes:

Low Specific Speed Turbine

The values between 1 and 10 are low specific speeds. Impulse turbines operate in this range. For example, the Pelton turbine usually operates at a specific speed of about 4.

Medium Specific Speed Turbine

Turbines that operate in the specific speed range of 10 to 100, such as Francis, have a medium specific speed.

High Specific Speed Turbine

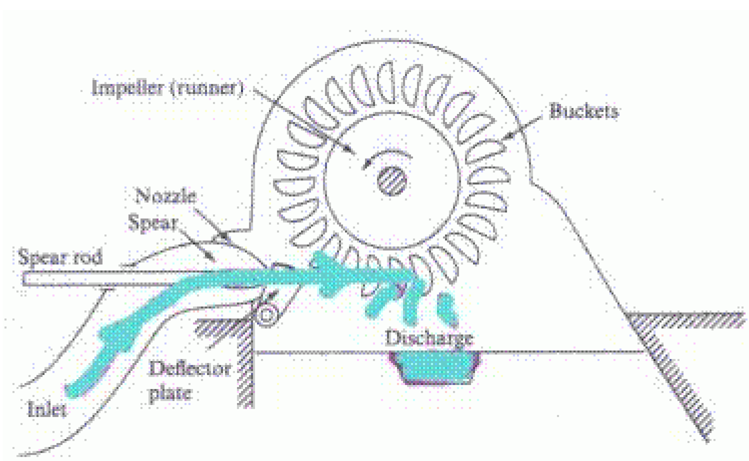
Specific speeds above 100 are considered high values. Kaplan turbine works at a high specific speed.

Pelton wheel

A Pelton turbine is a type of **impulse turbine** in which the flow enters the wheel **tangentially**. The whole set is at atmospheric pressure, the flow with potential energy and high pressure flows in the Penstock and reaches the nozzle(s). The nozzle is responsible for converting high-pressure flow to high-speed flow. Therefore, the current hits the blades of this turbine, which are in the shape of a bucket, at high speed and causes the runner to rotate.

These turbines are suitable for **high heads** (up to 2000 meters) and **low flow rates** (4-15 m^3/s). They are classified as **low specific speed** turbines. They are produced in various sizes and have been used up even to a capacity of 200 MW.

In the figure below, you can see the main components of the Pelton turbine, including nozzle(s), deflector plate (to prevent water jets in case of load stop), runner, and bucket-shaped blades.



Main parts of a Pelton turbine

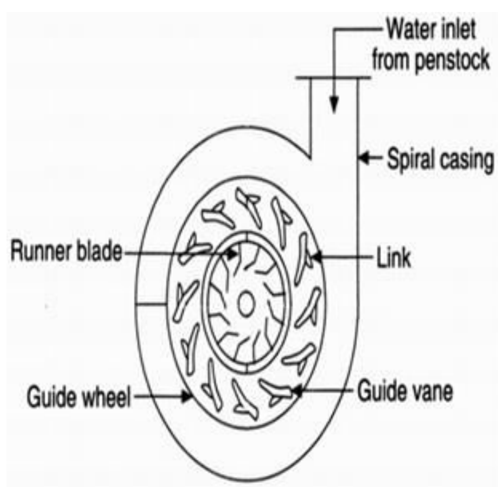
__Francis Turbine__

Francis Turbine is a reaction turbine used for medium heads (10-650 meters) and medium flows. Output power can be from 10 MW to 750 MW. These turbines are in the range of medium specific speed turbines. The main components of these turbines include spiral case, stay vanes, Guide vanes, runner, and draft tube.

The spiral case distributes the water around the wheel, and because its cross-sectional area gradually decreases, it does not allow the water velocity to decrease. The flow is directed to the wheel by stay vanes. Guide vanes are responsible for changes in the direction and velocity of water during changes in flow rate.

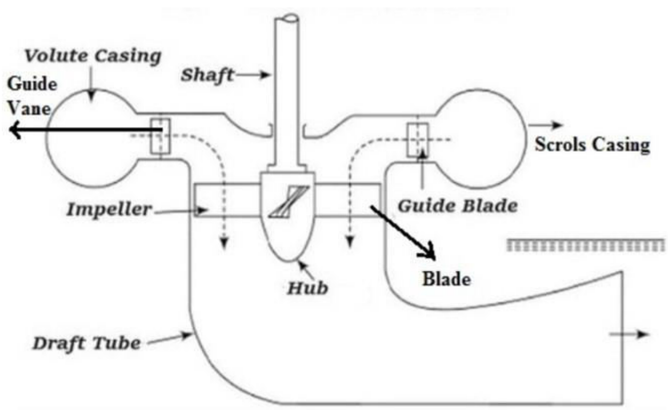
Finally, the energy exchange takes place in the runner section. The draft tube also acts as an outlet which increases the net head by moving the exiting water level upwards.

The wheels of these turbines are **inward radial or mixed**. The higher the specific speed, the closer the wheel gets to the mixed flow. The axis of these turbines is made vertically or horizontally; the horizontal type is used for less power and smaller power plants.



Kaplan Turbine

The Kaplan turbine is an inward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy. Power is recovered from both the hydrostatic head and from the kinetic energy of the flowing water.



The turbine shaft is vertical in an axial flow reaction turbine. The bottom end of the shaft is thickened, forming a hub or boss.

The hub functions as the axial flow reaction turbine's runner because the vanes are attached to it. The Francis turbine evolved into the Kaplan turbine. Its invention enabled efficient power generation in low-head applications, which the Francis turbine could not do. The *Kaplan turbine* is currently widely employed for high-flow, low-head power generation all over the world. Because the water flows in an axial direction, the Kaplan turbine is an axial flow reaction turbine.

Unit quantities

Unit Quantities of a Turbine are certain quantities related to a turbine, which are obtained when the turbine operates under unit head (i.e. H = 1m).

It is assumed that efficiency of the turbine remains same in both the cases (i.e. when turbine is working at unit head and when turbine is working at full head).

While studying turbines it is important to understand following three unit quantities.

- Unit Power (P_u)

- Unit Discharge (Q_u)
- Unit Speed (N_u)

What is Unit Power (P_u) of a Turbine?

Unit Power of a Turbine is the power generated by a turbine working at unit head.

$P_u = P/H^{3/2}$

Where:

H = Available head to turbine

P = Power generated by the turbine at the given head i.e. H

What is Unit Discharge (Q_u) of a Turbine?

Unit discharge of a Turbine is the discharge of turbine working at unit head.

$Q_u = Q/H^{1/2}$

Where:

H = Available head to turbine

Q = Discharge of the turbine at the given head i.e. H

What is Unit Speed (N_u) of a Turbine?

Unit speed of a turbine is the speed of turbine working under unit head.

$N_u = N/H^{1/2}$

Where:

H = Available head to turbine

N = Speed of the turbine at the given head i.e. H

Draft tube

A draft tube is a kind of tube which connects (or acts as an intermediately) between the water turbine exit and tail race.

There are four major types of draft tubes which are available to us.

1. Conical draft tube
2. Simple elbow draft tube

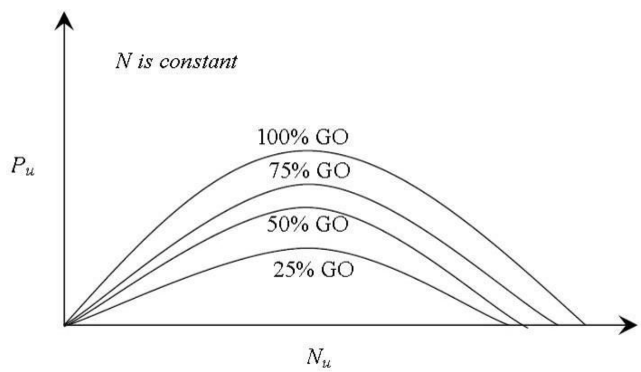
3. Moody spreading draft tube
4. Draft tube with circular inlet and rectangular outlet

Specific Speed of a turbine

The specific speed value for a turbine is the speed of a geometrically similar turbine which would produce unit power (one kilowatt) under unit head (one meter). The specific speed of a turbine is given by the manufacturer (along with other ratings) and will always refer to the point of maximum efficiency.

Characteristic curves in turbine:

Characteristic curves of a hydraulic turbine are the curves, with the help of which the exact behavior and performance of the turbine under different working conditions, can be known.



Types of PC curves

- Main Characteristic curves / Constant head curves
- Operating characteristic curves / Constant Speed curves
- Constant efficiency curves (Muschel Curves)

Cavitation and its effects

Cavitation is the formation and collapsing of cavities or bubbles in a liquid mostly developed in the areas which have relatively low pressure around the pump impeller. It occurs in the absence of the net positive suction head the pump. It's the formation of bubbles in the liquid flowing in any Hydraulic Turbine

Effects of cavitation

It is this micro jet that does all the damage. Micro jets are powerful enough to damage even high strength material. Implosions release packets of energy in a short duration concentrated at a micro spot. If a microjet hits a surface, it causes short term over-straining. It gradually leads to cavitation corrosion and cavitation damage. Over time, the material develops cracks with repeated bursts and eventually breaks off.

Thus cavitation in turbines is an unsteady phenomenon that triggers low-frequency pressure oscillations and high-frequency pressure pulses. The pressure oscillations are due to the cavity dynamics, while the pressure pulses are associated with cavity collapse. These sources of excitement that act inside the main flow or adjacent to walls generate vibrations and acoustic noise. When they propagate through the hydrodynamic and mechanical systems, it results in high vibrations, blade erosion and instabilities, ultimately leading to the destruction of the whole machinery.

There are different types of cavitations in turbines. They are usually categorized based on how they are formed, their structure, their motion in the fluid medium, etc.