# LABORATORY MANUAL FOR **Hydraulic Engineering**

Subject Code: **CEP 1402**

DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
MIZORAM

# LIST OF EXPERIMENTS

## EXPERIMENT NO. 01

**Determination of Manning's Rugosity coefficient and Chezy's constant for uniform flow**

**AIM:** To determine the Manning's rugosity coefficient and Chezy's constant in an open channel under uniform flow condition.

**THEORY:** An open channel flow is a conduit in which water flows with a free surface open to the atmosphere. Examples include streams, rivers and culverts not flowing full. The channels are generally built with a small slope such that water flows under gravity from one point to another. Since the free surface is at atmospheric pressure, the only pressure variation is hydrostatic and the driving force for open channel flows is gravity. Open channel flow assumes that the pressure at the surface is constant and the hydraulic grade line is at the surface of the fluid. The counter acting force on the water flow is the frictional force, which depends upon the area of the wetted surface and the flow velocity. That is, the head available due to the slope of the channel is lost in overcoming the frictional resistance.

**APPARATUS:**

Open channel with measuring devices, linear scale to measure the dimensions, pointer gauge to measure flow depth of the channel, centrifugal pump and motor for steady supply of water, piezometer to measure water rise of the collecting tank, stop watch to measure the time of collection of discharge for known rise of water level in the collecting tank, measuring tank with control valve to collect the water.

**EXPERIMENTALSETUP:**

**Fig. 1.** Tilting Flume Apparatus

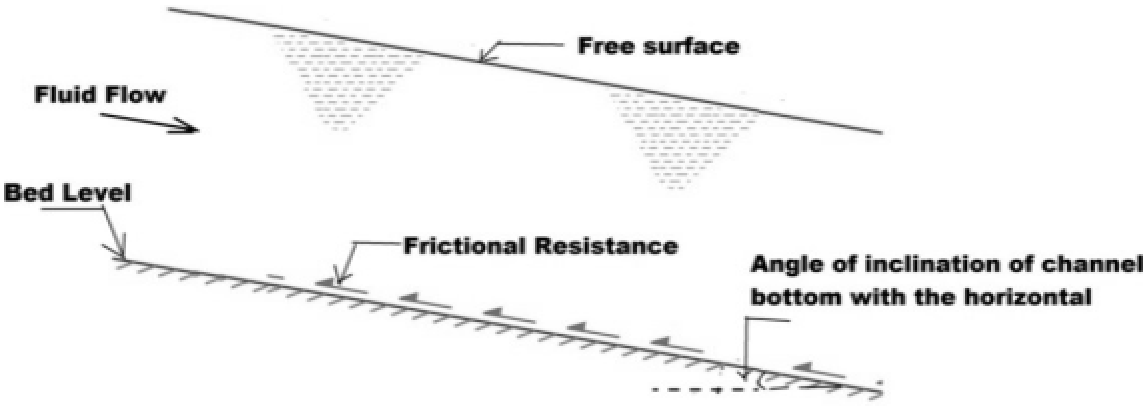



**Fig. 2.** Steady Uniform Flow in an Open Channel

**FORMULA:**

As per Chezy's formula,

$$V = C\sqrt{RS}$$

Hence, Chezy's constant, C is given by: $C = V/\sqrt{RS}$

As per Manning's Formula:

$$V = \frac{1}{n} \times R^{2/3} \times S^{1/2}$$

Hence, Manning's rugosity coefficient, $n$ is given by: $n = \frac{1}{V} \times R^{2/3} \times S^{1/2}$

**PROCEDURE:**

1. Remove all the models in the channel and lift both the upstream and downstream gates such that there is no obstruction to the flow.
2. Raise (or lower) the flume body by rotating the screw rod handles slope. The slope-scale arrangement on the flume and support stand directly indicates the slope.
3. Using the pointer gauge note the bottom surface level channel such that a steady flow is achieved.
4. Using the pointer gauge, measure the water level in the channel. From the earlier measured bottom level, calculate the depth of the water flow.
5. Note: As the water flow will be slightly disturbed at the inlet region, best results can be obtained by measuring the water level closer to the outlet where the water flow will be steadier.

6. Measure the actual flow rate with the collecting tank.

**OBSERVATIONS:**

Let, $h_1$ = Pointer gauge reading at bed level

$h_2$ = Pointer gauge reading at water surface

$H$ = Depth of water level

$Q$ = Actual discharge

$A$ = Area of water flow

$V$ = Velocity of flow

$R$ = Hydraulic mean depth

$C$ = Chezy's constant

$n$ = Manning's rugosity coefficient

| **Sl No.** | $h_1$ **(m)** | $h_2$ **(m)** | $H = h_2 - h_1$ **(m)** | $Q = \frac{A \times R}{t}$ **(m³/s)** | **A** $= B \times H$ **(m²)** | $V = \frac{Q}{B \times H}$ **(m/s)** | $R = \frac{B \times H}{B + 2H}$ | **C** $= V/\sqrt{RS}$ | $n = \frac{1}{V} \times R^{2/3} \times S^{1/2}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | |
| 2 | | | | | | | | | |
| 3 | | | | | | | | | |

**CALCULATION:**

1. Area of collecting tank $A$ = …… $m^2$

   Rise in water level $R$ = 0.1 m (say)

   Time taken for rise in water level for $R$ m ($t$) = ……. sec

   Actual discharge, $Q = \frac{A \times R}{t}$ $m^3/s$

2. Slope of the channel = $S$

   Pointer gauge reading at bed level ($h_1$) = …… m

   Pointer gauge reading at water surface ($h_2$) = …… m

   Depth of water level ($H$) = $h_2$-$h_1$ = …… m

   Width of channel ($B$) = …… m

Area of flow $(A) = B \times H$ = ……. $m^2$

Velocity of flow $(V) = \frac{Q}{B \times H}$ = …….. m/sec

Hydraulic mean radius $(R) = \frac{B \times H}{B + 2H}$ = ……. m

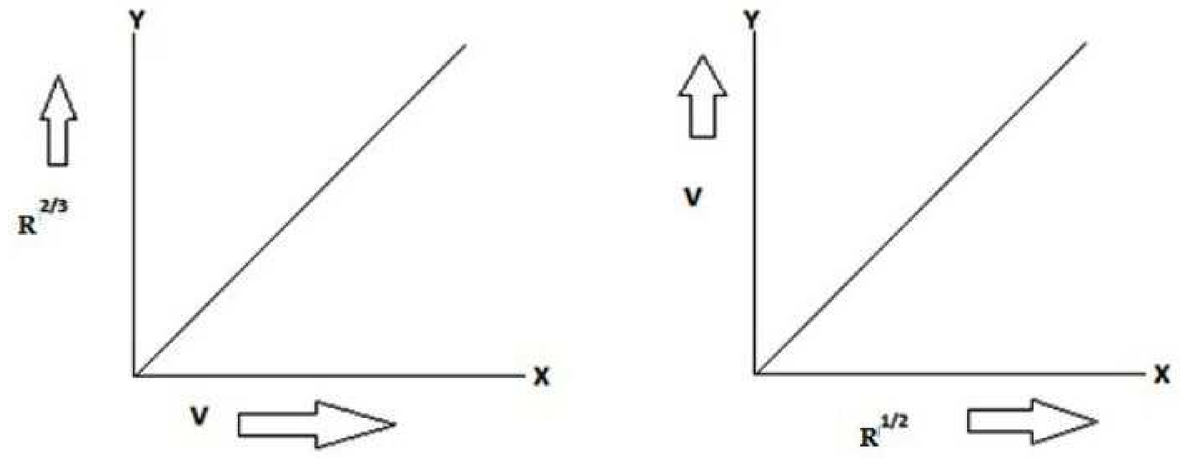
As per Chezy's formula, $V = C\sqrt{RS}$

Hence, Chezy's constant, $C$ is given by: $C = V/\sqrt{RS}$

As per Manning's Formula: $V = \frac{1}{n} \times R^{2/3} \times S^{1/2}$

Hence, Manning's rugosity coefficient, $n$ is given by: $n = \frac{1}{V} \times R^{2/3} \times S^{1/2}$

**NATURE OF GRAPH:**




**RESULT AND CONCLUSIONS:**

**PRECAUTIONS:**

1. Ensure the priming condition of the pump during experimentation.
2. Maintain proper earthing of electrical connections
3. Check the gate valves frequently to avoid leakages.
4. Reading errors may occur at gauge and volumetric piezometric scale by not recording the readings at the eye level.

5. Synchronize the stopwatch operations for volumetric measurements.
6. Operate the equipment under the supervision of laboratory technical staff.
7. In case of emergency, contact the laboratory technical staff.

**QUESTIONS:**

1. What is the difference between pipe flow and open channel flow?
2. What is open channel flow and give examples?
3. What are the different types of open channel flow?
4. What are the characteristics of uniform flow?
5. Differentiate between uniform flow and non-uniform flow in open channel?
6. List out the factors affecting Manning's coefficient.

## EXPERIMENT NO. 02

## Determination of Energy loss in Hydraulic jump

**AIM:** To determine the conjugate depths and loss of specific energy in a hydraulic jump for given slope.

**THEORY:** A hydraulic jump is a phenomenon in the science of hydraulics, frequently observed in open channel flow. The hydraulic jump occurs in open-channel flow when the flow changes from supercritical to subcritical, typically as a result of imposed downstream conditions. When liquid at high velocity discharges into a zone of lower velocity, a rather abrupt rise (a step or standing wave) occurs in the liquid surface. The rapidly flowing liquid expands (which in an open channel appears as an increase in elevation), converting some of the initial kinetic energy of flow into a lower kinetic energy, an increased potential energy and the remainder to irreversible losses (turbulence which ultimately converts the energy to heat). The phenomenon is dependent upon the initial fluid speed. If the initial fluid speed is below the critical speed then no jump is possible. For relatively low initial flow speeds above the critical speed an undulating wave appears. As the flow speed increases further the transition grows more abrupt, and at high enough speeds the front will break and curl back upon itself. This rise can be accompanied by violent turbulence, eddying, air entrainment, and surface undulations.

**APPARATUS:**

Open channel with measuring devices, liner scale to measure the dimensions, pointer gauge to measure flow depth of the channel, centrifugal pump and motor for steady supply of water, piezometer to measure water rise of the collecting tank, stop watch to measure the time of collection of discharge for known rise of water level in the collecting tank, measuring tank with control valve to collect the water.

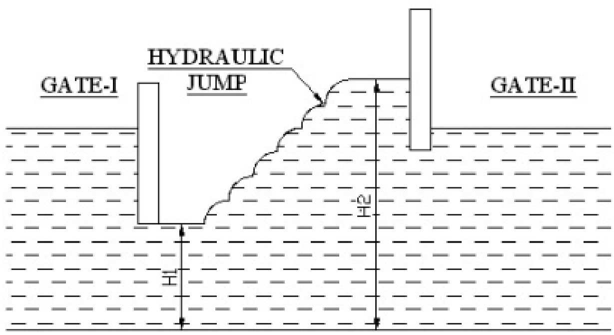



**Fig. 3. Hydraulic jump phenomena**

**Formulas**

Velocity before the jump, $V_1 = \frac{Q}{B \times H_1}$

Actual depth after the jump = $H_2$

Froude Number, $F_{r1} = \frac{V_1}{\sqrt{gH_1}}$

Energy before jump, $E_1 = H_1 + {V_1^2}/{2g}$

Theoretical value: $H_{2t} = \left(\frac{H_1}{2}\right)\left(-1 + \sqrt{1 + 8F_{r1}^2}\right)$

Energy after jump, $E_2 = H_2 + {V_2^2}/{2g}$

Loss of energy, $E_1 - E_2 = (H_1 - H_2) + {(V_1^2 - V_2^2)}/{2g}$

**PROCEDURE:**

1. Set the channel for a given slope.
2. Remove all the models.
3. Close both the inlet (I) and outlet (II) gates.
4. Allow water in the channel.
5. Open the gate II completely.
6. Open the gate I slightly, so that water flows under the gate in supercritical (shooting) condition.
7. Close the gate II gently, so that it causes obstruction to the shooting flow, and a Hydraulic Jump is formed.
8. Regulate the gate I finely that the Hydraulic jump stays at the middle of the channel.
9. With the help of traveling hook gauge measure the conjugate depths of the flow before and after the Hydraulic Jump, H1 and H2.
10. Measure the actual flow rate with the collecting tank.

## OBSERVATIONS:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Length of jump = 5 × $H_j$ | | | | | | | |
| Height of jump $Hj = (H_1\text{-}H_2)$ | | | | | | | |
| Computation of $F_{r1}$ and $H_{2t}$ (theoretical) | | $H_{2t} = \frac{H_1}{2}\left[-1+\sqrt{1+8Fr_1^2}\right]$ | | | | | |
| | | $F_{r1} = \frac{V_1}{\sqrt{gH_1}}$ | | | | | |
| Computation of energy loss (ΔE) | | $\Delta E = E_1 - E_2$ | | | | | |
| | | $E_2 = H_2 + V_2^2/2g$ in m | | | | | |
| | | $E_1 = H_1 + V_1^2/2g$ in m | | | | | |
| | | Velocity after the jump $V_2 = \frac{Q}{B \times H_2}$ m/s | | | | | |
| | | Velocity before the jump $V_1 = \frac{Q}{B \times H_1}$ m/s | | | | | |
| Computation of Actual Discharge | | Actual discharge $Q_{act} = \frac{AR}{T}$ $m^3/s$ | | | | | |
| | | Time taken for rise of *R* m rise (sec) | | | | | |
| | | Rise in water level (R) in m | | | | | |
| | Hook Gauge Reading | Depth of water after jump $H_2$ (m) | | | | | |
| | | Depth of water before jump $H_1$ (m) | | | | | |
| Sl No. | | | 1 | 2 | 3 | 4 | 5 |

**CALCULATION:**

1. Area of collecting tank $A$ = …… m$^2$

   Rise in water level $R$ = 0.1 m (say)

   Time taken ($t$) = ……. sec

   Actual discharge, $Q_{act} = \frac{AR}{t}$ m$^3$/s

2. Width of the channel $B$ = …… m

   Velocity before the jump, $V_1 = \frac{Q}{B \times H_1}$

   Froude number, $F_{r1} = \frac{V_1}{\sqrt{gH_1}}$

3. Theoretical value:

   $$H_{2t} = \left(\frac{H_1}{2}\right)\left(-1 + \sqrt{1 + 8F_{r1}^2}\right)$$

   Actual depth after the jump = $H_2$

   Find the theoretical $H_{2t}$ for different $H_1$ and compare with actual $H_2$.

   Energy before jump, $E_1 = H_1 + V_1^2/2g$

   Energy after jump, $E_2 = H_2 + V_2^2/2g$

   Loss of energy, $E_1 - E_2 = (H_1 - H_2) + (V_1^2 - V_2^2)/2g$

**RESULT AND CONCLUSIONS:**

**PRECAUTIONS:**

1. Ensure the priming condition of the pump during experimentation.
2. Maintain proper earthing of electrical connections
3. Check the gate valves frequently to avoid leakages.
4. Reading errors may occur at gauge and volumetric piezometric scale by not recording the readings at the eye level.
5. Synchronize the stopwatch operations for volumetric measurements.

6. Operate the equipment under the supervision of laboratory technical staff.
7. In case of emergency, contact the laboratory technical staff.

**QUESTIONS:**

1. What is hydraulic jump and give examples?
2. What are the main causes of hydraulic jump?
3. What type of flow is hydraulic jump?
4. How do you calculate hydraulic jump?
5. What is the length of hydraulic jump?
6. Is hydraulic jump a steady flow? Justify.
7. What are the applications of hydraulic jump?

## EXPERIMENT NO. 03

### Determination of Velocity distributions in open channels

**AIM:** To study the velocity distribution in an open channel and to determine the energy and momentum correction factors.

**THEORY:** The velocity of flow at any channel section is not uniformly distributed. This is due to the presence of free surface and the frictional resistance offered to free flow of water by the boundary of the channel. The velocity distribution curve is required for the study of many open channel flow problems such as computation of discharge, mean velocity, Manning's coefficient *n*, energy correction factor α, and the momentum correction factor β.

The velocity at any point is generally measured with a pitot-static tube or a velocity meter, and is given by:

$$V = C\sqrt{2gl\sin\theta\left(\frac{\rho_m}{\rho_w}-1\right)}$$

where,

C is the coefficient of the pitot-static tube (=1.0)

$l$ is the deflection of the manometer

$\theta$ is the inclination of the manometer tubes.

$\rho_m$ and $\rho_w$ are the densities of the manometer liquid and water, respectively.

The discharge $Q$ can be computed from the velocity distribution curve as:

$$Q = \int vdA = B\int vdy$$

where, $B$ is the width of the flow.

Thus discharge can be computed as:

$$Q = B\sum vdy = B\times(\text{the area of the velocity diagram})$$

The mean velocity $V$ can be computed as:

$$V = \frac{Q}{A} = \frac{B\sum v\Delta y}{B\times Y} = \frac{(\text{Area of velocity diagram})}{Y}$$

where, $Y$ = depth of flow

From the Manning's formula, the velocity can be expressed as:

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

where,

$n$ is the Manning's coefficient

$R$ = Hydraulic radius

$S$ = bed slope

The kinetic energy correction factor ( $\alpha$ ) is given by:

$$\alpha = \frac{\int v^3 dA}{v^3 A} = \frac{\sum v^3 dY}{v^3 Y} = \frac{\text{Area of } v^3 \text{ diagram}}{v^3 Y}$$

The momentum correction factor (β) is given by

$$\beta = \frac{\int v^2 dA}{v^2 A} = \frac{\sum v^2 dY}{v^2 Y} = \frac{\text{Area of } v^2 \text{ diagram}}{v^2 Y}$$

**APPARATUS:** Rectangular tilting flume, Water tank, Collecting tank, Stop watch

**EXPERIMENTAL SETUP**

The set-up consists of a rectangular tilting flume. The water is supplied from an overhead water tank through a 100 mm diameter pipe. Gates with rack and pinion arrangement are provided at the inlet and exit sections for controlling the flow. The inlet portion of the flume is provided with the baffle walls (or honey comb walls) to calm the flow. The flume is provided with rails on top of the side walls on which a trolley can move to and fro. The pitot-static tube (if provided) and the pointer gauge are provided on the trolley. The flume can be tilted with a screw jack provided for this purpose to give the required slope. For the measurement of discharge, a large collecting tank is provided at the downstream end of the flume.

**PROCEDURE:**

1. Measure the width of the flume.

2. Take the pointer gauge at the water surface to determine the depth of flow (Y).
3. The width of the flume is divided into segments of equal width (b) for the measurement of velocity. Because of symmetry the measurements may be taken only on the segments on one side of the centre line.
4. Bring the pitot-static tube trolley (or place the current meter) over the center line of the segment no.1. Take the manometer reading (l) (or velocity meter readings) and the pointer gauge readings at 8 to 10 points between the bed and water surface.
5. Shift the trolley to the centre of the other segments, one by one, and repeat step 4.
6. Measure the discharge by noting the water level rise in a collecting tank, and recording the area of collecting tank and time taken for the level rise.
7. Repeat steps 2 to 6 for different discharges.

**OBSERVATION**

Inclination of manometer attached to the pitot-static tube (θ) = …….

Pointer Gauge reading when the point touches the bed ($G_0$) = …….

Diameter of the pitot-static tube, (d) = ……. m

Width of the flume, (B) = ……. m

No. of segments, = …….

Width of each segment, (b) = ……. m

**Discharge measurement:**

Area of collecting tank: …….. $m^2$

| **Sl No.** | **Water levels of collecting tank** | | **Difference, $h = h_2 - h_1$ (m)** | **Volume, V = A×h** | **Time reqd. to raise water level from $h_1$ to $h_2$ . $t$ (sec)** | **Q= V/t ($m^3/s$)** |
|---|---|---|---|---|---|---|
| | **Initial, $h_1$ (m)** | **Final, $h_2$ (m)** | | | | |
| **1** | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **2** | | | | | | |
| **3** | | | | | | |
| **Average Q ($m^3/s$)** | | | | | | |

**Depth of flow:**

Pointer Gauge at the water surface (G) =

Depth of flow, $Y = G - G_0 =$

**Velocity measurement:**

| **Sl No.** | **Gauge reading (G)** | **Depth, y** | **Velocity** | | | |
|---|---|---|---|---|---|---|
| | | | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |

**Graphs to plot:**

a) Plot v vs y curve for each segment.
b) Plot $v^2$ vs y curve for each segment.
c) Plot $v^3$ vs y curve for each segment.

Compute mean velocity, V = (area of v-y plot)/Y

V1 = , V2 = , V3 = , V4 = , Average V =

Compute momentum correction factor, ( $\beta$ ) = (area of $v^2$-y plot)/ Y

$\beta_1 =$ , $\beta_2 =$ , $\beta_3 =$ , $\beta_4 =$ , Average $\beta =$

Compute energy correction factor, $\alpha$ = (area of $v^3$-y plot)/Y

$\alpha_1 =$ , $\alpha_2 =$ , $\alpha_3 =$ , $\alpha_4 =$ , Average $\alpha =$

Discharge Q = B×Y×V

Compare this discharge with the measured discharge.

**Manning's n:**

$$n_1 = \frac{R_1^{2/3} S^{1/2}}{V_1} = \quad , n_2 = \frac{R_2^{2/3} S^{1/2}}{V_2} = \quad , n_3 = \frac{R_3^{2/3} S^{1/2}}{V_3} = \quad , n_4 = \frac{R_4^{2/3} S^{1/2}}{V_4} =$$

Average, $n = \frac{n_1 + n_2 + n_3 + n_4}{4}$ , Alternatively, average $n = \frac{R^{2/3} S^{1/2}}{V}$

**RESULTS:**

Average value of $\alpha$ =

Average value of $\beta$ =

Average value of n =

**PRECAUTIONS:**

**QUESTIONS:**

1. What are the factors affecting factors affecting velocity distribution in open channel flow?
2. Show the velocity distribution profile in open channel flow.
3. At what position, the velocity of water is found to be maximum?
4. What is the effect of the roughness of the channel on the velocity distribution of the water?
5. What is the effect of the slope of channel bed on the velocity distribution of the water?

## EXPERIMENT NO. 04

## Computation of pressure drag coefficient for flow past a cylinder in a subsonic wind tunnel

**AIM:** To determine the pressure drag coefficient for flow past a cylinder in a subsonic wind tunnel.

**THEORY:** The flow past a two-dimensional cylinder is one of the most studied of aerodynamics. It is relevant to many engineering applications. The flow pattern and the drag on a cylinder are functions of the Reynolds number $R_D = U_\infty D/\nu$ based on the cylinder diameter $D$ and the undisturbed free-stream velocity $U_\infty$. It may be recalled that the Reynolds number represents the ratio of inertial to viscous forces in the flow. The drag is usually expressed as a coefficient $C_d = d/\left(0.5\rho U_\infty^2 D\right)$, where $d$ is the drag force per unit span.

The flow pattern at high Reynolds numbers ($R_D > 10000$) is sketched in Figs. 4(a) and 4(b). At the leading edge of the cylinder a stagnation point is formed where the oncoming flow is brought to rest. The pressure here is equal to the stagnation pressure. The pressure coefficient, $C_p$ can be expressed as:

$$C_p = \frac{(p_i - p_s)}{q} = \frac{\Delta h_i}{q}$$

where, $p_i$ = Static pressure values measured around cylinder

$p_s$ = Tunnel static pressure

$\Delta h_i$ = manometer differential column height with respect to tunnel static

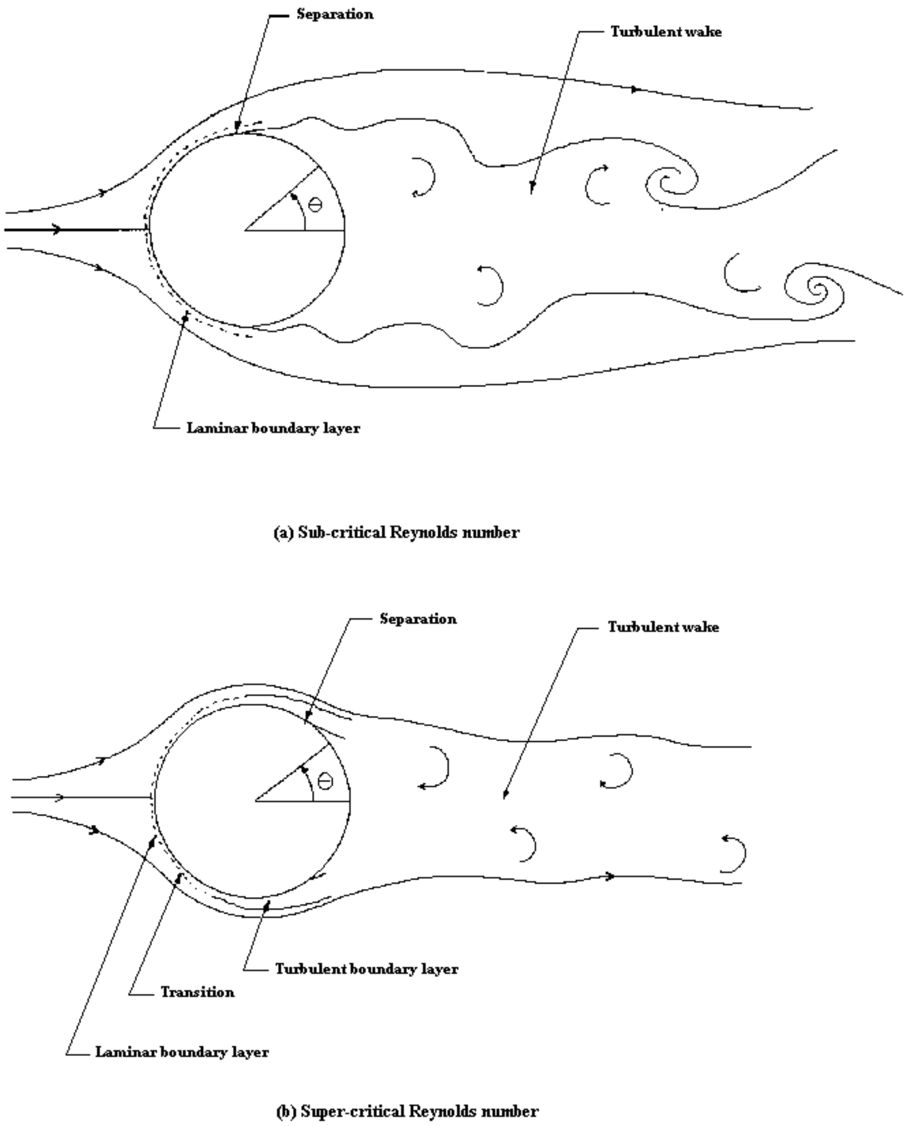



**Fig. 4.** Basic features of the flow past a circular cylinder.

On the other hand, the theoretical value of the pressure coefficient is given by the expression as follows:

$$C_p = 1 - 4\sin^2\theta$$

where, $\theta$ = angle measured from the back of the cylinder as shown in Fig. 5.

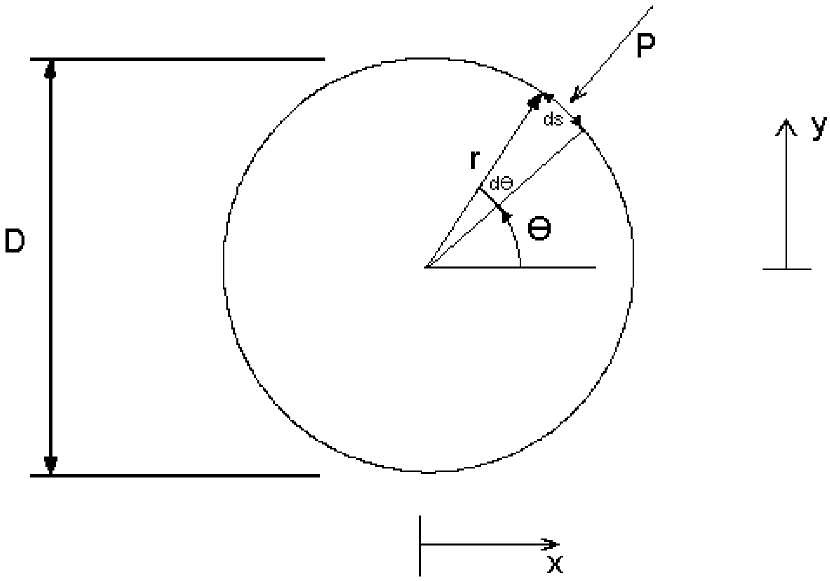



**Fig. 5.** Definition of symbols for calculation of drag.

To either side of the stagnation point the flow accelerates around the forward surface of the cylinder producing a drop in the pressure. Immediately adjacent to the cylinder surface a thin boundary layer is formed. The boundary layer is a region where the velocity drops rapidly to zero to satisfy the no slip condition at the cylinder surface. The direct effects of viscosity are felt only within the boundary layer.

The drag on a real cylinder is, of course, not zero and can be estimated from a measured pressure distribution as follows. Consider an element of the cylinder surface of length $ds = rd\theta$ as shown in Fig. 5. The force per unit span on the element due to a pressure normal to the element is

$$df = pds = prd\theta$$

The drag component of this force is the component acting in the direction of the free-stream velocity is $-prd\theta\cos\theta$. The integral of this around the cylinder circumference gives the total drag on the cylinder per unit span *d*.

$$d = -\int_0^{2\pi} pr\cos\theta d\theta$$

Putting the value of *d* in the expression for $C_d$ and $C_p$, we get,

$$C_d = -\int_0^{2\pi} \frac{pr\cos\theta d\theta}{\left(0.5\rho U_\infty^2 D\right)} = -\int_0^{2\pi} \frac{\cos\theta}{2}\left[C_p + \frac{p_\infty}{\left(0.5\rho U_\infty^2 D\right)}\right] d\theta$$

$$\text{or } C_d = -\frac{1}{2}\int_0^{2\pi} C_p \cos\theta d\theta - \frac{1}{2}\frac{p_\infty}{\left(0.5\rho U_\infty^2 D\right)}\int_0^{2\pi} \cos\theta d\theta$$

the second integral is zero, giving,

$$C_d = -\frac{1}{2}\int_0^{2\pi} C_p \cos\theta d\theta$$

This integration can be done numerically using Simpson's or the trapezium rule or by plotting $C_p \cos\theta$ vs $\theta$ and measuring the area under the curve. Note that $\theta$ is measured in radians. The above estimate of $C_d$ takes account only of the pressure drag on the cylinder. In calculating this, however, it is fairly accurate, the main source of error probably being the numerical integration.

**APPARATUS:** Low speed wind tunnel, Multi tube manometer, Cylinder model with pressure tapings and with support mount, Pitot - static tube

**EXPERIMENTAL SETUP**

The wind tunnel motor RPM is set remotely by a DC power supply (as shown in Fig. 6). The freestream velocity is calculated from the pressure acquired inside a settling chamber of the wind tunnel. The settling chamber pressure (where velocity is close to zero) is close to the stagnation pressure of the flow in the test section, and therefore can be calibrated by applying Bernoulli's equation between the settling chamber and the room, and using the known contraction ratio of 5.5:1. Flow speed in the test section can also be monitored directly using a 3-mm diameter Pitot-static probe (Fig. 6). To get the freestream velocity with the probe, it is needed to ensure it is placed towards the upstream end of the test section and away from the cylinder and edges of the jet where it is assumed to be unaffected by the presence of a model. Note that placing a large model in the test section may artificially increase the velocity sensed by the probe. All pressure systems are connected to the pressure scanner for data recording and described below.

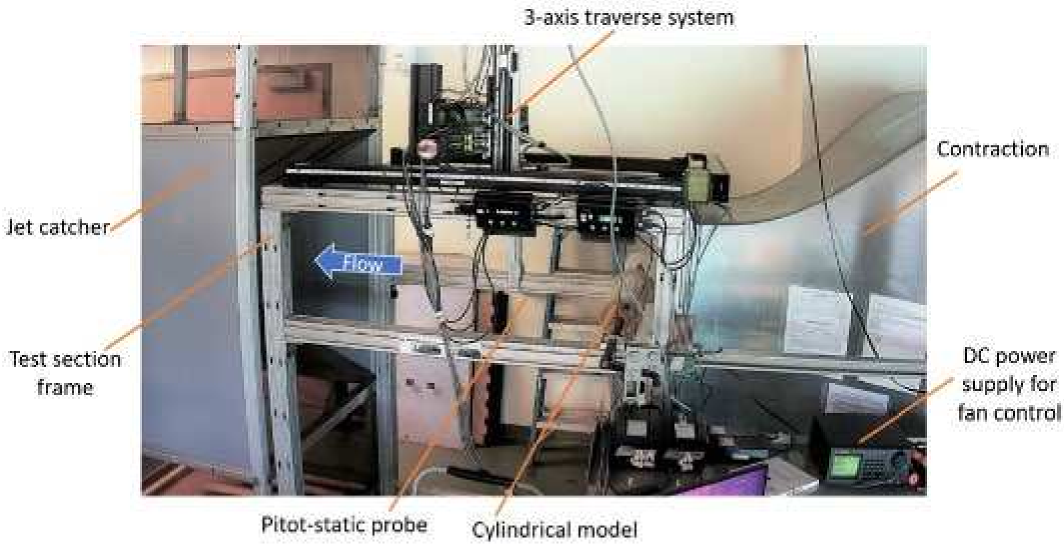



**Fig. 6.** The open-jet wind tunnel default experimental setup.

A Pitot-static probe is perhaps the simplest device for measuring flow-velocity at a point. A Pitot probe measures stagnation pressure (the pressure produced by bring the flow to a halt). It consists of a tube connected at one end to a pressure sensing device (such as a manometer or pressure transducer) and open at the other. Stagnation pressure is measured by pointing the open end of the tube towards the oncoming flow. A static probe measures static pressure (the actual pressure in the flow). It consists of an opening (or 'pressure tap') parallel to the local flow direction. The pressure tap may be located in a tube or in the surface of a model.

A Pitot-static probe is a combination of a Pitot tube and static tube. Given the flow density a Pitot-static probe can thus be used to measure velocity. The principle sources of error in velocity measurements made with a Pitot-static probe are misalignment and turbulence. Since the local direction of the flow around a model is not know in advance it is usual to make measurements are made with the Pitot-static probe pointing in the direction of the oncoming free stream. Some misalignment of the Pitot-static probe may therefore occur. Errors become substantial for angles greater than about 30º.

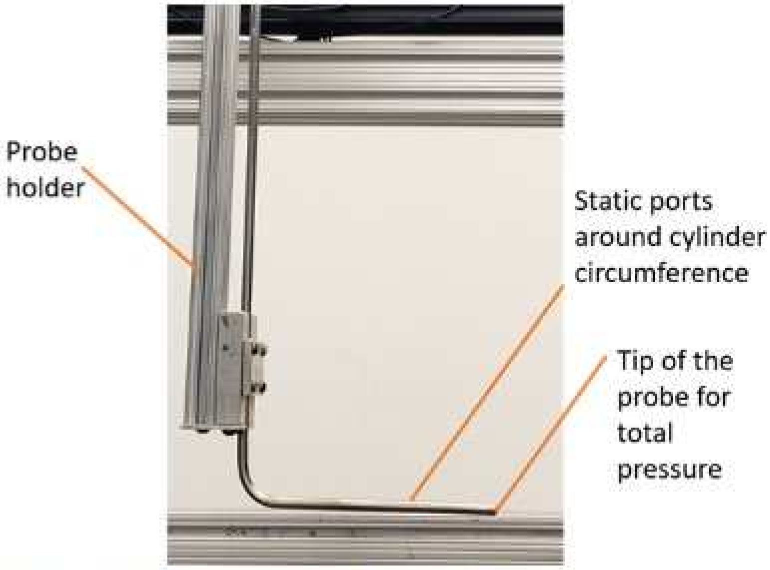



**Fig. 7.** Pitot-Static probe for velocity measurements.

**PROCEDURE:**

1. Assemble the cylinder with pressure tapings in the test section with the help of support. Connect the pressure tapping to manometer.
2. Rotate the cylinder such that the static holes form the upper or lower surface of the cylinder.
3. Ensure the tunnel for any loose components and start the tunnel.
4. Run the tunnel at various desired speeds and note down the manometer reading which measures the surface pressure distribution of the cylinder.
5. Also note down the Pitot-Static tubes manometer reading.
6. Since the cylinder is axially symmetric the pressure distribution is measured for half the surface and the same trend follows for another half portion.
7. Gradually shut down the tunnel.

**OBSERVATION:**

$$\frac{2(p_t - p_s)}{\rho} = V_\infty^2 \Rightarrow V_\infty = 129.7\sqrt{\Delta h} = \ldots\ldots$$

$$q = \frac{1}{2}\rho V_\infty^2$$

Experimental pressure coefficient, $C_{p,exp} = \frac{\Delta h}{q}$

Experimental pressure drag coefficient, $C_{d,exp} = C_{p,exp} \cos\theta d\theta$

Velocity: ……

Static Pressure, $P_s$ (reading on 34th port): ……

| **Pressure tappings** | $P_i$ | **$C_p$ Experimental** $C_p = \frac{\Delta h_i}{q}$ | **$C_p$ Theoretical** $C_p = 1 - 4\sin^2\theta$ | $\theta$ **(radian)** | **Interval between Ports** $d\theta$ | **Experimental Pressure drag** |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| $C_d = \sum C_p \cos\theta d\theta$ | | | | | | |

**Graphs to plot:**

$C_p$ Vs $\theta$ theoretical and compare with experimental values

**RESULTS AND DISCUSSION:**

1. Thus the pressure distribution around the cylinder is measured and the drag of the cylinder is estimated.
2. The coefficient of drag of cylinder, $C_d$ =

**PRECAUTIONS:**

**QUESTIONS:**

1. What is Bernoulli's principle and equation?
2. Define drag and list the different types of drag.
3. Define aerodynamic center, center of pressure, center of gravity and coefficient of pressure.
4. Draw the pressure distribution over an airfoil.
5. What is the basic purpose of wind tunnel testing?
6. Sketch the pressure distribution round a circular cylinder in ideal flow and in real flow.

## EXPERIMENT NO. 05

### Performance Characteristics of single stage centrifugal pump

**AIM:** To determine the efficiency and study the performance characteristics of a single stage Centrifugal Pump.

**THEORY:** In general a pump may be defined as a mechanical device which, when interposed in a pipe line, converts the mechanical energy supplied to it from some external source into hydraulic energy, thus resulting in the flow of liquid from lower potential to higher potential.

The pumps are of major concern to most engineers and technicians. The types of pump vary in principle and design. The selection of the pump for any particular applications is to be done by understanding their characteristics. The most commonly used pumps for domestic, agriculture and industries are; centrifugal, piston, axial flow (stage pumps), air jet, diaphragm and turbine pumps. Most of these pumps fall into the main class, namely; Rotodynamic, reciprocating (positive displacement) and fluid (air) operated pumps.

While the principle of operation of other pumps is discussed elsewhere, the centrifugal pump which is of present concern falls into the category of rotodynamic pumps. In this pump, the liquid is made to rotate in a closed chamber (volute casing) thus creating a centrifugal action which gradually builds up the pressure gradient towards outlet, thus resulting in the continuous flow. These pumps compared to reciprocating pumps are simple in construction, more suitable for handling viscous, turbid (muddy) liquids, can be directly coupled to high speed electric motors (without any speed reduction ) and easy to maintain. But, their hydraulic heads at low flow rates is limited, and hence not suitable for very high heads compared to reciprocating pump of same capacity. But still in most cases, this is the only type of pump which is being widely used for agricultural applications because of its practical suitability. The present testing allows the students to understand and draw the operating characteristics at various heads, flow rates and speeds using different size of impellers.

The hydraulic head per stage at low flow rates is limited and hence not suitable for high heads, in case of single stage centrifugal pumps. But as the pump in this case in a multi stage construction the pressure gradually builds up in successive stages almost equally in each stage. Thus, achieving considerably higher heads. The multi stage centrifugal pump test rig allows the students to understand and study the various characteristics and pressure build up pattern in individual stages. A schematic diagram of a single stage centrifugal pump is shown in Fig. 8.

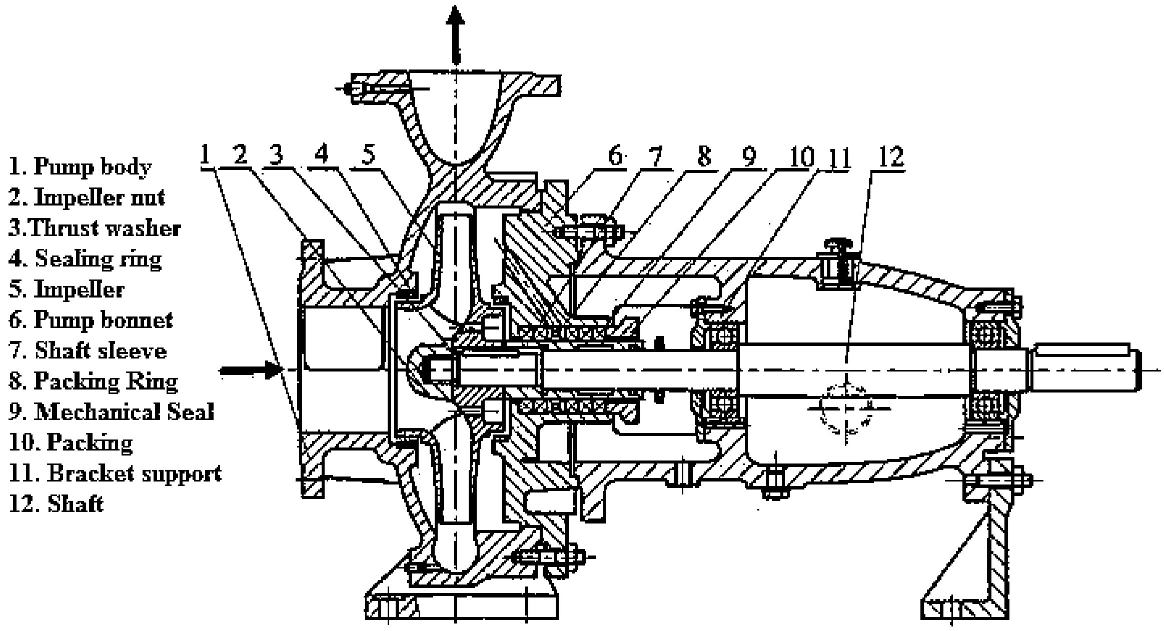



**Fig. 8.** Single stage centrifugal pump

**APPARATUS:**

Centrifugal pump, Energy meter, pressure gauge, vacuum gauge, speed indicator, (digital rpm indicator), control valves (suction and delivery), collecting tank and stopwatch.

**EXPERIMENTAL SETUP:**

The single stage Centrifugal pump test rig mainly consists of:

a) Single stage Centrifugal pump

b) AC Drive motor of suitable capacity coupled to pump by stepped pulley arrangement.

c) SS sump tank and measuring tank with a piezometer

d) G. I. Pipe connections with necessary control valve etc., mounted on a neatly painted M.S. structure. The panel board is equipped with an energy meter for measurement of power input to the motor, a digital RPM indicator to indicate the speed of the pump/motor, a Vacuum gauge to measure suction head, & pressure gauge for measurement of delivery head, a starter of suitable capacity, indicating lamps and fuse etc.

**PROCEDURE:**

1. Clean the apparatus and make all tanks free from dust.

2. Close the drain valve provided.
3. Open flow control valve given on the water discharge.
4. Now switch on the main power supply 220 V AC, 50 Hz.
5. Operate the flow control valve to regulate the flow of water.
6. Set the desired RPM of motor/ Pump.
7. Operate the control valve to regulate the suction of pump.
8. Record discharge pressure by means of pressure gauge.
9. Record suction pressure by means of suction gauge.
10. Measure the discharge by measuring tank by using stop watch.
11. Repeat the same procedure for different speed.

**OBSERVATION:**

| **Speed of pump, N (rpm)** | **Delivery pressure, p ($kgf/cm^2$)** | **Suction pressure $P_v$ mm of Hg** | **Time taken for 10 impulse of energy meter (t), sec** | **Water level rise in tank R (m)** | **Discharge time ($m^3/s$)** |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |

**CALCULATIONS**:

| **Speed of pump N (rpm)** | **Total pressure head in m** | **Discharge in $m^3/s$** | **$HP_{pump}$** | **Input to Motor $HP_{electric}$** | **% Pump Efficiency** |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |

**1. Basic Data / Constants:**

1 HP = 746 Watts

1 kg / cm$^2$ = 760 mm of Hg (10m of water)

Specific weight of water = 1000 kgf / m$^3$

Energy Meter Constant (EMC) = …….. Rev. / kWh

Area of Collecting Tank = …… m2

**2. Electrical Power as indicated by Energy Meter:**

Electrical input, $HP_{elec} = \frac{P}{EMC} \times \frac{1000}{736} \times \frac{3600}{t}$

where, $t$ is the time taken by the Energy meter for 10 revolutions, in seconds.

**3. Discharge rate "*Q*" in m$^3$/s:**

$$Q = \frac{A \times h}{t}$$

where, $A$ = Area of collecting tank = …… m$^2$

$h$ = height of water collected in measuring tank = ……. m

$t$ = the time taken in seconds for collecting tank =…….. sec

**4. Total Head '*H*' in meter:**

$H$ =10(Delivery Pressure + Vacuum head)

= 10(P + $P_v$/760)

where, P is pressure in kg/cm$^2$, $P_v$ is the Vacuum in mm of Hg

**5. Hydraulic Horse Power (Delivered by the Pump):**

$$HP_{pump} = \frac{WQH}{75}$$

where,

$W$ = 1000 kgf / m$^3$

$Q$ and $H$ are obtained using (3) and (4) respectively.

**6. Overall Efficiency:**

$$\%\eta_{overall} = \frac{HP_{pump}}{HP_{elec}} \times 100$$

**RESULT /CONCLUSION:**

**PRECAUTIONS:**

1. Do not run the pump at low voltage.
2. Never fully close the drain line and bypass line valve simultaneously.
3. Always keep apparatus free from dust.
4. Frequently grease/oil the rotating parts
5. Always use clean water.

**QUESTIONS:**

1. What is meant by a Roto-dynamic machine?
2. What is meant by priming of a pump?
3. What energy is converted in a pump?
4. What type of fluids are pumped by centrifugal pumps?
5. What are the pumping characteristics of a centrifugal pump?
6. What is meant by efficiency of a pump?

## EXPERIMENT NO. 06

## Performance Characteristics of multi stage centrifugal pump

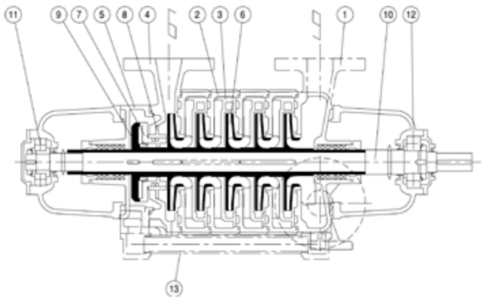
**AIM:** To determine the efficiency and study the performance characteristics of a multi stage Centrifugal Pump.

**THEORY:** In general a pump may be defined as a mechanical device which, when interposed in a pipe line, converts the mechanical energy supplied to it from some external source into hydraulic energy, thus resulting in the flow of liquid from lower potential to higher potential.

The pumps are of major concern to most engineers and technicians. The types of pump vary in principle and design. The selection of the pump for any particular applications is to be done by understanding their characteristics. The most commonly used pumps for domestic, agriculture and industries are; centrifugal, piston, axial flow (stage pumps), air jet, diaphragm and turbine pumps. Most of these pumps fall into the main class, namely; Rotodynamic, reciprocating (positive displacement) and fluid (air) operated pumps.

While the principle of operation of other pumps is discussed elsewhere, the centrifugal pump which is of present concern falls into the category of rotodynamic pumps. In this pump, the liquid is made to rotate in a closed chamber (volute casing) thus creating a centrifugal action which gradually builds up the pressure gradient towards outlet, thus resulting in the continuous flow. These pumps compared to reciprocating pumps are simple in construction, more suitable for handling viscous, turbid (muddy) liquids, can be directly coupled to high speed electric motors (without any speed reduction ) and easy to maintain. But, their hydraulic heads at low flow rates is limited, and hence not suitable for very high heads compared to reciprocating pump of same capacity. But still in most cases, this is the only type of pump which is being widely used for agricultural applications because of its practical suitability. The present testing allows the students to understand and draw the operating characteristics at various heads, flow rates and speeds using different size of impellers.

In Multi Stage centrifugal pump the liquid is made to rotate in a closed chamber (Volute Casing), thus resulting in the continuous flow. These pumps compared to Reciprocating Pumps are simple in construction, more suitable for handling viscous, turbid (muddy) liquids. But, their hydraulic heads per stage at low flow rates is limited, and hence not suitable for very high heads compared to Reciprocating Pumps of same capacity. But, still in most cases, this is the only type of pump which is being widely used for agricultural purposes. A diagram of a 5 stage centrifugal pump is shown in Fig. 9.



| | Part name | | Part name |
|---|---|---|---|
| 1 | 1st-stage suction casing | 11 | Multistage impeller |
| 2 | 1st-stage casing | 12 | Seal impeller |
| 3 | 2nd-stage suction casing | 13 | Exhaust cover |
| 4 | Intermediate-stage casing | 14 | Balancing drum |
| 5 | Intermediate-stage guide vane | 15 | Balancing drum bush |
| 6 | Final-stage casing | 16 | Balancing disk |
| 7 | Balancing chamber cover | 17 | Shaft |
| 8 | 1st-stage guide vane | 18 | Ball bearing |
| 9 | Guide vane | 19 | Ball bearing |
| 10 | 1st-stage impeller | 20 | Balancing pipe |

**Fig. 9.** A 5 stage centrifugal pump

**APPARATUS:**

Multi stage centrifugal pump test rig, AC motor, Energy meter, pressure gauge, vacuum gauge, speed indicator, (digital rpm indicator), control valves (suction and delivery), collecting tank and stopwatch.

**EXPERIMENTAL SETUP:**

The present Pump Test Rig is a self – contained unit operated on Closed Circuit (Recirculation) Basis. The Multi Stage Centrifugal Pump, AC Motor, Sump Tank, Collecting Tank, control Panel are mounted on rigid frame work with anti-vibration mounts and arranged with the following provisions:

1. For conducting the experiments at three speeds using AC Motor.
2. To measure overall input power to the AC motor using Energy Meter.
3. For recording the Pressure & vacuum.
4. For recording the speed using Digital RPM Indicator.
5. For changing the pressure (Delivery Head) and Vacuum (Suction Head) by operating the valves.
6. For measuring the discharge by Collecting Tank-Level Gauge provision.
7. For recirculation of water back to the sump tank by overflow provision.

A schematic diagram of the experimental setup is shown in Fig 10.

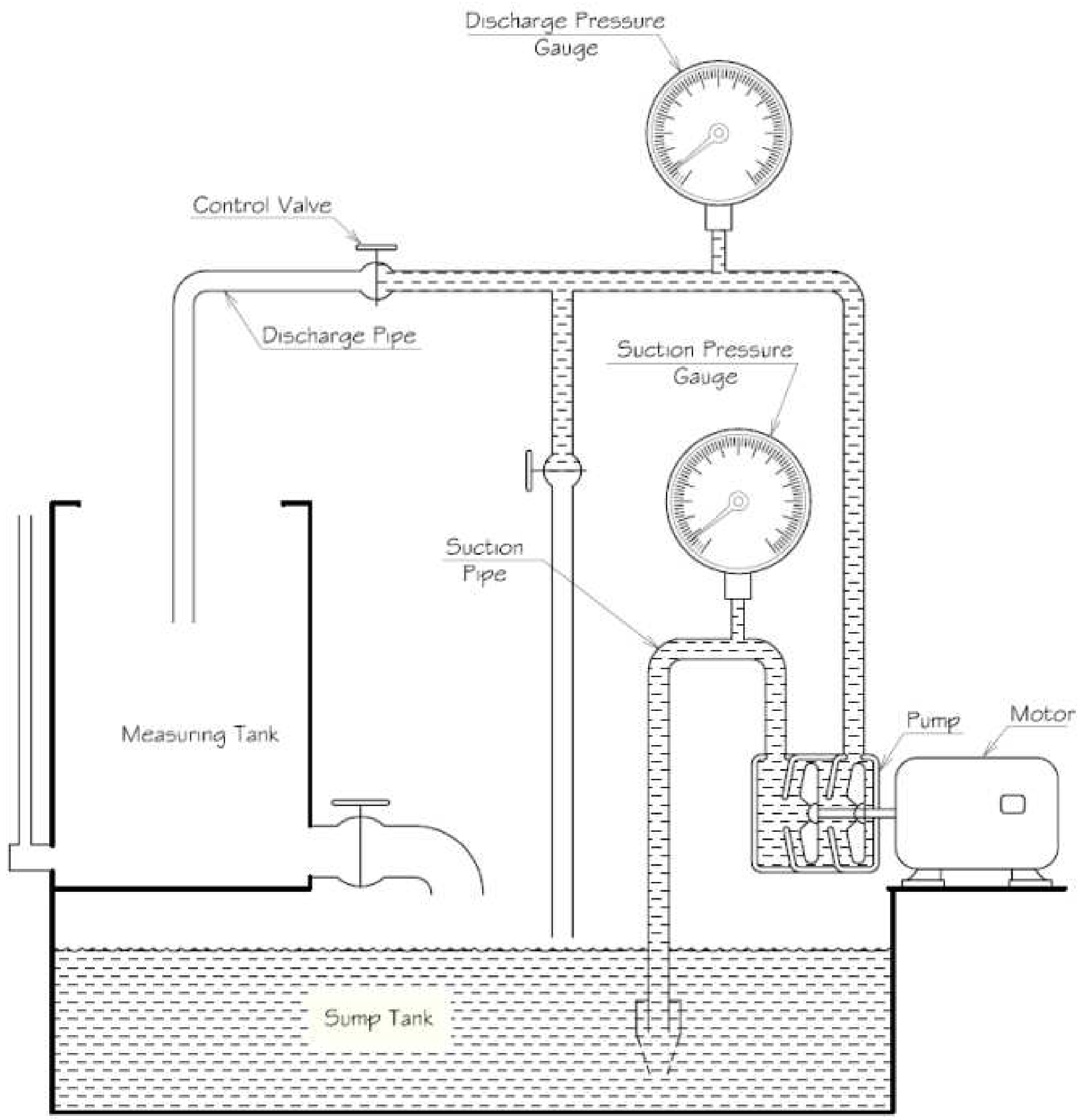



**Fig. 10.** Multi stage centrifugal pump

**PROCEDURE:**

All the necessary instrumentations along with its accessories are readily connected. It is just enough to follow the instructions below

1. Fill in the Sump Tank with clean water.
2. Keep the delivery valve closed and suction valve open, after initially priming the pump.
3. Connect the power cable to 1 Ph, 230V, 15A with earth connection.
4. Confirm the belt is put to the lowest speed position.

5. Switch ON the Mains, so that the Mains On Indicator glows. Now, switch-ON the starter.
6. Now you will find the water starts flowing to the Measuring Tank.
7. Close the delivery valve slightly, so that the delivery pressure is readable
8. Operate the Butterfly valve to note down the collecting tank reading against the known time and keep it open when the readings are not taken.
9. Note down the Pressure Gauges, Vacuum Gauges, and time for number of revolutions of Energy Meter Disc.
10. Note down the other readings as indicated in the tabular column.
11. Repeat the experiment for different openings of the Delivery Valve and Suction Valve.
12. Change the belt to different speed positions and repeat the experiment.
13. After the experiment is over, keep all the delivery and suction valves open.

**OBSERVATION:**

| Sl No. | Discharge pressure, $P_d$ (kg/cm$^2$) | Suction Vacuum $P_s$ mm of Hg | Time taken for n=…..rev of energy meter ($t_e$), sec | Time taken for …..lit water (….cm of tank) ($t_m$), sec |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |

**CALCULATIONS**:

| Speed of pump N (rpm) | Total pressure head in m | Discharge in m$^3$/s | $HP_{pump}$ | Input to Motor $HP_{electric}$ | % Pump Efficiency |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |

**1. Basic Data / Constants:**

1 HP = 746 Watts

1 kg / $cm^2$ = 760 mm of Hg (10m of water)

Specific weight of water = 1000 kgf/$m^3$

Energy Meter Constant (EMC) = …….. Rev. / kWh

Area of Collecting Tank = …… $m^2$

**2. Electrical Power as indicated by Energy Meter:**

Electrical input, $HP_{elec} = \frac{P}{EMC} \times \frac{1000}{736} \times \frac{3600}{t}$

where, $t$ is the time taken by the Energy meter for 10 revolutions, in seconds.

**3. Discharge rate "$Q$" in $m^3$/s:**

$$Q = \frac{A \times h}{t_m}$$

where, $A$ = Area of collecting tank = …… $m^2$

$h$ = height of water collected in measuring tank = ……. m

$t_m$ = the time taken in seconds for collecting tank =…….. sec

**4. Total Head '$H$' in meter:**

$H$ =10(Delivery Pressure + Vacuum head)

= 10[P + ($P_v$/760)]

where, P is pressure in kg/$cm^2$, $P_v$ is the Vacuum in mm of Hg

**5. Hydraulic Horse Power (Delivered by the Pump):**

$$HP_{pump} = \frac{WQH}{75}$$

where,

$W$ = 1000 kgf / $m^3$

$Q$ and $H$ are obtained using (3) and (4) respectively.

**6. Overall Efficiency:**

$$\%\eta_{overall} = \frac{HP_{pump}}{HP_{elec}} \times 100$$

**RESULT /CONCLUSION:**

**PRECAUTIONS:**

1. Do not run the pump at low voltage.
2. Never fully close the drain line and bypass line valve simultaneously.
3. Always keep apparatus free from dust.
4. Frequently grease/oil the rotating parts
5. Always use clean water.

**QUESTIONS:**

1. What is meant by a Roto-dynamic machine?
2. What is meant by priming of a pump?
3. What energy is converted in a pump?
4. What type of fluids are pumped by centrifugal pumps?
5. What are the pumping characteristics of a centrifugal pump?
6. What is meant by efficiency of a pump?

## EXPERIMENT NO. 07

## Performance Characteristics of Pelton turbine

**AIM:** To determine the efficiency and study the performance characteristics of a Pelton wheel turbine.

**THEORY:** Hydraulic (or Water) Turbines are the machines, which uses the energy of water (Hydro-Power) and convert it into mechanical energy. Thus the turbines become the prime mover to run the electrical generators to produce the electricity, Viz, Hydro-electric power.

The turbines are classified as Impulse and Reaction types. In impulse turbine, the head of water is completely converted into a jet, which impulses the forces on the turbine. In reaction turbine, it is the pressure of following water, which rotates the runner of turbine. Of many types of turbine, the Pelton wheel, most commonly used, falls into the category of turbines. While Francis and Kaplan falls in category of impulse reaction turbines.

Normally, Pelton wheel (impulses turbine) requires high heads and low discharge, while the Francis and Kaplan (Reaction Turbine) requires relatively low heads and high discharge. These corresponding heads and discharges are difficult to create in laboratory size Turbine from the limitation of the pumps availability in the market. Nevertheless, at least the performance characteristics could be obtained within the limited facility available in the laboratories. Further, understanding various elements associated with any particular turbine are possible with this kind of facility.

A Turbine acts as a pump in reverse, to subtract energy from a fluid system. In impulse turbine the fluid energy, first in the potential form, is next converted wholly into the kinetic energy by means of one nozzle before striking the runner. The jet ensuing from the nozzle is made to impinge on the runner tangentially. A powerful jet issues out of the nozzle, impinges on the buckets provided on the periphery of the nozzle. In practice these buckets are usually spoon shaped, with a central ridge splitting the impinging jet into two halves which are deflected backward. As there is no pressure variation in flow, the fluid partly fills the buckets and the fluid remains in contact with the atmosphere. The nozzle is provided with spear mechanism to control the quantity of the water. The actual energy transfer from jet to wheel is by changing the momentum of the stream. The impact thus produced causes the runner to rotate and hence produces mechanical power at the shaft.

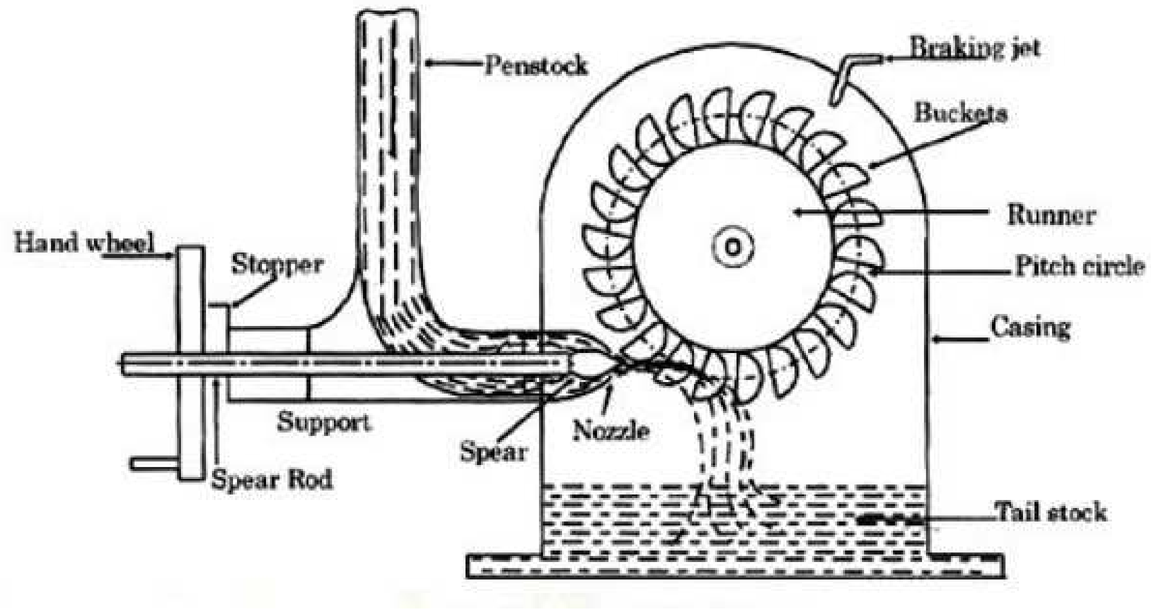



**Fig. 11.** Pelton wheel turbine

Different parts of a typical Pelton wheel turbine is shown in Fig. 11. The main parts of a Pelton wheel turbine are:

**a) Spear Valve Mechanism**

In a Pelton turbine the flow regulation is done with the help of a spear shaped needle valve. It consists of a spear connected to a shaft with a hand wheel at its end. By rotating the hand wheel the spear valve can be moved inside the nozzle axially. When the spear is moved forward it reduces the flow area and hence flow through nozzle reduces, similarly when it is moved backwards flow increases. Water flow can also be regulated by the gate valve provided.

**b) Runner with Buckets**

The runner consists of a circular disc with a number of evenly spaced double hemispherical buckets fixed along its periphery. The disc is mounted on a shaft. The buckets are divided into two parts by a sharp splitter edge at the centre, which divides striking of the jet into two equal parts. The buckets are so shaped that after flowing around its inner surface, the water leaves it with a relative velocity almost opposite in direction to the original jet but does not interface with the passage of water to the bucket preceding it during rotation. There is notch cut at outer rim of each bucket only when it is almost normal to the jet.

## c) Casing

The casing of a Pelton turbine has no hydraulic function to perform. It is provided only to prevent splashing and to lead the water to the tailrace. It is generally made up of stainless steel and it is fabricated to form 'D' section. Front part of the casing is made of acrylic.

**APPARATUS:**

Centrifugal pump, turbine unit, sump tank, Venturimeter, break drum with rope, spring balance, digital RPM indicator, pressure gauges, control panel, recirculation water system, spear valve mechanism (spear needle valve), runner with buckets, casing, penstock, nozzle, breaking jet, deflector, tailrace and butterfly valve.

**EXPERIMENTAL SETUP:**

The experimental facility supplied consists of a centrifugal pump set, turbine unit, sump tank arranged in such a way that the whole unit works on recirculation water system. The centrifugal pump set supplies the water from the sump tank to the turbine through control valve. One more valve is provided to control the water flow through Venturimeter. The water before passing through the turbine units enters the Venturimeter and then flows back to the sump tank. The loading of the turbine is achieved by rope brake drum connected to spring balance. The provision for measurement of turbine speed (digital RPM indicator), Head on turbine (pressure gauge) are built in on the control panel.

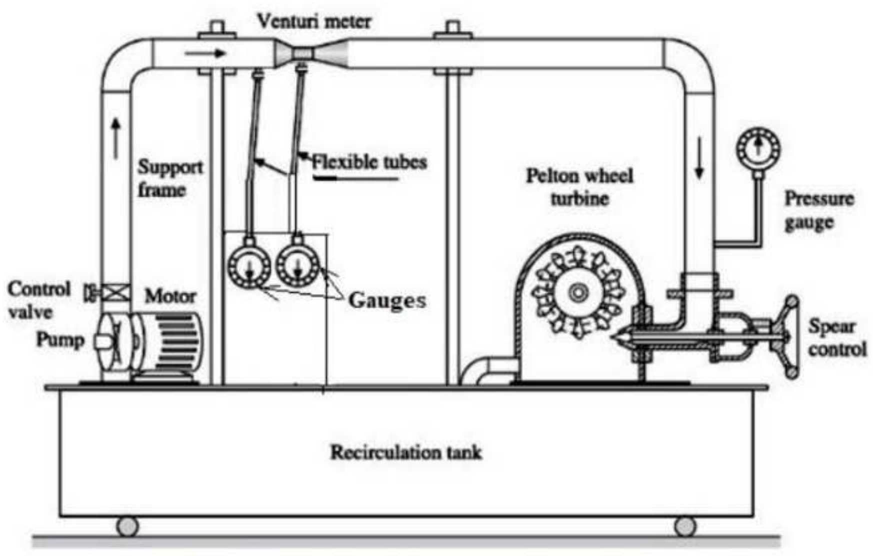



**Fig. 12.** Experimental setup of Pelton wheel turbine

**SPECIFICATIONS:**

1. **Supply Pump/Motor Capacity:** HP, Ph, V, Hz, AC .
2. **Turbine**

   Mean Dia. : mm

   No. of Buckets :

   Diameter of Jet : mm

   Runaway Speed : RPM

   Turbine Head: m (min to max.)
3. **Loading:** Brake Drum
4. **Brake Drum Radius:** 0.15 m
5. **Coefficient Of Discharge:** $C_d = 0.98$

**PROCEDURE:**

1. Connect the supply water pump unit to 3 ph, 440V, 30A, electrical supply, with neutral and earth connections and ensure for correct direction of rotation of the pump motor unit.
2. Keep the brake drum loading at zero position.
3. Keep the butterfly valve partially open initially and the sphere valve at desired opening say full, ¾, ½ and ¼ open.
4. Press the green button of the supply pump starter and gradually open the butterfly valve to its maximum. Now the pump picks-up the full speed and becomes operational.
5. Set the sphere valve to a required opening and also the butterfly valves in full open position so that the turbine rotor picks the speed and conduct experiment on constant speed and constant head.
6. Note down the speed, load, and pressure gauge readings and tabulate the readings.

**OPERATING CHARACTERISTICS:**

**To Obtain Constant Speed Characteristics**

1. Keep the sphere valve opening at required position (full, ¾, ½ and ¼ open)

2. For different brake drum loads on the turbine, change the butterfly valve setting between maximum and minimum so that the speed is held constant.
3. Tabulate the readings as per table given.
4. For different brake drum loading and openings of sphere valve conduct the experiment.

**To Obtain Constant Head Characteristics**

1. Keep the sphere valve at a particular position and butterfly valve at full open position
2. For different brake drum load, note down the speed and pressure gauge readings. Tabulate the readings as per table given.
3. For different openings of sphere valve and loading, repeat the experiment.

**Performance under Unit Head-Unit Quantities:**

In order to predict the behavior of a turbine working under varying conditions and to facilitate comparison between the performances of the turbines of the same type but having different outputs and speeds and working under different Heads, it is often convenient to express the test results in terms of certain unit quantities. Unit quantities refer to the turbine parameters which are obtained when a particular turbine operates under a unit head, discharge and power output. Thus making it possible to predict the behavior of a turbine working under different conditions and compare the performance of turbines of different sizes but of same type. The different unit quantities are:

***Unit Speed:***

It is the theoretical speed at which a given turbine would operate under a given head (i.e. at 1m) unit speed, $N_U = N/\sqrt{H}$ .

***Unit Discharge:***

It is the theoretical discharge, at which a given turbine would operate under a unit head and unit speed, $Q_U = Q/\sqrt{H}$ .

***Unit Power:***

It is the theoretical power at which a given turbine would develop under a unit head (i.e. at 1m) unit power, $P_U = P/H^{3/2}$

***Specific Speed:***

It is the speed of a geometrically similar turbine (i.e. a turbine identical in shape, blade angles etc.) which would develop unit power when working under a unit head. The $N_s$ is usually computed or the operating conditions corresponding to the maximum efficiency.

$$N_S = N\sqrt{P}/H^{5/4}$$

Specific speed provides a basis in which different types of turbines can be compared irrespective of their sizes.

**Formulae:**

*Head on Turbine in meters of water 'H'*

$H = 10P_I$ in m of water

where, $P_I$ is the venturi inlet pressure gauge reading in kg /cm$^2$.

*Flow Rate of Water through the Turbine 'Q'*

$$Q_{th} = C_d \times \frac{A_1 A_2 \sqrt{2gH_v}}{\sqrt{\left(A_1^2 - A_2^2\right)}} \text{ m}^3/\text{s}$$

where,

$A_1$= Area of inlet section of Venturimeter in m2

$A_2$= Area of throat section of Venturimeter in m2

$H_v = 10 \times$ h in m

$h$ = (Difference in pressure read from pressure gauge) = $P_I - P_T$

$P_T$ =Venturi throat pressure

*Hydraulic input to the turbine:*

$$P_{Hyd} = \frac{WQH}{1000} \text{ in KW}$$

where,

$W$ = Specific Weight of the water = 9810 N/m3

$Q$ = Discharge in $m^3/sec$

$H$ = Head on turbine in m of water.

*Break power of the turbine:*

$$BP = \frac{2\pi N\left(F_1 - F_2\right)\times 9.81\times r}{60000}$$

Where,

$N$ = speed in rpm

$F_1$ and $F_2$ = Load in kgf,

$r$ = 0.15 m radius of brake drum.

*Turbine Efficiency:*

$$\%\eta_{Turbine} = \frac{BP}{P_{Hyd}}\times 100$$

**Unit quantities - under unit head:**

*Unit Speed:*

$$N_U = N/\sqrt{H}$$

Where,

$N$ = Speed in rpm

$H$ = Head in m.

*Unit Power:*

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

Where,

$P$ = Power output $BP_{shaft}$ in watts

$H$ = Head in m.

*Unit discharge:*

$$Q_U = Q/\sqrt{H}$$

Where,

$Q$ = Discharge in $m^3$/sec

$H$ = Head in m.

*Specific Speed:*

$$N_S = N\sqrt{P}/H^{5/4}$$

Where,

$N$ = Speed in rpm

$P$ = Power output $BP_{shaft}$ in watts

$H$ = Head in m.

**Percentage Full Load:** $= \dfrac{\text{Part load BP}}{\text{Max. load BP}} \times 100$

**GRAPHS**

For Constant Head Method

- Unit Speed Vs Unit Discharge
- Unit speed Vs Efficiency
- Unit speed Vs Unit power

For Constant Speed Method

- % Full load Vs Efficiency

**OBSERVATIONS / TABULAR FORM (*Constant Head Operation*):**

| Gate Openings (Sphere Head) | Spring Balance Reading. $F_1$ | Spring Balance Reading. $F_2$ | Speed (RPM) | Venturimeter Pressure (Inlet), $P_I$ (kg/cm$^2$) | Venturimeter Pressure (Throat), $P_T$ (kg/cm$^2$) | Pressure Difference in Venturimeter $h$ (kg/cm$^2$) | Head on Turbine, $H$(m) | Discharge , $Q$ (m$^3$/s) | Power Output, $BP_{shaft}$ (kW) | Hydraulic Power, $P_{hyd}$ (kW) | Efficiency $\frac{BP}{P_{Hyd}}x100$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Full Open (100%) | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| ¾ Open (75%) | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| ½ Open (50%) | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| ¼ Open (25%) | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

**Unit Quantities under Unit Head:**

| Unit speed ($N_u$) | Unit discharge ($Q_u$) | Unit Power ($P_u$) | Specific speed ($N_s$) | Gate opening |
|---|---|---|---|---|
| | | | | Full opening |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | ¾ opening |
| | | | | |
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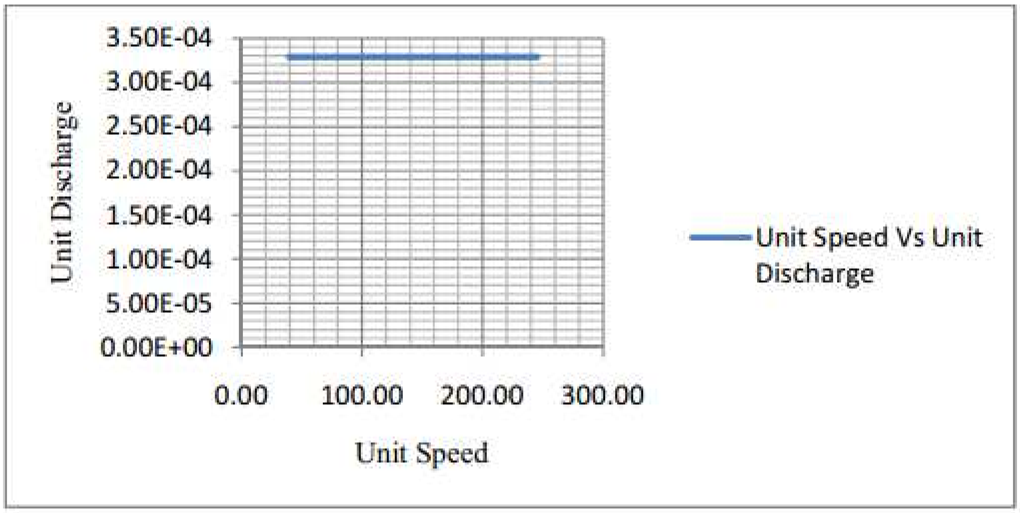
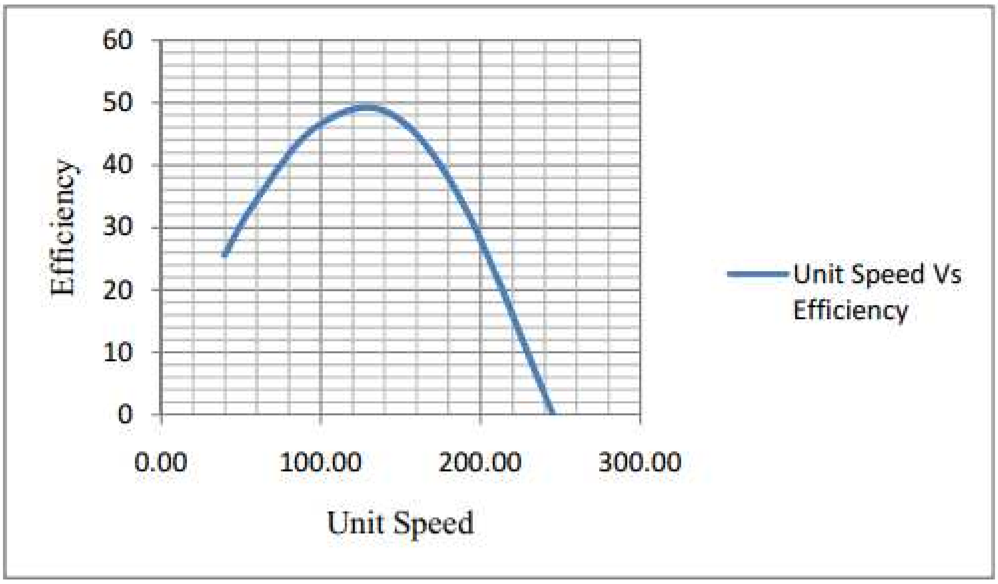
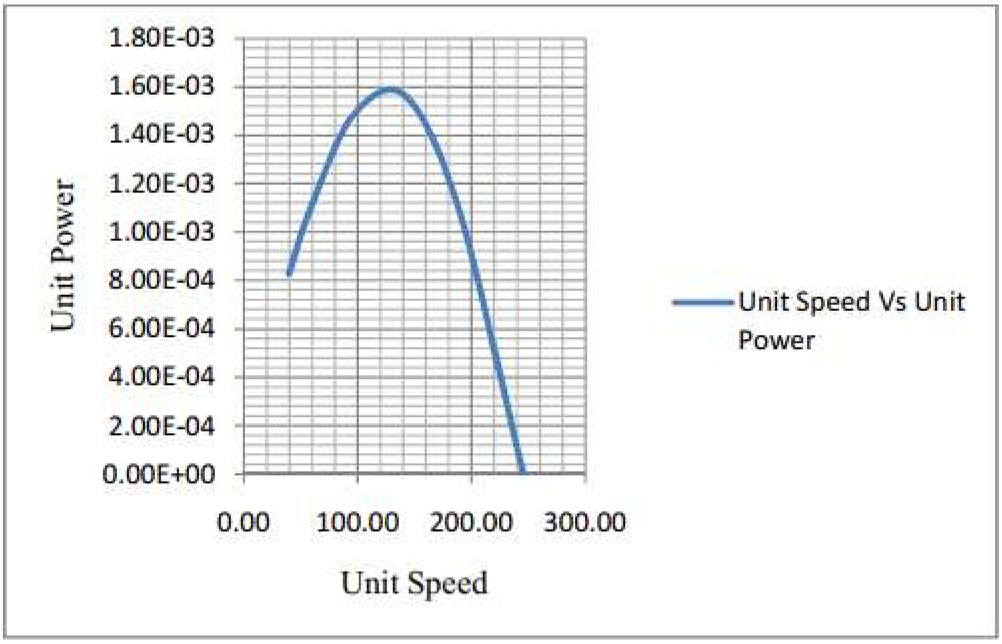
**Sample Performance Characteristic Curve - Constant Head:**






**OBSERVATIONS / TABULAR FORM (*Constant Speed Operation*):**

| Gate Openings (Sphere Head) | Spring Balance Reading. $F_1$ | Spring Balance Reading. $F_2$ | Speed (RPM) | Venturimeter Pressure (Inlet), $P_I$ (kg/cm$^2$) | Ventrurimeter Pressure (Throat), $P_T$ (kg/cm$^2$) | Pressure Difference in Venturimeter $h$ (kg/cm$^2$) | Head on Turbine, $H$(m) | Discharge $Q$ (m$^3$/s) | Power Output, $BP_{shaft}$ (kW) | Hydraulic Power, $P_{hyd}$ (kW) | Efficiency $\frac{BP}{P_{Hyd}}x100$ (%) | % Full Load |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Full Open | | | | | | | | | | | | |
| | | | | | | | | | | | | |
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| | | | | | | | | | | | | |
| ½ Open | | | | | | | | | | | | |
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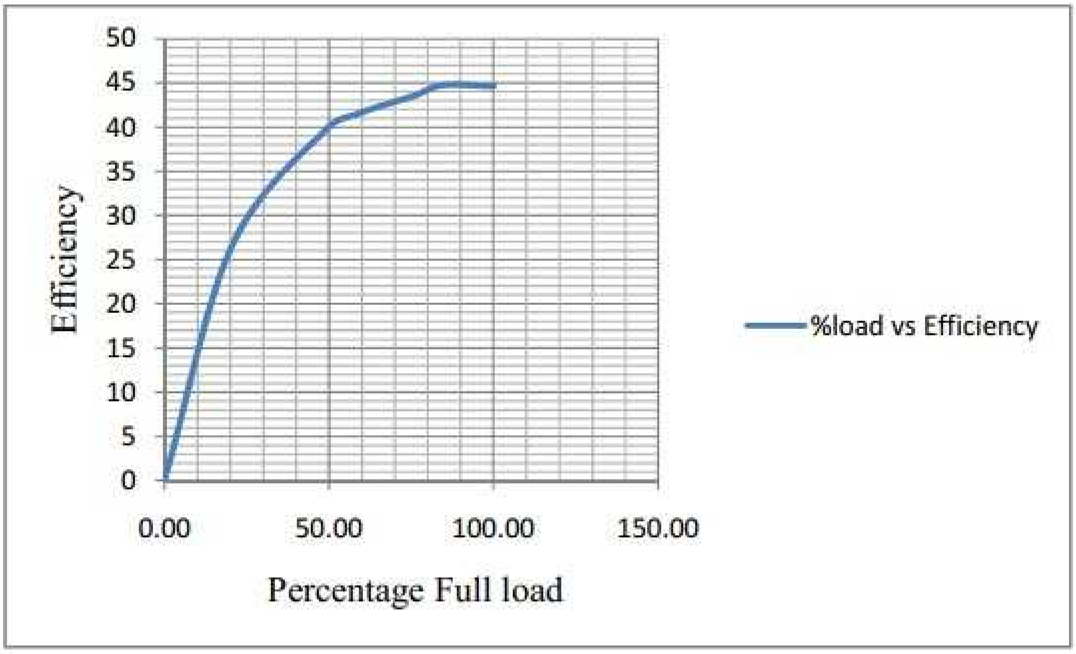
**Sample Graphs**

*Performance Characteristic Curve - Constant Speed*




**RESULT AND DISCUSSION:**

**PRECAUTIONS:**

1. Always operate the turbine with a load. Since the runaway speed of the turbine is high, running the turbine without any load will lead to excess vibrations and noise.
2. Provide cooling water for the brake drum when it is loaded. Absence of cooling water will cause brake drum heating and even charring of the rope under extreme conditions. Amount of cooling water must be controlled to avoid excessive spillage and splashing.
3. The motor is provided with Direct on line starter to trip under overload, low voltage, and uneven phase supply conditions. If the motor trips, check for voltage conditions. Also, do not run the supply pump at fully open valve conditions, as this is an overload condition for the pump.
4. Ensure the priming condition of the pump during experimentation.
5. Ensure the proper working of pressure gauges.
6. Maintain proper earthing of electrical connections.
7. Check the gate valves frequently to avoid leakages.
8. Ensure the free rotation of the break drum and check the stiffness of the rope.

9. Carefully place the weights.
10. Operate the equipment under the supervision of laboratory technical staff.
11. In case of emergency, contact the laboratory technical staff.

**QUESTIONS:**

1. Define the impulse turbine.
2. How turbines are classified?
3. How does an impulse differ from a reaction turbine?
4. Whether Pelton wheel turbine is impulse turbine or reaction turbine?
5. Is draft tube is used in Pelton wheel turbine? Justify.
6. Define the hydraulic efficiency, mechanical efficiency, volumetric efficiency and overall efficiency.
7. On what principle does the Pelton wheel turbine work?
8. What is the specific speed of a turbine?
9. What are the uses of unit quantities?
10. What is the function of spear in Pelton wheel turbine?

## EXPERIMENT NO. 08

## Performance Characteristics of Francis turbine

**AIM:** To determine the efficiency and study the performance characteristics of a Francis turbine.

**THEORY:** Francis turbine is a reaction type hydraulic turbine, used in dams and reservoirs of medium height to convert hydraulic energy into mechanical and electrical energy. Francis Turbine is a radial inward flow reaction turbine. This has the advantage of centrifugal forces acting against the flow, thus reducing the tendency of the turbine to overspeed. Francis Turbines are best suited for medium heads. The specific speed ranges from 25 to 300.

Water under pressure from pump enters through the guide vanes into the runner. While passing through the sprial casing and guide vanes, a portion of the pressure energy is converted into velocity energy. Water thus enters the runner at a high velocity and as it passes through the runner vanes, the remaining pressure energy is converted into kinetic energy. Due to the curvature of the vanes, the kinetic energy is transformed into the mechanical energy i.e., the water head is converted into mechanical energy and hence the runner rotates. The water from the runner is then discharged into the tailrace. The discharge through the runner can be regulated also by operating the guide vanes.

The flow through the pipe line into the turbine is measured with the venturimeter fitted in the pipe line. The Venturimeter is provided with a set of pressure gauges. The net pressure difference across the turbine inlet and outlet is measured with a pressure gauge and a vacuum gauge. The turbine output torque is determined with a rope brake drum dynamometer. A tachometer is used to measure the rpm.

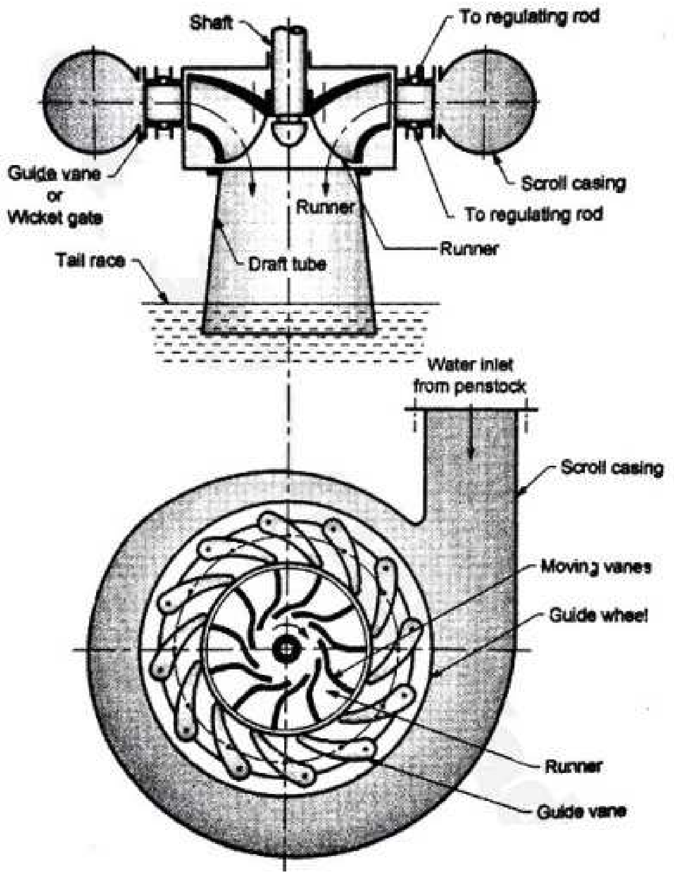



**Fig. 13.** Francis Reaction turbine

**PROCEDURE:**

1. Add minimum load to the brake drum with the help of spring balance and belt arrangement on one side .Note the deflection in the spring balance on other side.
2. Close the main gate valve and start the pump.
3. Open the gate valve while monitoring the inlet pressure to the turbine. Set it for the design value of 1.0 kg/sq.cm.
4. Open the cooling water valve for cooling the brake drum.
5. Measure the turbine rpm with tachometer.
6. Note the pressure gauge and vacuum gauge readings at the turbine inlet and outlet.
7. Note the venturimeter pressure gauge readings, P1 and P2.
8. Add additional weights and repeat the experiments for other loads.
9. For constant speed tests, the main valve has to be adjusted to reduce or increase the inlet head to the turbine for varying loads.

**OBSERVATIONS:**

| Sl. No. | Inlet Pressure $P$ (kg/cm$^2$) | Outlet Vacuum $V$ mm of Hg | Total head $H$ m of water | Venturimeter Pressure gauge readings | | | Flow rate $Q$ (m$^3$/s) | Speed $N$ (rpm) | Weight on Hanger $T_1$ (kg) | Weight on spring balance $T_2$ (kg) | Net weight $T$ (kg) | Turbine output $P_O$ (kW) | Turbine Input $P_I$ (kW) | Efficiency $\eta_{Turbine}$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $P_1$ (kg/cm$^2$) | $P_2$ (kg/cm$^2$) | $dH$ m of water | | | | | | | | |
| 1 | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | | |

**CALCULATIONS:**

**I. To determine discharge:**

$$Q_{th} = C_d \times \frac{A_1 A_2 \sqrt{2gH_v}}{\sqrt{\left(A_1^2 - A_2^2\right)}} \text{ m}^3/\text{s}$$

Where,

$D_1$= Inlet diameter = ….. .m

$D_2$ = Throat diameter = ……. m

$A_1$= Area of inlet section of Venturimeter in m$^2$

$A_2$= Area of throat section of Venturimeter in m$^2$

Venturimeter inlet pressure gauge reading = $P_1$ kg/cm$^2$

Venturimeter throat pressure gauge reading = $P_2$ kg/cm$^2$

Pressure difference, $dH = (P_1 - P_2) \times 10$ m of water

$C_d$= Venturimeter discharge coefficient = ……..

**II. To determine inlet head of water:**

Turbine Pressure gauge reading = P kg/sq.cm

Turbine vacuum gauge reading = V mm of Hg

$$\text{Total Head H} = [10 \times P] + \left[10 \times \frac{V}{760}\right] \text{m head of water}$$

**NOTE:** 1 kg/cm$^2$ = 10 m head of water column

$$1 \text{ V mm of Hg} = \left[10 \times \frac{V}{760}\right] \text{(or)} \left[\frac{V \times 13.6}{1000}\right]$$

**III. Input to the turbine:**

$$\text{Input Power, } P_I = \frac{9810 \times Q \times H}{1000} \text{ in Kw}$$

**IV. Turbine output:**

Brake drum diameter = …… m.

Rope diameter = ……. m

Equivalent drum diameter = ……. m

Radius of drum = $r$ = …… m

Hanger weight = $T_O$ = ……. kg.

Weight = $T_1$ kg

Spring Load = $T_2$ kg

Resultant load = $T = (T_1 - T_2 + T_O)$ kg

Speed of the turbine = N rpm

$$\text{Output Power, } P_O = \frac{2\pi N\left[\left(T_1 - T_2 + T_0\right) \times 9.81\right] \times r}{60000} \text{ in kW}$$

**V. Turbine efficiency:**

$$\eta_{Turbine} = \frac{P_{Output}}{P_{Input}} \times 100\%$$

**RESULT AND DISCUSSION:**

**PRECAUTIONS:**

1. Always operate the turbine with a load. Since the runaway speed of the turbine is over 4000 rpm, running the turbine without any load will lead to excess vibrations a noise.
2. Provide cooling water for the brake drum when it is loaded. Absence of cooling water will cause brake drum heating and even charring of the rope under extreme conditions. Amount of cooling water must be controlled to avoid excessive spillage and splashing.
3. The motor is provided with direction line starter to trip under overload, low voltage, and uneven phase supply. If the motor trips, check for voltage conditions. Also, do not run the supply pump at fully open valve conditions as this is an overload condition for the pump.
4. Make sure that the pressure gauges work properly.
5. Maintain proper earthing of electrical connections.
6. Ensure the gate valves to avoid leakages.
7. Check the free rotation of the break drum and the stiffness of the rope.
8. Carefully place the weights.
9. Operate the equipment under the supervision of laboratory technical staff.
10. In case of emergency, contact the laboratory technical staff.

**QUESTIONS:**

1. Define a reaction turbine with some examples.
2. Under what conditions are reaction turbines used?
3. What is the radial flow turbine?
4. What is the value of water pressure at the outlet of a reaction turbine?
5. Define the draft tube. What are its uses? Which are the different shapes of draft tubes?
6. What is cavitation? How do you prevent it?
7. What do you mean by governing of turbines?
8. State the uses of characteristic curves.
9. Which type of draft tube is used in Francis turbine?

## EXPERIMENT NO. 09

### Performance Characteristics of Kalpan turbine

**AIM:** To determine the efficiency and study the performance characteristics of a Kalpan turbine.

**THEORY:** Kaplan-turbine is an axial flow reaction turbine used in dams and reservoirs of low height to convert hydraulic energy into mechanical and electrical energy. They are best suited for low heads say from 10 m to 50 m. The specific speed ranges from 200 to 1000.

The test rig consists of a 1 KW (3.7 HP) Kaplan turbine supplied with water from a suitable 5 HP pump through: pipelines, a valve, and a flow measuring Venturimeter. The turbine consists of a cast iron body with a volute casing, an axial flow gunmetal runner, a ring of adjustable guide vanes and a draft tube. The runner consists of three vanes of aerofoil section. The guide vanes can be rotated about their axis by means of hand wheel. A rope brake drum is mounted on the turbine shaft to absorb the power developed. Suitable dead weights and a hanger arrangement, a spring balance and cooling water arrangement is provided for the brake drum.

Water under pressure from pump enters through the volute casing and the guide vanes into the runner. While passing through the spiral casing and guide vanes, a portion of the-pressure energy (potential energy) is converted into velocity energy (kinetic energy). Water thus enters the runner at a high velocity and as it passes through the runner vanes, the remaining potential energy is converted into kinetic energy. Due to the curvature of the vanes, the kinetic energy is transformed into the mechanical energy i.e., the water head is converted into mechanical energy and hence the runner rotates. The water from the runner is then discharged into the draft tube.

The flow through the pipe lines into the turbine is measured with the Venturimeter fitted in the pipe line. Two pressure gauges are provided to measure the pressure difference across the Venturimeter. The net pressure difference across the turbine inlet and exit is measured with a pressure gauge and vacuum gauge. The turbine output torque is determined with the rope brake drum. A tachometer is used to measure the rpm.

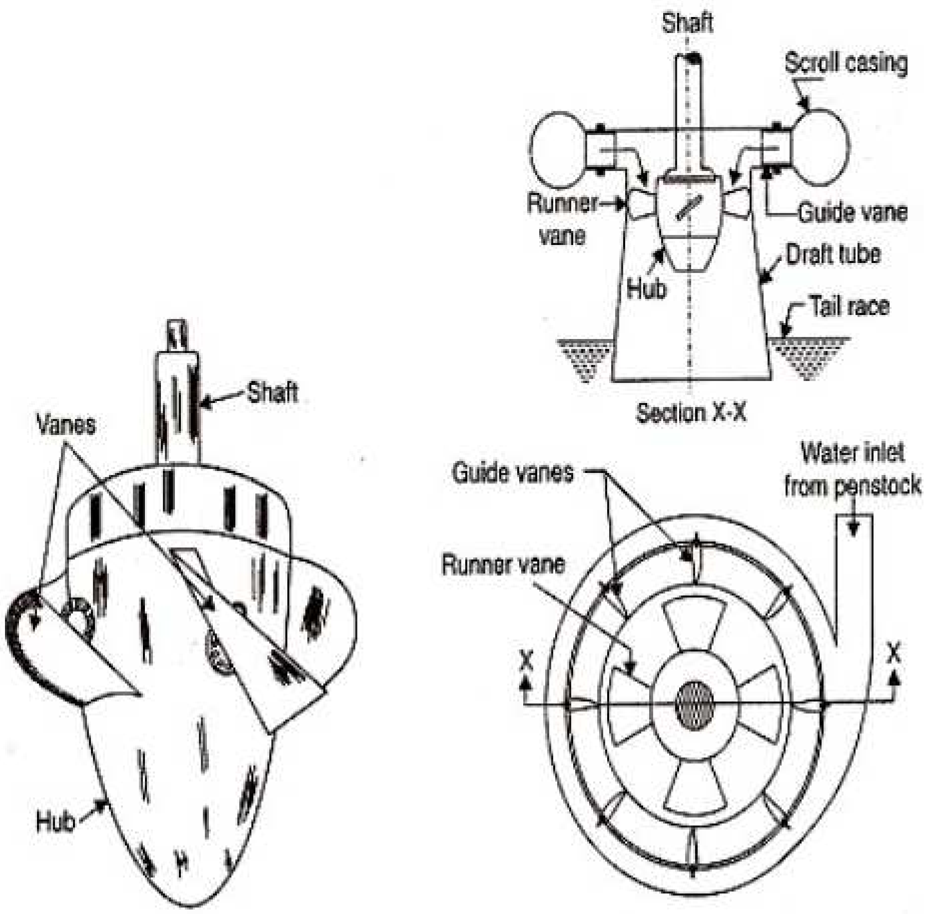



**Fig. 14.** Kaplan Turbine

**PROCEDURE:**

1. Add minimum load to the weight hanger of the brake drum ~ say 1 kg.
2. Close the main gate valve and start the pump.
3. Open the gate valve while monitoring the inlet pressure to the turbine.
4. Open the cooling water valve for cooling the brake drum.
5. Measure the turbine rpm with tachometer.
6. Note the pressure gauge and vacuum gauge readings at the turbine inlet and outlet.
7. Note the Venturimeter pressure gauge readings, P1 and P2.
8. Add additional weights and repeat the experiments for other loads.
9. For constant speed tests, the main valve has to be adjusted to reduce or increase the inlet head to the turbine for varying loads.

**OBSERVATIONS:**

**1. Constant speed (or) 2. Variable speed**

| Sl. No. | Inlet Pressure $P$ (kg/cm$^2$) | Outlet Vacuum $V$ mm of Hg | Total head $H$ m of water | Venturimeter Pressure gauge readings | | | Flow rate $Q$ (m$^3$/s) | Speed $N$ (rpm) | Weight on Hanger $T_1$ (kg) | Weight on spring balance $T_2$ (kg) | Net weight $T$ (kg) | Turbine output $P_O$ (kW) | Turbine Input $P_I$ (kW) | Efficiency $\eta_{Turbine}$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $P_1$ kg/cm$^2$ | $P_2$ (kg/cm$^2$) | $dH$ m of water | | | | | | | | |
| 1 | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | | |

**I. To determine discharge:**

$$Q_{th} = C_d \times \frac{A_1 A_2 \sqrt{2gH_v}}{\sqrt{\left(A_1^2 - A_2^2\right)}} \text{ m}^3/\text{s}$$

Where,

$D_1$= Inlet diameter = ….. .m

$D_2$ = Throat diameter = ……. m

$A_1$= Area of inlet section of Venturimeter in m$^2$

$A_2$= Area of throat section of Venturimeter in m$^2$

Venturimeter inlet pressure gauge reading = $P_1$ kg/cm$^2$

Venturimeter throat pressure gauge reading = $P_2$ kg/cm$^2$

Pressure difference, $dH = (P_1 - P_2) \times 10$ m of water

$C_d$= Venturimeter discharge coefficient = ……..

**II. To determine inlet head of water:**

Turbine Pressure gauge reading = $P$ kg/sq.cm

Turbine vacuum gauge reading = $V$ mm of Hg

Total Head H = $[10\times P]+\left[10\times\frac{V}{760}\right]$ m head of water

**NOTE:** 1 kg/cm$^2$ = 10 m head of water column

1 V mm of Hg = $\left[10\times\frac{V}{760}\right]$ (or) $\left[\frac{V\times 13.6}{1000}\right]$

**III. Input to the turbine:**

Input Power, $P_I = \frac{9810\times Q\times H}{1000}$ in kW

**IV. Turbine output:**

Brake drum diameter = …… m.

Rope diameter = ……. m

Equivalent drum diameter = ……. m

Radius of drum = $r$ = …… m

Hanger weight = $T_O$ = ……. kg.

Weight = $T_1$ kg

Spring Load = $T_2$ kg

Resultant load = $T = (T_1 - T_2 + T_O)$ kg

Speed of the turbine = N rpm

Output Power, $P_O = \frac{2\pi N\left[\left(T_1 - T_2 + T_0\right)\times 9.81\right]\times r}{60000}$ in kW

**V. Turbine efficiency:**

$$\eta_{Turbine} = \frac{P_{Output}}{P_{Input}}\times 100\%$$

**RESULT AND DISCUSSION:**

**PRECAUTIONS:**

1. Always operate the turbine with a load. Since the runaway speed of the turbine is about 4000 rpm, running the turbine without any toad will lead to excess vibrations and noise.
2. Provide cooling water for the brake drum when it is loaded. Absence of cooling water will cause brake drum heating and even charring of the rope under extreme conditions, Amount of cooling water must be controlled to avoid excessive spillage and splashing.
3. The motor is provided with directon line starter to trip under overload, low voltage, and uneven phase supply. If the motor trips, check for voltage conditions. Also, do not run the supply pump at fully open valve conditions as this is an overload condition for the pump.
4. Ensure that the pump is properly primed during experimentation.
5. Check the working condition of the pressure gauges.
6. Hold the tachometer properly in horizontal position while recording the speed of the turbine.
7. Maintain proper earthing of electrical connections.
8. Ensure the gate valves to avoid leakages.
9. Check for the free rotation of the break drum and the stiffness of the rope.
10. Carefully place the weights.
11. Operate the equipment under the supervision of laboratory technical staff.
12. In case of emergency, contact the laboratory technical staff.

**QUESTIONS:**

1. Under what conditions are Kaplan turbines used?
2. What is the speed ratio of Kaplan turbine?
3. Which type of blade is used in Kaplan turbine?
4. What is the principle of Kaplan turbine?
5. Define the boss or hub.
6. What is the difference between Kaplan turbine and propeller turbine?
7. Is the Kaplan turbine radial flow turbine or axial flow turbine?