ME-421

FLUID MACHINERY

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Contents

1 Lecture 01: Introduction

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Booklist

- Hydraulic Mechanics **Govind Rao**
- Hydraulic Machines Through worked out problems **Published by BUET**

Fluid Machines

The working principle of certain machinery where a fluid is employed to do work.

Components

Chemically, any petroleum is an extremely complex mixture of hydrocarbon (hydrogen and carbon) compounds with minor amounts of nitrogen, oxygen, and sulfur as impurities. The weight percentage of petroleum is as follows:

- Liquid Fluid [1]
  - Pumps
    - **Rotodynamics** : Axial flow pump, centrifugal pump etc
    - **Positive Displacement** : Reciprocating, gear, screw pump etc
  - Turbines
    - **Impulse** : Felton wheel (high head)
    - **Reaction** :
      - Radial Flow
      - Mix Flow
      - Axial Flow
- Gaseous Material
  - Fans
  - Blowers
  - Compressors
  - Fluid Coupling
  - Torque Converter

In the case of -

Turbines Energy is extracted from the fluid to produce torque on a rotating shaft.

Pumps Pump is a device to convert mechanical energy into hydraulic energy.

Pumps

Positive Displacement Type

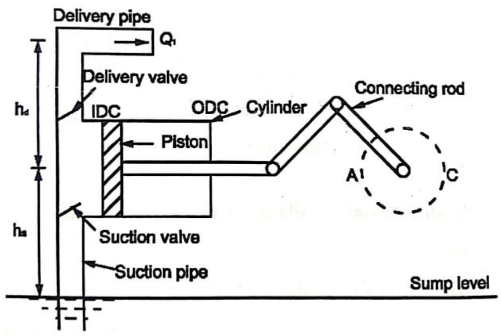
Usually consists of one or more chambers which are alternately filled with liquid to be pumped and then emptied again. The rate of discharge depends on the speed of rotation. It takes care relatively small volume of liquid. Example - **reciprocating pump, gear pump, screw pump** etc

[1] Pump and turbine built together to transmit power smoothly.

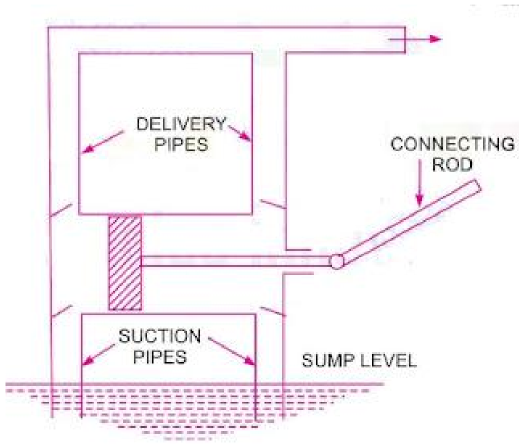
Rotodynamics Pump

In the case of a roto dynamic pump, a rotating element called **impeller** imparts energy to the liquid and there is a pressure rise.
Example - **centrifugal pump, axial flow pump** etc

Reciprocating Pump



(a) Single Acting Pump



(b) Double Acting Pump

Figure 1: Types of Reciprocating Pump

Charateristics

- Reciprocating pump is a positive displacement which is driven by power from an external source and consists of a cylinder in which a piston or plunger is blloked backwards and forwards
- The movement of the piston or plunger creates alternating vacuum pressure and positive pressure inside the cylinder by means of which water is rised.
- If the water acts one side of pistons only, the pump is single acting. If the water acts on both side of the piston, it will suck and deliver during one stroke. such a pump is known as double acting pump.
- The reciprocating pump is generally used for producing very high pressure.

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2 Lecture 2: Reciprocating Pump

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Schamatic diagram of a Reciprocating Pump:

[Note: Non-return valve, check valve, foot valve - all are same.]

Main Components:

- A piston and a cylinder
- Suction & delivery valve
- Suction & delivery pipes
- Crank & connecting rod

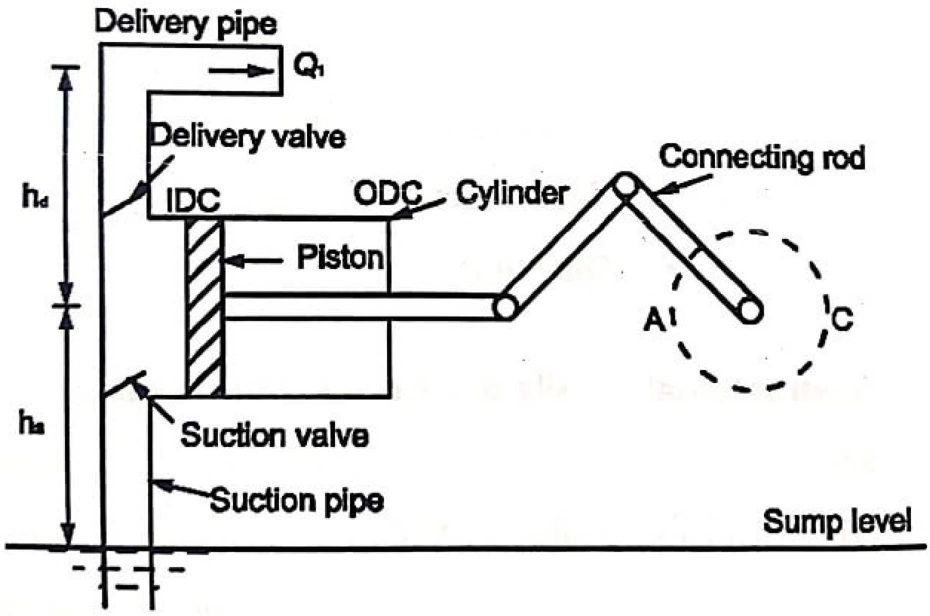

Figure 2: Schamatic diagram of a Reciprocating Pump

Applications:

The reciprocating pump is best suited for relatively small capacities and high heads. The reciprocating pump is used for -

- Oil drilling operations
- Pneumatic pressure systems
- Feeding small boilers condensate return
- Light oil pumping

Operation Principle:

- For a reciprocating pump as crank rotate for piston p moves backwards and forwards with the cylinder c. The piston moves to the right during the suction stroke, which causes vaccum in the cylinder.
- The atmospheric pressure under sump (reservoir) water surface forces the water up the suction pipe.
- The suction valve a is opened and water enters into the cylinder. The delivery valve b remains closed.
- During the return stroke of the piston, the water pressure closes the suction valve and opens the delivery valve b. Water is then forced up the delivery pipe and raised to the required height or pressure.
- For a single acting pump, the theoretical volume of water raise per revolution is equal to the stroke volume of the cylinder and twice this volume is, if the pump is double acting.

Coefficient of Discharge, C_d:

It is the ratio of actual volume of water discharge to the volume swept by the piston.

$$C_d = \frac{\text{actual discharge per stroke}}{\text{volume swept per stroke}}$$

Slip :

Slip is the difference between actual discharge and theoretical discharge.

$$Slip = Q_t - Q_a$$

$$\text{where,} \quad Q_t \rightarrow \text{Theoretical Discharge}$$
$$\text{and} \quad Q_a \rightarrow \text{Actual Discharge}$$

$$\text{percentage slip} = \frac{Q_t - Q_a}{Q_t} \times 100$$

Negative Slip:

In case of a reciprocating pump with long suction pipe, short delivery pipe and running at high speed, inertia force in the suction pipe becomes large as compared to the pressure force on the outside of delivery valve. This opens the delivery valve even before the piston has completed its suction stroke. Some of the water is pushed into the delivery pipe before the delivery stroke is actually commenced. The actual discharge will be more than the theoretical discharge and slip will be negative. The coefficient of discharge will be greater than 1.

Problem 01:

The actual discharge of a single acting reciprocating pump is 0.02 m^3/s, when running at 55 rpm. The length of the stroke is 500 mm and diameter of the piston is 250 mm. For a total static heads of 16 m, calculate the percentage slip, coefficient of discharge and power required to drive the pump.

Solution:

Given data :

Actual Discharge, Q_a	$= 0.02\ m^3/sec$
Speed of the pump, N	= 55 rpm
Stroke Length, L	= 500 mm
Diameter of piston, d	= 250 mm
Total static head, H_{st}	= 16 m

Find - (a) Percentage Slip, (b) Coeff. of discharge, (c) Power required to drive the pump.

$$\begin{aligned}\text{Cross sectional area of piston, A} &= \frac{\pi}{4} \times d^2 \\ &= \frac{\pi}{4} \times (0.25)^2\, m^2 \\ &= 0.0491\, m^2\end{aligned}$$

$$\begin{aligned}\text{Theoretical Discharge, } Q_t &= \frac{L \times A \times N}{60} \\ &= \frac{0.5 \times 0.0491 \times 55}{60}\, m^3/sec \\ &= 0.0225\, m^3/sec\end{aligned}$$

$$\begin{aligned}\text{Percentage slip } &= \frac{Q_t - Q_a}{Q_t} \times 100 \\ &= \frac{0.0225 - 0.02}{0.0225} \times 100 \\ &= 11.10\%\end{aligned}$$

$$\begin{aligned}\text{Coefficient of Discharge, } C_d &= \frac{Q_a}{Q_t} \\ &= \frac{0.02}{0.0225} \\ &= 0.89\end{aligned}$$

$$
\begin{aligned}
\text{Power required to drive the pump } &= Q_t \times \gamma \times H_{st} \\
&= 0.0225 \times 9800 \times 16\, watt \\
&= 3.53\, kW
\end{aligned}
$$

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3 Lecture 3: Flow Rate and Work Done

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let,

r = crank radius

L = Length of stroke = 2r

A = Cross Sectional Area of Piston

N = RPM

H_s = Suction Head

H_d = Delivery Head

γ = Specific weight of water

Volume of water supplied in one stroke = AL

Theoretical flow rate per second, $Q = \frac{LAN}{60}$

For a double acting pump discharge = $\frac{2LAN}{60}$

W = weight flow rate = $Q\gamma$

Total height lifted, H = $H_s + H_d$

Theoretical power required to drive the pump = $Q\gamma\,(H_s + H_d) = WH$

The actual power required will be greater than the theoretical power due to friction, leakage etc.

Indicator diagram of a reciprocating pump:

Indicator diagram may be defined as the graphical representation of pressure head in the cylinder and the volume swept by piston for one complete revolution.

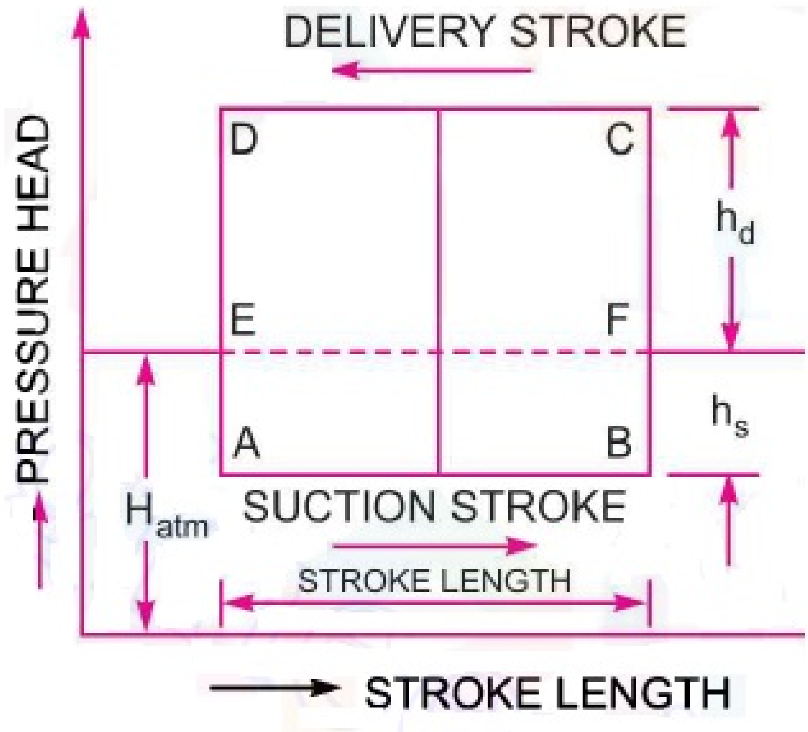

Figure 3: Indicator diagram of a reciprocating pump.

In the above figure, shows the theoretical indicator diagram of a reciprocating pump under an ideal conditions (without friction and leakage). The stroke length and pressure head inside the cylinder are represented by x and y axis in the diagram respectively.

In the diagram,

H_d = Delivery Head

H_s = Suction Head

Line ef = Represents atmospheric pressure

Line ab = Represents pressure inside the cylinder during suction stroke

Line cd = Represents pressure inside the cylinder during delivery stroke

x-axis = absolute zero pressure

area $abfe$ = Work done by the piston dring suction stroke

area $cdef$ = work done by the piston during delivery stroke

Variation of Pressure due to acceleration of piston

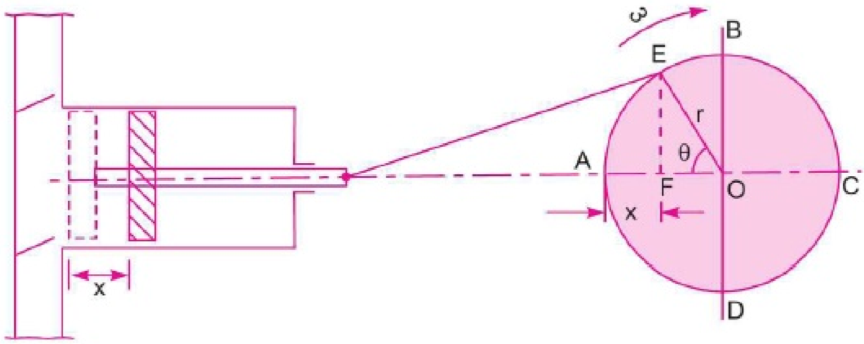

Figure 4: Variation of Pressure due to acceleration of piston

Due to reciprocating motion of the piston, there will be acceleration at the beginning and retardation at the end of each stroke. For this reason, the inertia of water will cause a variation in the pressure in the cylinder.

Assumption

- Length of the connecting rod is very large
- The rotation of the crank is uniform
- The piston makes simple harmonic motion

Nomenclature

A = Cross sectional area of piston

a = Cross sectional area of pipe

ω = Angular velocity of rotating crank

r = crank radius

l = Total length of pipe

γ = specific weight of water

v = velocity of water in a pipe

V = velocity of piston

Derivation of Equation

Let, adter time t, the crank makes an angle θ with horizontal. Therefore,

$$\theta = \omega \times t$$

Displacement of piston in time t, $x = r - r\cos\theta = r - r\cos(\omega t)$

Velocity of piston in time t, $v = \frac{dx}{dt} = r\omega \sin(\omega t)$

acceleration of piston in time t, $f = \frac{dv}{dt} = r\omega^2 \cos(\omega t)$

From continuity equation,

Cross sectional area of pipe × velocity of water in pipe = Velocity of pison × cross sectional area of piston

i.e., $av = AV$

or, $v = \frac{A}{a}V = \frac{A}{a}r\omega \sin \omega t = \frac{A}{a}r\omega \sin\theta$

Acceleration of water in pipe = $\frac{dv}{dt} = \frac{A}{a} r\omega^2 \cos\omega t = \frac{A}{a}\omega^2 r \cos\theta$
weight of water in pipe = γal
mass of water in pipe = $\frac{\gamma al}{g}$
let, P_a = intensity of pressure due to acceleration of water in pipe
from newton's second law of motion,
Force = Mass $\times$ Acceleration

$$P_a \times a = \frac{\gamma al}{g}\frac{A}{a}\omega^2 r \cos\theta$$

$$P_a = \frac{\gamma l}{g}\frac{A}{a}\omega^2 r \cos\theta \tag{1}$$

Let, H_a = acceleration pressure head $= \frac{\text{intensity of pressure}}{\text{specific weight of water}} = \frac{P_a}{\gamma}$
Dividing the equation (1) by γ we have,

$$\frac{P_a}{\gamma} = \frac{l}{g}\frac{A}{a}\omega^2 r \cos\theta$$

$$H_a = \frac{l}{g}\frac{A}{a}\omega^2 r \cos\theta \tag{2}$$

From equation (2) it is found that pressure head due to acceleration vary with the angle θ.
At the beginning of stroke, $\theta = 0, cos\theta = 1$

$$\therefore H_a = \frac{l}{g}\frac{A}{a}\omega^2 r$$

At the middle of stroke, $\theta = 90, cos\theta = 0$

$$\therefore H_a = 0$$

At the end of stroke, $\theta = 180, cos\theta = -1$

$$\therefore H_a = -\frac{l}{g}\frac{A}{a}\omega^2 r$$

✓ here (-ve) means retardation.
