CE 15023

FLUID DYNAMICS

LECTURE NOTES

MODULE-IV

Prepared By

Dr. Prakash Chandra Swain

Professor in Civil Engineering

Veer Surendra Sai University of Technology, Burla

Branch - Civil Engineering
Semester – 6th Sem

Department of Civil Engineering
VSSUT, Burla

Disclaimer

This document does not claim any originality and cannot be used as a substitute for prescribed textbooks. The information presented here is merely a collection by Prof. P.C.Swain with the inputs of Post Graduate students for their respective teaching assignments as an additional tool for the teaching-learning process. Various sources as mentioned at the reference of the document as well as freely available materials from internet were consulted for preparing this document. Further, this document is not intended to be used for commercial purpose and the authors are not accountable for any issues, legal or otherwise, arising out of use of this document. The authors make no representations or warranties with respect to the accuracy or completeness of the contents of this document and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose.

COURSE CONTENTS

Module-IV

Impact of free jet: Introduction, force exerted by fluid jet on stationary flat plate, moving flat plate, Stationary curved vane, moving curved vane, Torque exerted on a wheel with radial curved vanes.

Turbines: Classification, reaction, impulse, outward flow, inward flow & mixed flow turbines, Francis & Kaplan turbines, Pelton Wheel, Physical description and principle of operation, Governing of turbine.

Centrifugal Pump: Principles of classification, Blade angles, Velocity triangle, Efficiency, Specific Speed, Characteristic curves.

Reciprocating Pump: Principle of working, Slip, work done, effect of acceleration & Frictional resistance, Separation.

LECTURE NOTES-1

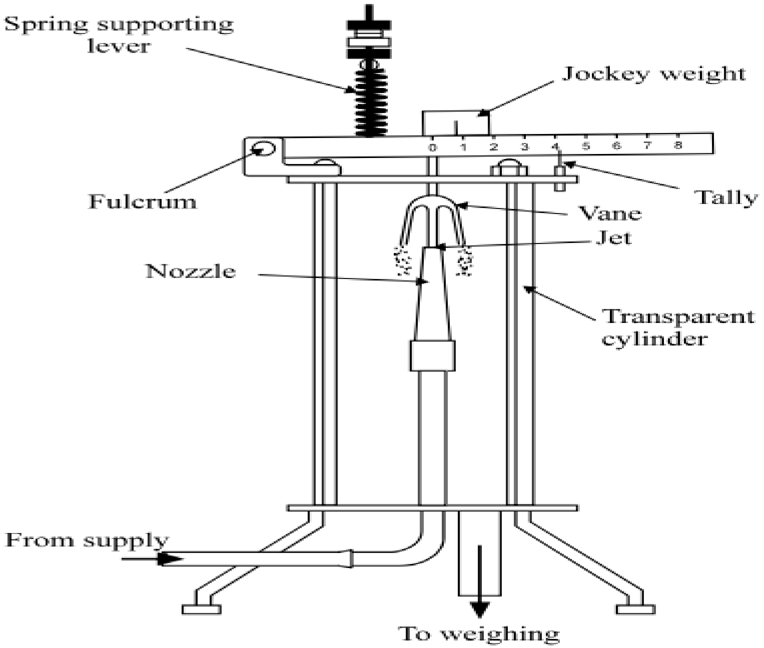
Impact of free jet

4.1 Introduction:

Water turbines are widely used throughout the world to generate power. In the type of water turbine referred to as a Pelton† wheel, one or more water jets are directed tangentially on to vanes or buckets that are fastened to the rim of the turbine disc. The impact of the water on the vanes generates a torque on the wheel, causing it to rotate and to develop power. Although the concept is essentially simple, such turbines can generate considerable output at high efficiency. Powers in excess of 100 MW, and hydraulic efficiencies greater than 95%, are not uncommon. It may be noted that the Pelton wheel is best suited to conditions where the available head of water is great, and the flow rate is comparatively small. For example, with a head of 100 m and a flow rate of 1 m3 /s, a Pelton wheel running at some 250 rev/min could be used to develop about 900 kW. The same water power would be available if the head were only 10 m and the flow were 10m3 /s, but a different type of turbine would then be needed.

To predict the output of a Pelton wheel, and to determine its optimumrotational speed, we need to understand how the deflection of the jet generates a force on the buckets, and how the force is related to the rate of momentum flow in the jet. In this experiment, we measure the force generated by a jet of water striking a flat plate or a hemispherical cup, and compare the results with the computed momentum flow rate in the jet.

1.1 Figure of impact jet



The jet of water is directed to hit the vanes of a particular shape a force is exerted on the vane by the jet.The amount of force depends on the diameter of the jet shape and the fluid flow rate it also depends on whether thevane is moving or stationary. In this experiment we are concerned about the stationary vane. The force on vane isgiven by the following formulas:

Flat Plate: $F_t = \rho a v^2$

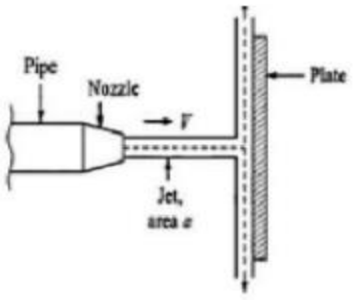
Hemispherical $F_t = 2 \rho a v^2$

Where a = area of jet in m^2

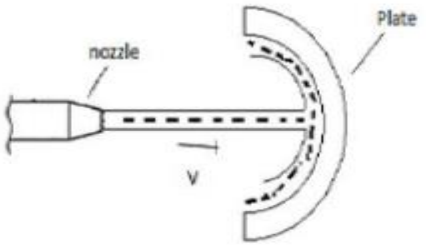
ρ = density of water = 1000 kg/ m^3

v = velocity of jet in m/s

F_t = Force acting parallel to the direction of jet



Flat plate



Hemispherical plate

4.2 Impact of jet

The liquid comes out in the form of a jet from the outlet of a nozzle which is fitted to a pipe through which the liquid is flowing under pressure.A **jet** is a stream of fluid that is projected into a surrounding medium, usually from some kind of a nozzle, aperture or orifice.[1] Jets can travel long distances without dissipating.

Jet fluid has higher momentum compared to the surrounding fluid medium. In the case that the surrounding medium is assumed to be made up of the same fluid as the jet, and this fluid has a viscosity, the surrounding fluid is carried along with the jet in a process called entrainment.

4.3 Force Exerted By Fluid Jet On Stationary Flat Plate

The following cases of the impact of jet, i.e. the force exerted by the jet on a plate will be considered considered:-

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 curve

2. Force exerted by the jet on a moving plate

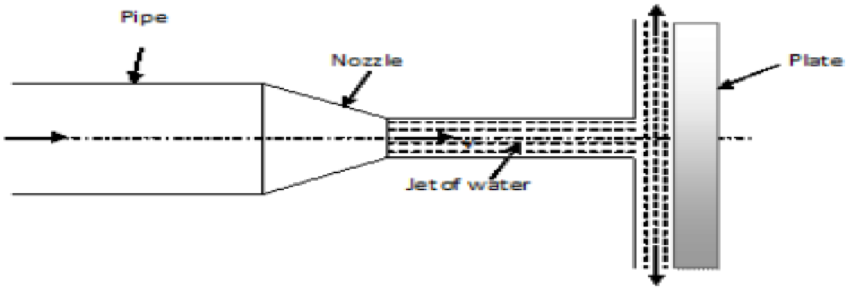
a) Plate is vertical vertical to the jet

b) Plate is inclined to the jet

c) Plate is curved

4.4 Force exerted by the jet on a stationary vertical plate

Consider a jet o f water coming out from the nozzle strikes the vertical plate



V = velocity of jet, d = diameter of the jet, a = area of x – section of the jet

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

Fx = 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 mass/ sec x (velocity of jet before striking – final velocity of jet after striking)

4.5 Force of Jet Impinging On An Inclined Fixed Plate:

Consider a jet of water impinging normally on a fixed plate as shown in fig-2.

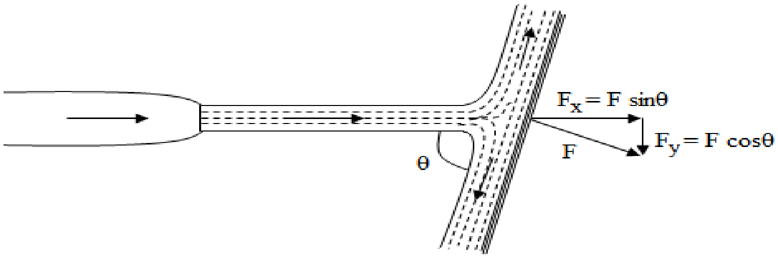


Fig-2 : Jet impinging on an inclined fixed plate

Let, • ϴ = Angle at which the plate is inclined with the jet

Force exerted by the jet on the plane = $\frac{waV^2}{g}$ KN

Force exerted by the jet in a direction normal to the plate, $F = \frac{waV^2 \sin\theta}{g}$ and the force exerted by the jet in the direction of flow,

$$F_x = F\sin\theta = \frac{waV^2 \sin\theta}{g} \times \sin\theta = \frac{waV^2 \sin^2\theta}{g}$$

Similarly.force exerted by the jet in a direction normal to flow,

$$F_y = F\cos\theta = \frac{waV^2 \sin\theta}{g} \times \cos\theta$$

$$\therefore F_y = \frac{waV^2 \sin 2\theta}{2g}$$

4.6 Force Of Jet Impinging On A Moving Plate*:*

Consider a jet of water imping normally on a plate. As a result of the impact of the jet, let the plate move in the direction of the jet as shown in fig-3.

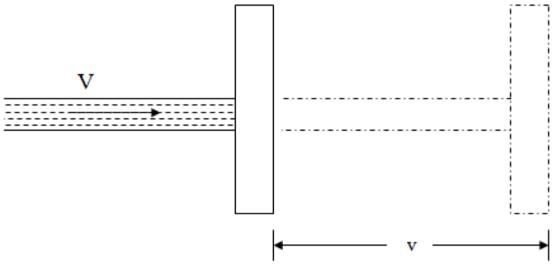


Fig-3 : Jet impinging on a moving plate

Let, v= Velocity of the plate, as a result of the impact of jet A little conversation will show that the relative velocity of the jet with respect to the plate equal to **(V-v)** m/s. For analysis purposes, it will be assumed that the plate is fixed and the jet is moving with a velocity of **(V-v)** m/s. Therefore force exerted by the jet,

$$F = Mass\ of\ water\ flowing\ per\ second \times Change\ of\ velocity$$

$$\Rightarrow F = \frac{wa(V-v)}{g} \times [(V-v)-0]$$

$$\Rightarrow F = \frac{wa(V-v)^2}{g} KN$$

4.7 Force Of Jet Impinging On A Moving Curved Vane:

Consider a jet of water entering and leaving a moving curved vane as shown in fig-4.

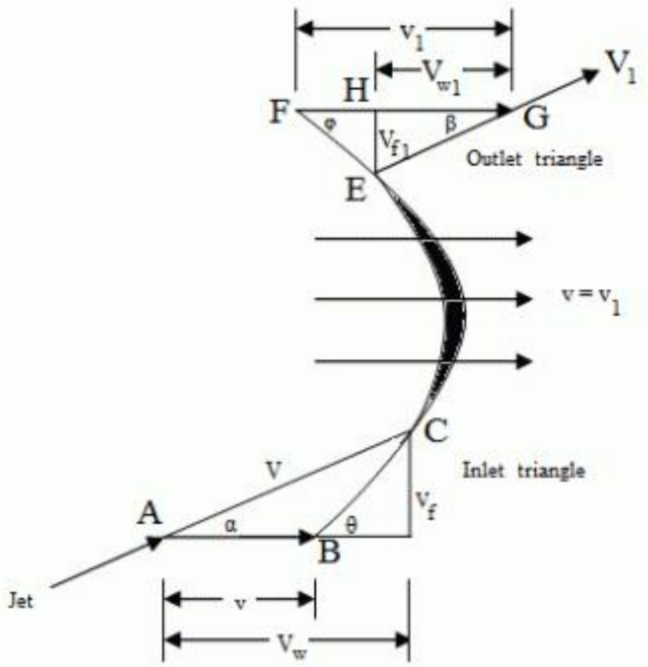


Fig-4 : Jet impinging on a moving curved vane

Let,

- V = Velocity of the jet (AC), while entering the vane,
- V1 = Velocity of the jet (EG), while leaving the vane,
- v1, v2 = Velocity of the vane (AB, FG)
- α = Angle with the direction of motion of the vane, at which the jet enters the vane,

- β = Angle with the direction of motion of the vane, at which the jet leaves the vane,
- Vr = Relative velocity of the jet and the vane (BC) at entrance (it is the vertical difference between V and v)
- Vr1 = Relative velocity of the jet and the vane (EF) at exit (it is the vertical difference between v1 and v2)
- Ɵ = Angle, which Vr makes with the direction of motion of the vane at inlet (known as vane angle at inlet),
- β = Angle, which Vr1 makes with the direction of motion of the vane at outlet (known as vane angle at outlet),
- Vw = Horizontal component of V (AD, equal to). It is a component parallel to the direction of motion of the vane (known as velocity of whirl at inlet),
- Vw1 = Horizontal component of V1 (HG, equal to). It is a component parallel to the direction of motion of the vane (known as velocity of whirl at outlet),
- Vf = Vertical component of V (DC, equal to). It is a component at right angles to the direction of motion of the vane (known as velocity of flow at inlet),
- Vf1 = Vertical component of V1 (EH, equal to). It is a component at right angles to the direction of motion of the vane (known as velocity of flow at outlet),
- a = Cross sectional area of the jet. As the jet of water enters and leaves the vanes tangentially, therefore shape of the vanes will be such that Vr and Vr1 will be a long with tangents to the vanes at inlet and outlet. The relations between the inlet and outlet triangles (until and unless given) are: (i) V=v1 , and

(ii) Vr=Vr1 We know that the force of jet, in the direction of motion of the vane,

$$F_x = Mass\ of\ water\ \ flowing\ per\ second \times Change\ of\ velocity\ of\ whirl$$

$$\Rightarrow F_x = \frac{waV}{g}(V_w - V_{w1})$$

Lecture notes 2

Turbines

Introduction

Hydraulic turbines are Machines which convert hydraulic energy in to mechanical energy of rotating element which in turn is converted into electrical energy through generator and associated system. Uses the potential energy and kinetic energy of water and rotate the rotor by dynamic action of water. According to the principle of moment of momentum, if the moment of momentum of water is changed as it flows through the rotating element, there results a torque which rotates the turbine shaft. The hydraulic energy is thus converted in to the mechanical energy. The hydraulic turbines constitute an important and essential item of a hydro-electric power plant. The primary function of a hydraulic turbine is to rotate the electric generator the rotation of which produces electrical power. Since the turbine main shaft is coupled to the generator shaft, the rotation of the turbine shaft ensures the rotation of the generator. The water from the storage reservoir is allowed to flow through a pressure pipe know as penstock, to the turbine.

Classification of Hydraulic turbines:

1) Based on type of energy at inlet to the turbine:

- **Impulse Turbine :** The energy is in the form of kinetic form. e.g: Pelton wheel, Turbo wheel.
- **Reaction Turbine :** The energy is in both Kinetic and Pressure form. e.g: Tubular, Bulb, Propeller, Francis turbine.

2) Based on direction of flow of water through the runner:

- **Tangential flow:** water flows in a direction tangential to path of rotational, i.e. Perpendicular to both axial and radial directions.
- **Radial outward flow e.g:**Forneyron turbine.
- **Axial flow :** Water flows parallel to the axis of the turbine. e.g: Girard, Jonval, Kalpan turbine.
- **Mixed flow :** Water enters radially at outer periphery and leaves axially. e.g : Modern Francis turbine.

3) Based on the head under which turbine works:

- **High head, impulse turbine. e.g :**Pelton turbine.
- **Medium head,reaction turbine. e.g :** Francis turbine.
- **Low head, reaction turbine. e.g :** Kaplan turbine, propeller turbine.

4) Based on the specific speed of the turbine:

- **Low specific speed, impulse turbine. e.g:**Pelton wheel.
- **Medium specific speed, reaction turbine. e.g :**Francis wheel.
- **High specific speed, reaction turbine. e.g :** Kaplan and Propeller turbine.

5) Based on the name of the originator:

- Impulse turbine – Pelton wheel, Girard, Banki turbine.
- Reaction turbine – Forneyron, Jonval, Francis, Dubs, Deriaze, Thomson kalpan, Barker, Moody, Nagler, Bell

➢ Impulse turbine

In the impulse turbines, the total flow energy is converted in to kinetic energy of jet before the water strikes the runner. The conversion of the potential energy into the kinetic energy is made possible by passing the flow through a nozzle. As pressure around the jet or jets of water striking the runner is the same before and after the impact, the impulse turbines are also called constant pressure turbines.

The pressure of flow at the entrance and exit of the runner is thus equal and is usually atmospheric $P_1 = P_2 = P_{atm}$.

The impulse turbines are used for very high heads between 600 to 2000 m and low flow rate.

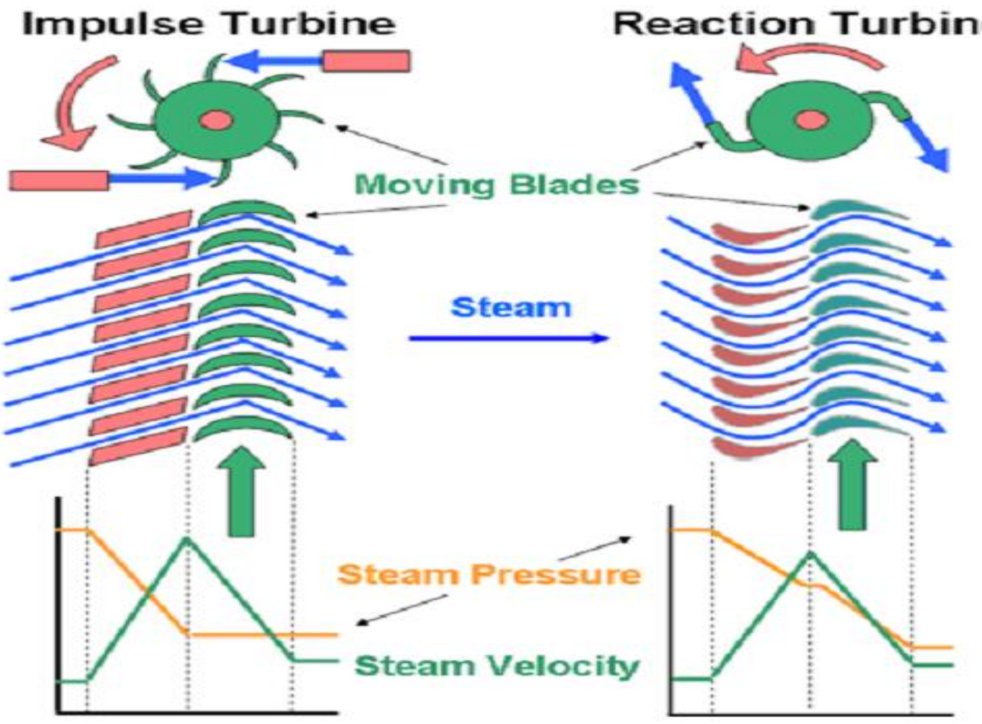
➢ Reaction turbine

The reaction turbines are the mixed flow and axial flow which differ mainly in the design of runner and its position relative to the turbine shaft. They both have certain common picture which are described subsequently.

The main features of the reaction turbine are that only a part of total energy is converted into kinetic energy before runner is reached and the working fluid completely fills the passage in the runner. The pressure of the flowing water changes gradually as it passes through the runner and therefore the runner must be enclosed within the water tight casing. Such turbines are also called as pressure turbine. Water is led from the storage reservoir through a penstock and enters the runner through the spiral casing and distributer with a system of stationary guide vanes. The water after doing work on the runner leaves it through the draft tube and joins the tail rage. The turbine space of a reaction turbine is formed by the following hydraulic elements such as spiral casing, staring, guide wheel, runner and draft tube.

$$H = \frac{p}{\gamma} + \frac{v^2}{2g}$$

P and v are the pressure and velocity of the nozzle.



➢ Francis turbines

The Francis turbine is a type of water turbine that was developed by James B. Francis in Lowel

Massachusetts. It is an inward-flow reaction turbine that combines radial and axial flow concepts.

Francis turbines are the most common water turbine in use today. They operate in a water head from 40 to 600 m (130 to 2,000 ft) and are primarily used for electrical power production. The electric generators that most often use this type of turbine have a power output that generally ranges from just a few kilowatts up to 800 MW, though mini-hydro installations may be lower Penstock (input pipes) diameters are between 3 and 33 ft (0.91 and 10 m). The speed range of the turbine is from 75 to 1000 rpm.

A wicket gate around the outside of the turbine's rotating runner controls the rate of water flow through the turbine for different power production rates. Francis turbines are almost always mounted with the shaft vertical to isolate water from the generator. This also facilitates installation and maintenance.

➢ Components

A Francis turbine consists of the following main parts:

- **Spiral casing**: The spiral casing around the runner of the turbine is known as the volute casing or scroll case. Throughout its length, it has numerous openings at regular intervals to allow the working fluid to impinge on the blades of the runner. These openings convert the pressure energy of the fluid into momentum energy just before the fluid impinges on the blades. This maintains a constant velocity despite the fact that numerous openings have been provided for the fluid to enter the blades, as the cross-sectional area of this casing decreases uniformly along the circumference.

- **Guide or stay vanes**: The primary function of the guide or stay vanes is to convert the pressure energy of the fluid into the momentum energy. It also serves to direct the flow at design angles to the runner blades.

- **Runner blades**:Runner blades are the heart of any turbine. These are the centers where the fluid strikes and the tangential force of the impact causes the shaft of the turbine to rotate, producing torque. Close attention in design of blade angles at inlet and outlet is necessary, as these are major parameters affecting power production.
- **Draft tube**: The draft tube is a conduit that connects the runner exit to the tail race where the water is discharged from the turbine. Its primary function is to reduce the velocity of discharged water to minimize the loss of kinetic energy at the outlet. This permits the turbine to be set above the tail water without appreciable drop of available head.

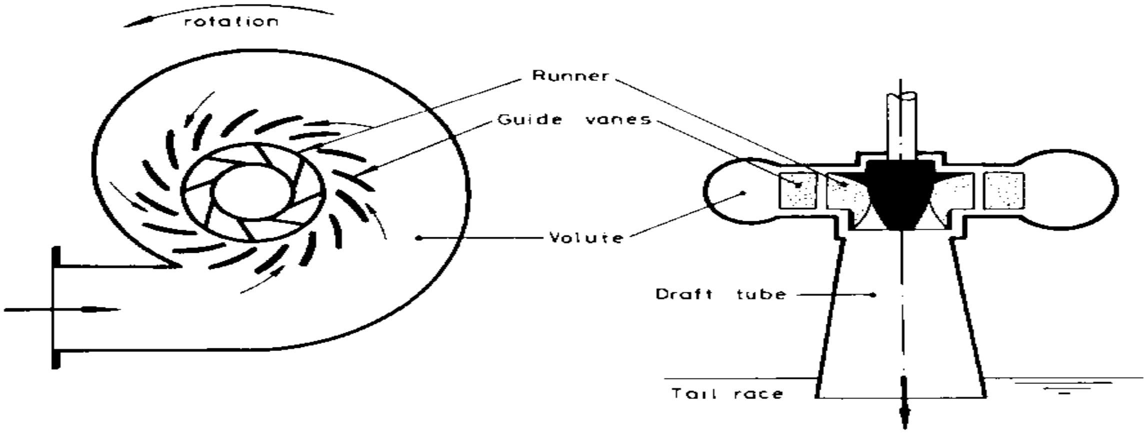


FIGURE B. 6 :
Sectional Views of a Francis Turbine

- Working proportions of francis runner

Ratio of wheel width B to runner diameter D is denoted by n

N=$^{B}/_{D}$

And its values ranges from .10 to .45

- Speed ratio ϕ represents the ratio of peripheral velocity u to the spouting velocity $\sqrt{2gh}$

$\Phi = \frac{u}{\sqrt{2gh}}$

The value of ϕ ranges from 0.6 to 0.9

Flow ratio Ψ is the ratio of the velocity of flow at inlet, V_f , to the spouting velocity,$\sqrt{2gh}$

$\Psi = \frac{v}{\sqrt{2gh}}$ its value varies from 0.15 to .30

Kaplan turbines

The Kaplan turbine is a propeller-type water turbine which has adjustable blades. It was developed in 1913 by Austrian professor Viktor Kaplan,[1] who combined automatically adjusted propeller blades with automatically adjusted wicket gates to achieve efficiency over a wide range of flow and water level.

The Kaplan turbine was an evolution of the Francis turbine. Its invention allowed efficient power production in low-head applications which was not possible with Francis turbines. The head ranges from 10–70 metres and the output ranges from 5 to 200 MW. Runner diameters are between 2 and 11 metres. Turbines rotate at a constant rate, which varies from facility to facility. That rate ranges from as low as 69.2 rpm (Bonneville North Powerhouse, Washington U.S.) to 429 rpm. The Kaplan turbine installation believed to generate the most power from its nominal head of 34.65 m is as of 2013 the TocomaDam Power Plant (Venezuela) Kaplan turbine generating 230 MW (Turbine capacity, 257MVA for generator) with each of ten 8.6 m diameter runners.[2]

Kaplan turbines are now widely used throughout the world in high-flow, low-head power production.

Theory of Operation

The working proportion are obtained in a similar manner as for a Francis turbine, however, the following changes are to be noted:

(i) Ratio n of the hub diameter d to the runner outside diameter D; n=$\frac{d}{D}$. From the continuity operation

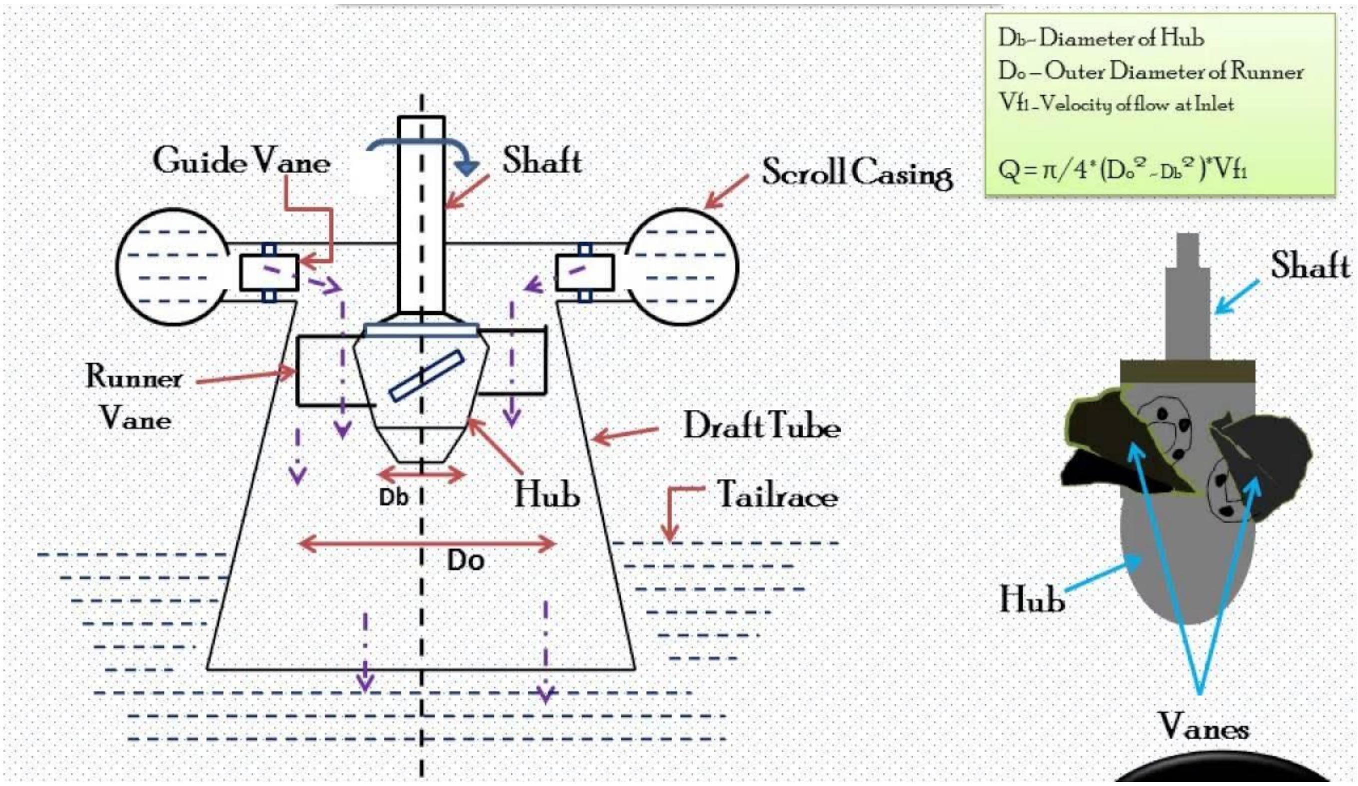
$$Q = \frac{\pi}{4}(D^2 - d^2)V_f$$

$$Q = \frac{\pi}{4}(D^2 - d^2)\Psi\sqrt{2gH}$$

$$Q = \frac{\pi}{4}D^2(1 - n^2)\Psi\sqrt{2gH}$$

Generally, the diameter ration “n” varies from 0.36 to 0.6 . The flow ratio Ψ has a value close to 0.70.

The blade speed u depends on the radius of the point under consideration and thus varies along the length of the blade. The blade angles thus vary continuously from the hub to the rim. The runner blades of a Kaplan turbine are thus warped or twisted.



KAPLAN TURBINE

SOURCE (INTERNET)

Lecture Notes

Centrifugal Pump

3.1 Introduction

Centrifugal pumps are a sub-class of dynamic axis symmetric work-absorbing turbo-machinery. Centrifugal pumps are used to transport fluids by the conversion of rotational kinetic energy to the hydrodynamic energy of the fluid flow. The rotational energy typically comes from an engine or electric motor. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from where it exits.

Common uses include water, sewage, petroleum and petrochemical pumping; a centrifugal fan is commonly used to implement a vacuum cleaner. The reverse function of the centrifugal pump is a water turbine converting potential energy of water pressure into mechanical rotational energy.

According to Reti, the first machine that could be characterized as a centrifugal pump was a mud lifting machine which appeared as early as 1475 in a treatise by the Italian Renaissance engineer Francesco di Giorgio Martini.[2] True centrifugal pumps were not developed until the late 17th century, when Denis Papin built one using straight vanes. The curved vane was introduced by British inventor John Appold in 1851.

The name of the pump ‘centrifugal’ is derived from the fact that discharge of the liquid from the rotating impeller is due to the centrifugal head created in it.

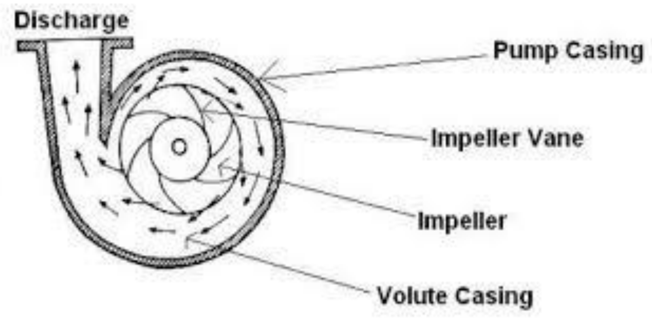
3.2 Classification

Centrifugal pump are divided in two category

1- Volute Pumps
2- Diffuser or Turbine Pumps

3.2.1 Volute Pump

The impeller is surrounded by a spiral casing, the outer boundary of which is a curve called Volute pump. The absolute velocity of the fluid leaving the impeller is reduced in the volute casing by passing the fluid through the gradually increasing cross-sectional area of the volutecasing, a part of its kinetic energy get converted into the pressure energy.

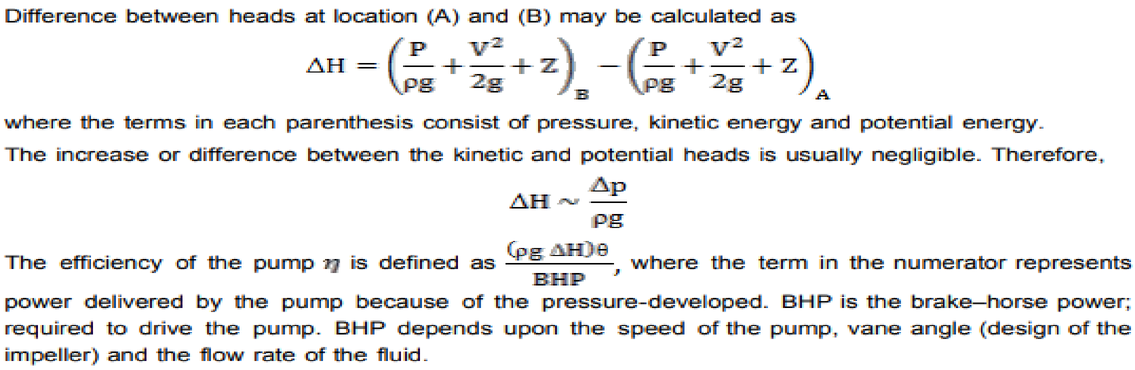


Source-Internet

3.2.2 Diffuser Type

The impeller is surrounded by a series of stationary guide vanes mounted on a diffuser ring. The guide vanes also known as diffuser vanes provide gradually enlarging passages so as to result in gradual reduction in velocity. Because of the superficial resemblance to a reaction turbine, this type of pump is obtained called a turbine pump. A diffuser pump is considered more efficient because of gradual reduction of velocity through guide vanes that results in less energy loss.

3.3 Efficiency Pump



Difference between heads at location (A) and (B) may be calculated as

$$\Delta H = \left(\frac{P}{\rho g} + \frac{V^2}{2g} + Z\right)_B - \left(\frac{P}{\rho g} + \frac{V^2}{2g} + Z\right)_A$$

where the terms in each parenthesis consist of pressure, kinetic energy and potential energy.

The increase or difference between the kinetic and potential heads is usually negligible. Therefore,

$$\Delta H \sim \frac{\Delta p}{\rho g}$$

The efficiency of the pump η is defined as $\frac{(\rho g\ \Delta H)\theta}{BHP}$, where the term in the numerator represents power delivered by the pump because of the pressure-developed. BHP is the brake–horse power; required to drive the pump. BHP depends upon the speed of the pump, vane angle (design of the impeller) and the flow rate of the fluid.

3.4 Net Positive – Suction Head (NPSH)

Defined as the net head developed at the suction port of the pump, in excess of the head due to the vapor pressure of the liquid at the temperature in the pump. NPSH must be positive for preventing the liquid from boiling. Boiling or cavitations may damage the pump.

$$\boxed{\mathrm{NPSH} = \left(\frac{P}{\rho g} + \frac{V^2}{2g} + z\right)_{\text{suction}} - \left(\frac{P_v}{\rho g}\right)}$$

where, P_v is the vapor–pressure of the liquid. If the pump is placed at a height 'z' above the free surface of a liquid where the atmosphere pressure is P_a, the NPSH may be evaluated by writing the Bernoulli's equation between the free surface and the suction port of the pump as

$$\boxed{\mathrm{NPSH} = \left(\frac{P_a}{\rho g} - z\right) - h_{fl} - \left(\frac{P_v}{\rho g}\right)}$$

where h_{fl} = frictional loss in the suction pipe between the liquid–surface and the pump.

Therefore, it is obvious that for NPSH to be positive or maximum, Z and h_{fl} should be minimum.

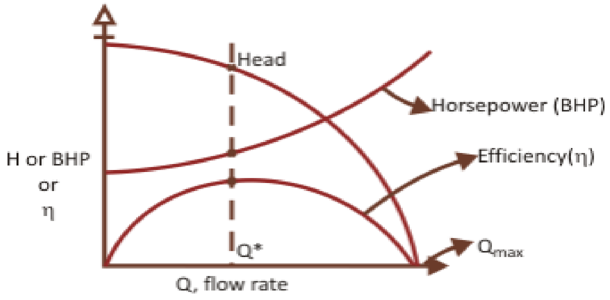
Most ideally, for maximum NPSH, $Z = h_{fl} = 0$ and $\boxed{\mathrm{NPSH} = \left(\frac{P_a - P_v}{\rho g}\right)}$

3.5 Performance Characteristics of a Pump

There are there performance characteristics of pump:

1. Head developed by the pump (H)
2. Brake horse power (BHP)
3. Efficiency of the pump (η)

-all plotted against the flow rate.

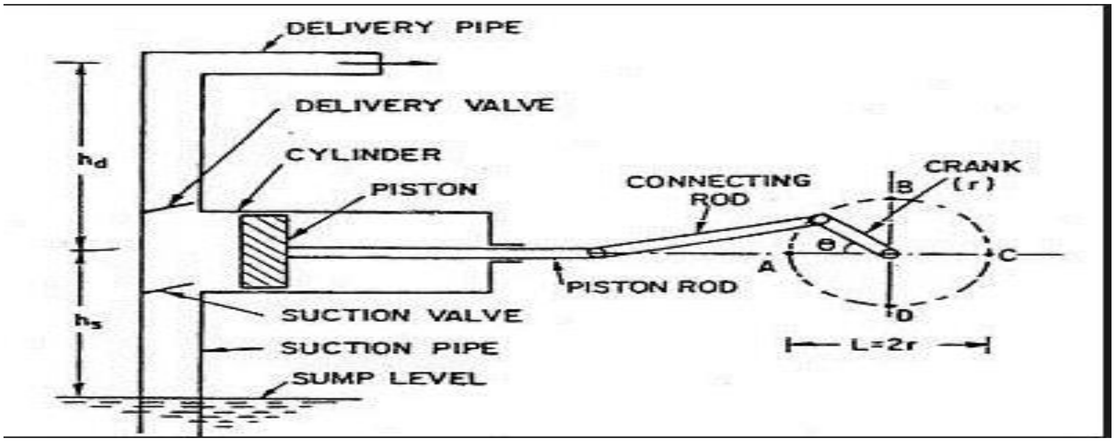


Lecture Notes

Reciprocating Pump

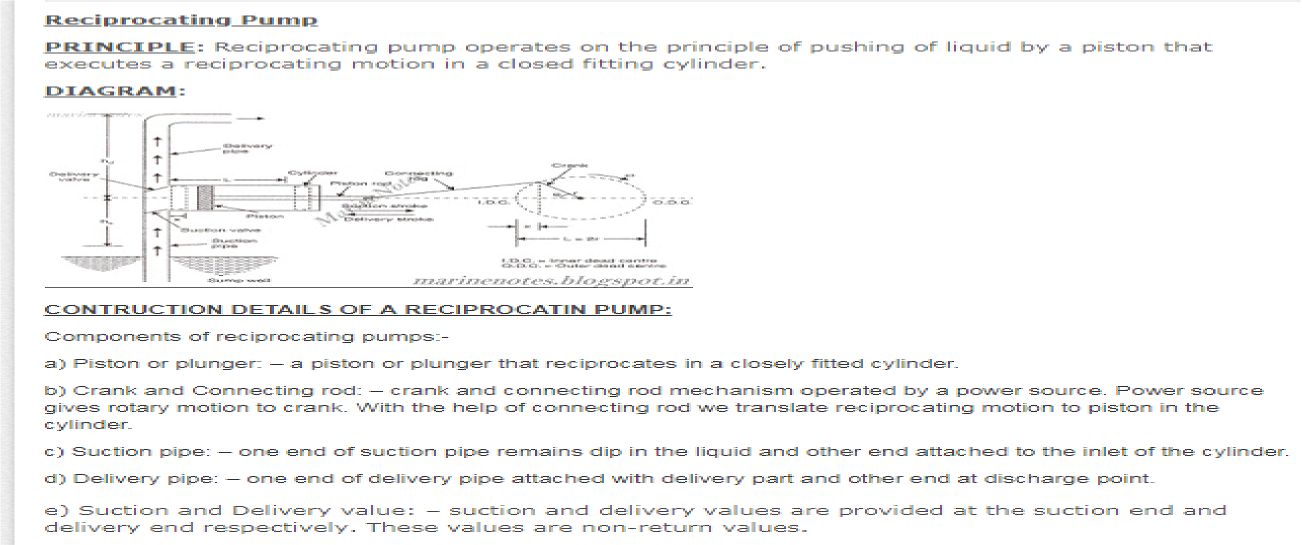
4.1 Introduction

A reciprocating pump is a class of positive-displacement pumps which includes the piston pump, plunger pump and diaphragm pump. When well maintained, reciprocating pumps will last for years or even decades; however, left untouched, they can undergo rigorous wear and tear.[1] It is often used where a relatively small quantity of liquid is to be handled and where delivery pressure is quite large. In reciprocating pumps, the chamber in which the liquid is trapped, is a stationary cylinder that contains the piston or plunger.



(Line Diagram Of Single Acting Reciprocating Pump)

4.2 Working Principle of Reciprocating Pump



Reciprocating Pump

PRINCIPLE: Reciprocating pump operates on the principle of pushing of liquid by a piston that executes a reciprocating motion in a closed fitting cylinder.

DIAGRAM:

CONTRUCTION DETAILS OF A RECIPROCATIN PUMP:

Components of reciprocating pumps:-

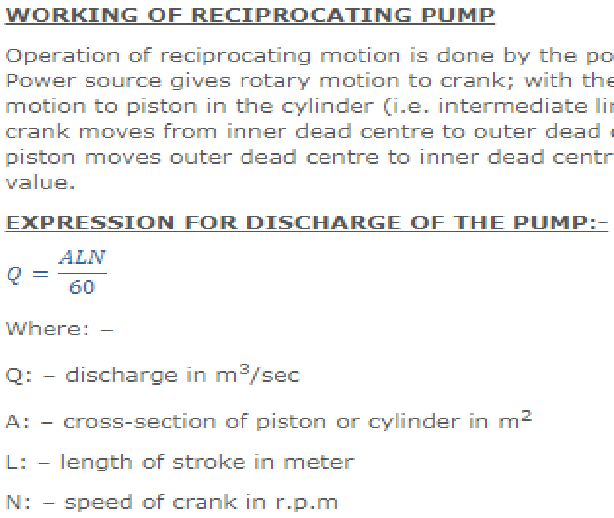
a) Piston or plunger: — a piston or plunger that reciprocates in a closely fitted cylinder.

b) Crank and Connecting rod: — crank and connecting rod mechanism operated by a power source. Power source gives rotary motion to crank. With the help of connecting rod we translate reciprocating motion to piston in the cylinder.

c) Suction pipe: — one end of suction pipe remains dip in the liquid and other end attached to the inlet of the cylinder.

d) Delivery pipe: — one end of delivery pipe attached with delivery part and other end at discharge point.

e) Suction and Delivery value: — suction and delivery values are provided at the suction end and delivery end respectively. These values are non-return values.



WORKING OF RECIPROCATING PUMP

Operation of reciprocating motion is done by the power source (i.e. electric motor or i.c engine, etc). Power source gives rotary motion to crank; with the help of connecting rod we translate reciprocating motion to piston in the cylinder (i.e. intermediate link between connecting rod and piston). When crank moves from inner dead centre to outer dead centre vacuum will create in the cylinder. When piston moves outer dead centre to inner dead centre and piston force the water at outlet or delivery value.

EXPRESSION FOR DISCHARGE OF THE PUMP:-

$$Q = \frac{ALN}{60}$$

Where: –

Q: – discharge in m^3/sec

A: – cross-section of piston or cylinder in m^2

L: – length of stroke in meter

N: – speed of crank in r.p.m

4.3 Slip of pump

Capacity is the total liquid displacement of the pump less slip. Slip is the quantity of fluid that leaks from the higher-pressure discharge to the lower-pressure suction. Slip occurs because all rotary pumps require clearances between the rotating elements and pump housing.

4.4 Effect of Acceleration

Flow from a piston or diaphragm pump is not linear- it accelerates at the start of the pump stroke, reaches maximum velocity at the mid point, and decelerates to zero flow at the end of the stroke.

While the flow is accelerating and decelerating, the fluid pressure at the pump's discharge is increasing and decreasing.

References

Text Book:

1. Fluid Mechanics by A.K. Jain, Khanna Publishers

Reference Book:

1. Fluid Mechanics and Hydraulic Machines, Modi & Seth, Standard Pulishers

2. Introduction to Fluid Mechanics and Fluid Machines, S.K. Som & G. Biswas,