

## UNIT - I

①

Hydraulics is that branch of engineering deals with study and physical behaviour of liquids at rest as well as in motion.

In the industry we use three methods for transmitting power from one point to another.

1. Mechanical Transmission is through shafts, gears, chains, belts etc.

2. Electrical Transmission is through wires and transformers etc.

3. Fluid power is through liquid (or) gas in a confined space.

Fluid power and its scope:-

Fluid power is the technology that deals with the generation, control and transmission of forces and movement of mechanical element (or) system with the use of pressurized fluid in a

Confined system. Both liquids and fluids are considered as fluids. Fluid power system includes

hydraulic system [hydra means water in greek].

and pneumatic system [Pneuma means air in greek].

Oil hydraulics employs pressurized liquid petroleum

oils and Synthetic Oils, and pneumatics employs

compressed air that is related to atmosphere after performing the work.

By the term fluid we refer to air (or) oil , for it has been show that water has certain drawbacks in the transmission of hydraulic power in machine operation and control. Commercially , Pure water contains various chemicals and also foreign matter and unless special precautions are taken when its is used it is nearly impossible to maintain valves and working surfaces in satisfactory condition. In the cases where hydraulic system is closed [ie the one with a self contained unit that serves one machine (or) one small group of machines] oil is commonly used, thus providing ,in addition to transmit the power, benefit of lubrication not afford by water as well as increased life and efficiency of packings and valves . It should be mentioned that in some special cases, soluble oil diluted water is used for safety reasons. The application of fluid power is limited only by ingenuity of the designer, Production designer,(or) plant Engineer If the application pertains to lifting , pushing Pulling , clamping , tilting , forcing , Pressing (or) any other straight line. [and many rotary] motions, it is possible that fluid power will meet the requirement.

Fluid Power applications can be classified into

two major segments:-

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1. Stationary hydraulics Systems remain firmly fixed in one position. The characteristics feature of stationary hydraulics is that the valves are mainly solenoid operated. The applications of stationary hydraulics are as follows.

- Production and assembly of vehicles all types
- Machine tools and transfer lines
- Lifting and conveying devices.
- Metal-forming Press
- Plastic Machinery such as injection moulding machines.
- Rolling Machines.
- lifts.
- food processing Machinery
- Automatic handling Equipment and Robots.

2. Mobile Hydraulics: Mobile Hydraulic

Systems move on wheels (or) trucks such as crane (or) excavator truck to operate in many different locations (or) while moving. A characteristic feature of mobile hydraulics is that the valves are frequently operated. The application of Mobile Hydraulics As follows

→ Automobiles, tractors, aeroplanes, missile, boats, etc.

→ Construction Machinery.

→ Tipplers, Excavators and elevating platforms

→ Lifting and Conveying devices.

→ Agricultural Machinery.

Hydraulics and pneumatics have almost unlimited application in the production of goods and nearly all sectors of country

### Applications of fluid power:-

1. Agriculture:- Tractors, farm equipment such as movers, ploughs, chemical and water sprayers, fertilizer spreaders  
Harvester.

2. Automation:- Automated transferred lines, Robotics

3. Automobile - Power steering, Power brakes, Suspension systems, hydrostatic transmission

4. Aviation:- Fluid power equipment such as landing wheels aircraft, Helicopters, aircraft test beds, luggage loading and unloading systems, ailerons, aircraft Servicing, Flight Simulator.

Construction industry / Equipment For metering and mixing of concrete rubbers , Excavators , lifts, bucket loaders, Crawlers, Post-hole diggers, road graders , road cleaners, road Maintenance vehicles, tippers.

Defense

- Missile - launching systems , navigation controls.
- roller coasters.

Entertainment

Fabrication industry - Hand tools such as pneumatic drills, grinders, borers, reviting Machines, Nut runners.

Food and beverages - All types of food processing equipment, Wrapping, bottling .

Foundry

- full and semi-automatic molding machines, tilting of furnaces , die-casting machines.

Glass Industry

- Vacuum suction cups for handling.

Manufacturing sector - For positing and holding the parts together ~~for~~ during welding

- To operate hand tools ~~and~~ such as Pneumatic drills and ~~pneumatic~~ revetting Machines

- To operate jack , hoist, Conveyor system

→ Robots, Presses , stamping Equipment

- Excavating equipment such as ~~the~~ backhoes and bulldozers,

Rockdrills and conveyors.

Mining

**Printing & Packing:-** To carry operations such as Edge trimming, stapling Pressing and bundle wrapping for publication of News papers, Periodicals and book

To operate Special purpose machines for rolling and Packing.

Hydraulic Systems are two types they are.

### 1. Fluid Transport Systems:-

Their sole objective is the delivery of a fluid from one location to another to accomplish some useful work

Ex:- Pumping stations for pumping water to homes, Cross-country Gas lines etc.

### 2. Fluid power Systems:-

These are designed to perform work. In fluid power systems work is obtained by pressurized fluid acting directly on a fluid cylinder (or) fluid motor. A cylinder produces a force resulting in a linear motion. whereas a fluid motor produces a torque resulting in rotary motion.

# Classification of fluid power systems:-

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## 1. Based on the Control System:

### i, Open-loop system:-

There is No feedback in the Open System and performance is based on the characteristics of individual Components of the System. The Open loop system is not accurate and error can be reduced by proper Calibration and Control.

### ii, Closed-loop System:-

This system uses the feed back. The output of the System is feed back to a comparator by measuring element. The error is used to change the actual output and bring it closer to the desired value. Simple closed loop system uses Servo Valves and advanced systems uses digital Electronics.

## 2. Based on the type of control:-

### i, Fluid logic control:

This type of system is controlled by hydraulic oil (or) air. The System employs fluid logic devices such as AND, NAND, OR, NOR etc. Two types of fluid logic systems are available.

Moving Part logic: These devices are miniature fluid element using moving parts such as diaphragms, disks and poppets to implement various

logic gates.

## Fluidics:

Fluid devices contains no moving parts and depend solely on interacting fluid jets to implement logic gates.

## Electrical Control :-

This type of system is controlled by electrical devices. Four basic electrical devices are used for controlling the fluid power systems: Switches, relays, timers and solenoids. These devices help to control the starting, stopping, sequencing, speed positioning, timing and reversing of actuating cylinders and fluid motors. Electrical control and fluid power work well together where remote control is essential.

## Electronic control:

This type of system is controlled by microelectronic devices. The electronic brain is used to control the fluid power muscles for doing work. This system uses the most advanced type of electronic hardware including programmable logic control [PLC] or microprocessor. In the electrical control a change in system operations results in a cumbersome process of redoing hardware connections. The difficulty is overcome by programmable electronic control. The program can be modified or new program can be fed to meet the change of operations. A number of such programs can be stored in these devices, which makes system more flexible.

## Advantages of Fluid power systems:

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Basically four methods of power transmission in industry Mechanical, Electrical, hydraulics and pneumatics. Each method of transmission has its own advantages and limitation. But the advantages of hydraulic transmission lies b/w mechanical and electrical.

Many advantages and disadvantages of fluid power systems are similar. Whether it is pneumatic (or) hydraulic. These are considered below.

→ Fluid power system is more compact than mechanical drive, because it eliminates the use of complicated linkages of levers, gears, cams etc.

Ex: Car braking System was at one time purely mechanical consisting of complicated linkage mechanism. It is completely replaced by hydraulic system which provide to be infinitely superior.

→ The maximum power transmitted in the mechanical system depends on the geometry (or) shape of its components. But in hydraulic system the medium power transmission is a liquid, which is not subjected to breakage like parts of mechanical system.

→ Fluid power systems, we need not pay attention towards the lubrication because the hydraulic oil lubricates the Sliding parts and prevents the rust formation and hence the system life improves.

→ Fluid power systems are able to produce Constant force (or) torque regardless of speed Variation. This is not possible with mechanical (or) electrical Systems.

Ex: In mechanical gear drive, with increase in Speed the torque transmitted is decreased.

\* Fluid power systems offer infinitely Variable Speed Control which is not possible with mechanical drive

\* The system has an automatic protection against overload because excess pressure due to overload is released through relief Valves.

\* Fluid power systems have less moving parts the comparable mechanical and electrical systems are easier to operate and maintain and are more reliable.

- \* Fluid power systems have less moving parts (6) than comparable mechanical and electrical systems are easier to operate and maintain and more reliable.
- \* In fluid power system, force multiplication can be (done) achieved easily without using cumbersome gears, levers, pulleys.
- \* In hydraulic systems because of the incompressibility of liquid accurates, speeds, torque, feed are possible. Hence, makes it suitable for aerospace and machine tool industry.
- \* Its maintenance is very simple. Prime importance should be given to keep away the fluid from contamination.
- \* Hydraulic systems have high force to weight ratio. This makes them attractive in situation where weight is at premium - such as aircraft and missiles.

## Disadvantages:-

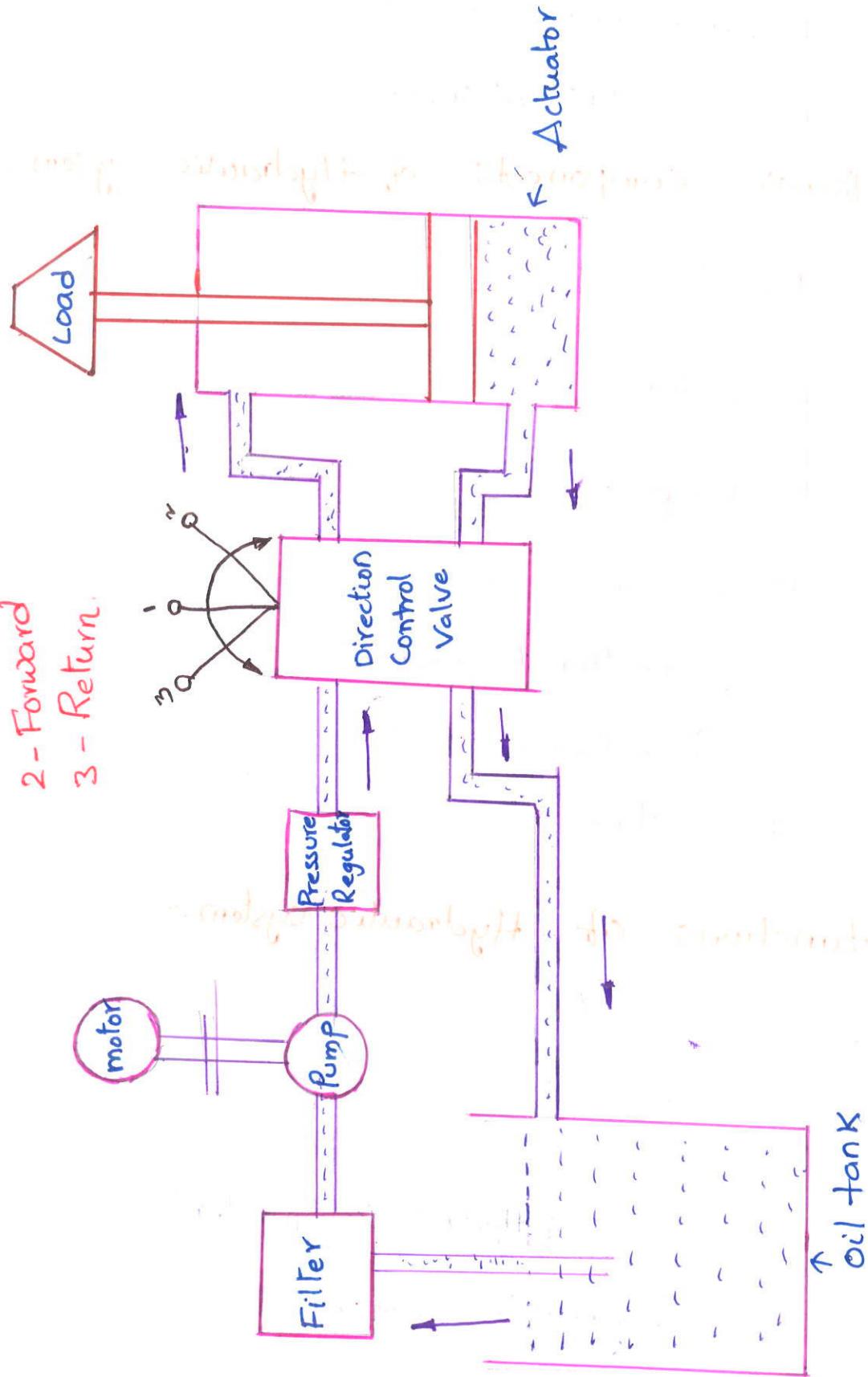
- Preventing leakages of oil in hydraulic Systems is very difficult. leakage of oil results in Slippery and dirty Surroundings.
- Fire Hazards may occurs if the leakage of oil takes place. in the hot environment.
- Bursting of hydraulic lines due to high pre. may occur if they are not designed properly.
- Noisy atmosphere due to Continuous Operation of Pumps.
- Contamination of fluid decreases the life of the Component.
- The System flow and response are dependent on liquid properties like viscosity, density, Solubility etc. Periodical replacement of oil is required Since Oil loses its properties Especially the Viscosity - in course of operation

= o =

# Structure of Hydraulic Systems:

Basic Components of hydraulic System:-

- 1 - Off.
- 2 - Forward
- 3 - Return



Hydraulic Systems are power-transmitting assemblies employing pressurized liquid as a fluid for transmitting energy from an energy-generating source to an energy-using point to accomplish useful work.

### Basic components of Hydraulic System:

1. Oil Reservoir.

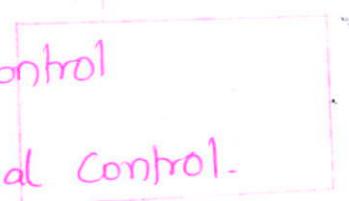


2. Filter.

3. Pump.



4. Pressure Control



5. Directional Control.

6. Functional Control

7. Actuator



### Functions of Hydraulic system:-

- The hydraulic actuator is a device used to convert the fluid power into mechanical power to do useful work. The actuator may be of linear type [Hydraulic cylinder] (or) rotary type [e.g. Hydraulic motor] to provide linear (or) rotary motion respectively.

→ The hydraulic pump is used to force the fluid from reservoir the ~~revers~~:reservoir to the rest of the hydraulic circuit by converting mechanical energy into hydraulic energy.

→ Valves are used to control the direction, pressure and flow rate of a flowing fluid ~~flow~~ flowing the circuit.

→ External power supply [motor] is required to drive the pump.

→ Reservoir is used to hold the hydraulic liquid, usually hydraulic oil.

→ Piping system carries the hydraulic oil from one place to another.

→ Filters are used to remove the foreign particles so as to keep the fluid system clean and efficient, as well as avoid damage to the actuators and valves.

→ Pressure regulator regulates the required level of pressure in the hydraulic oil.

The piping is of closed loop type with fluid transferred from the storage tank to one side position and return back from other side of the piston to the tank.

Fluid is drawn from the tank by pump that produces fluid flow at required level of pre.

If the fluid pressure exceeds the required level, ~~the pressure~~ then the excess fluid return back to the reservoir and remains there until the pressure acquired the required level.

Cylinder movement is controlled by three position Change over Control Valve.

- \* When the piston of the valve changed to upper position, the pipe pressure line is connected to Port A, thus the load raised.
- \* When the position of the valve change to lower position, the pipe pressure line is connected to Port B and thus the load is lowered.
- \* When the valve is at centre position, it locks the fluid into cylinder [there by hold it in position] and dead ends the fluid line. [causing all pump output fluid to return to tank via Pressure relief].

In Industry, a machine designer conveys the design of hydraulic system using symbols. The working fluid, which is a hydraulic oil, is stored in a reservoir. When the electric motor is switched ON, it runs a pump.

Positive displacement pumps that draws hydraulic oil through a filter and delivers at high pressure. The pressurized oil passes through the regulating valve and does work on actuator. Oil from the other end of the actuator goes back to the tank via return line. To and from motion of the cylinder is controlled using directional control valve.



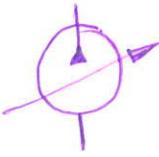
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ISO SYMBOLS :-

S.No	Description of the Part	Symbol.
	Lines and line functions	
1.	Line, Working	
2.	Line, Pilot [ $L > 2w$ ]	
3.	Line, Drain [ $L < 5w$ ]	
4.	Connector.	
5.	Line, Flexible.	
6.	Line, Joining	
7.	Line, Passing Variable displacement <small>(<math>20^\circ</math> min)</small>	
8.	Direction of flow, Hydraulics Pneumatic	 
9.	Line to Reservoir. Above fluid level	
	Below fluid level	
10.	Line to Vented manifold.	
11.	Plug (or) plugged Connection.	
12.	Restriction, Fixed.	

- 13 Restriction Variable.  
Inflow ~~flow off for multiplying~~
- 14 Non-flowing.
- 15 Pump flow
- 16 Tank flow.
- 17 Suction flow
- 18 Metered flow
- 19 Reduced pressure
- 20 Intensified fluid.
- 21 Drain.

### Pumps.

- 22 Pump, single fixed displacement
- 
- 23 Pump, Single variable displacement
- 

### MOTORS.

- 24 Rotary fixed displacement.
- 25 Rotary
- 26 Oscillating
- 
- 
- 

# Cylinders.

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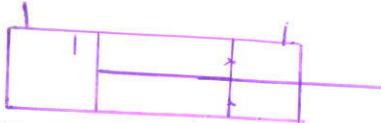
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Single acting



28

Double acting



29

Differential Rod.



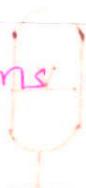
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Double ended Rod.



31

Cushions at both ends.



## Miscellaneous Units.

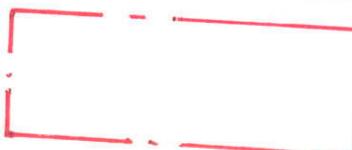
32

Direction of rotation  
(Arrow in front of shaft.)



33

Component enclosure.



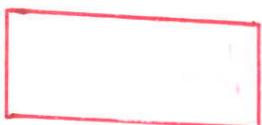
34

Reservoir Vented.



35

Pressurized Reservoir.



36

Pressure Gauge.



37

Temperature Gauge.



38

Flow meter [flow rate]



38

Electric motor

39



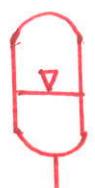
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Spring loaded accumulator.



41

Gas charged accumulator



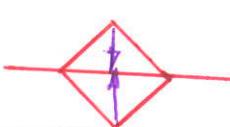
42

Filter or strainer.



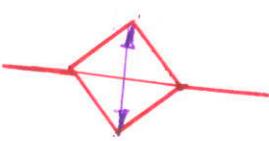
43

Heater.



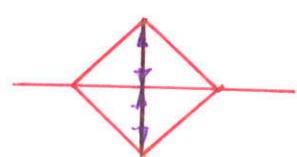
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Cooler



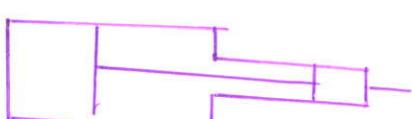
45

Temperature controller



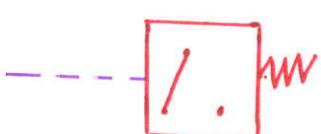
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Intensifier.



47

Power switch

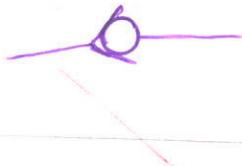


# Basic Valve Symbols.

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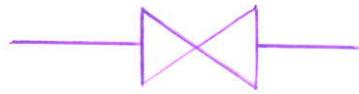
48 Check Valve.

48



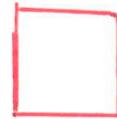
49 Manual Shut off Valve.

49



50 Basic Valve Envelope

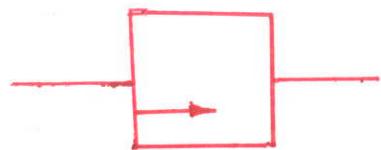
50



51 Single flow path

Normally closed valve

51

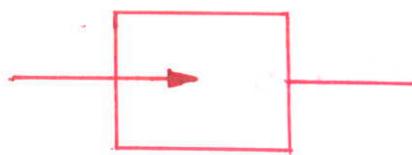


Valve:

Single flow path

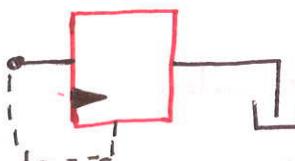
Normally open.

51



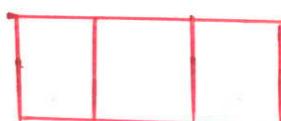
52 Maximum pressure relief valve.

52



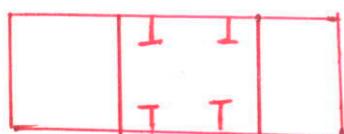
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Multiple flow paths.



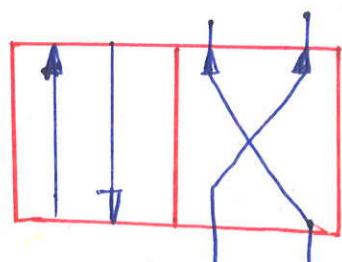
54

Flow paths Blocked in  
Centre position



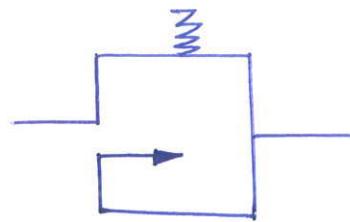
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Multiple flow paths  
[Arrow shows flow direction]

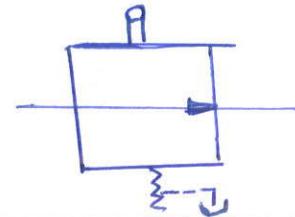


## Valve Examples:

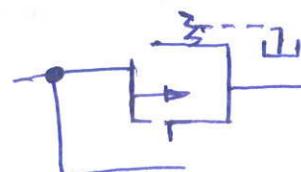
57 Unloading valve,  
Internal drain, Remotely  
operated.



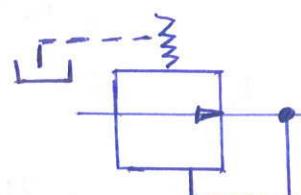
58 Direction Valve Normally open



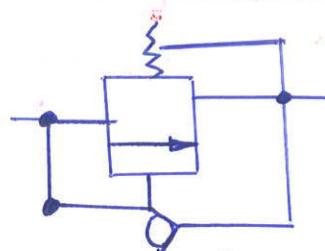
59 Sequence valve, Directly  
operated Externally Drained



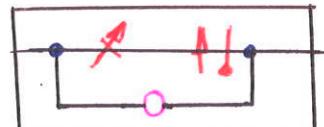
60 Pressure reducing valve.



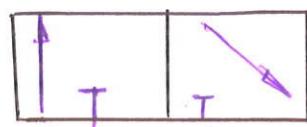
61 Counter balance valve with integral  
check.



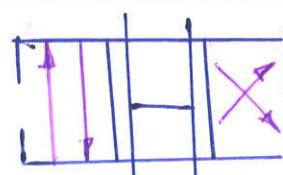
62 Temperature and pressure  
Compensated flow control  
with integral check.



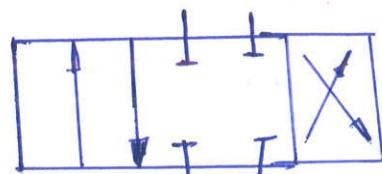
63 Direction Control Two position  
Three connection



64 Directional valve Three  
Position 4 connection.



65 Valve infinite positioning.  
[Indicated by horizontal bars]



1. If  $Re$  is less than 2000 -the flow is laminar.

2. If the  $Re$  greater than 4000 then the flow is Turbulent

3. If the  $Re$  lies b/w 2000 and 4000 covers a Critical zone b/w laminar and turbulent flow.

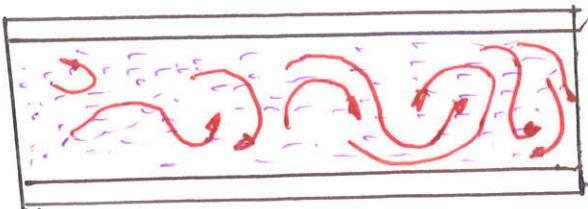
It is not possible to predict the type of with in a Critical zone .Thus if Reynolds Number lies in Critical zone, Turbulent flow should be assumed .if the turbulent flow is allowed to exist, higher fluid temperature occurs due to greater frictional energy losses. Therefore, turbulent flow systems suffering from excessive Fluid Temperature can be helped by increasing pipe diameter to establish laminar flow.



Darcy- Weisbach Equation:-

If the fluid flows through a length of pipe and pressure measured at two stations along the pipe , one finds that the pressure decreases in the direction of flow. This pressure decrease is mainly due to friction of fluid against the pipe wall.

Pattern, as in the case of eddies.



### Reynolds Number:-

In the flow of a fluid through a completely filled conduit, gravity does not affect the flow pattern. It is also obvious that capillarity is of no practical importance, and significant forces are inertia force and fluid friction due to viscosity. The same is true for an aeroplane travelling at speed below that with compressibility is appreciable. Also for submarine submerged far enough so as not to produce waves on the surface, the only forces involved are those of friction and inertia.

Reynolds number is the ratio of inertia force to viscous force.

$$Re = \frac{\rho D V}{\mu}$$

$V$  = Fluid Velocity

$D$  = Inside diameter of pipe.

$\rho$  = Fluid density

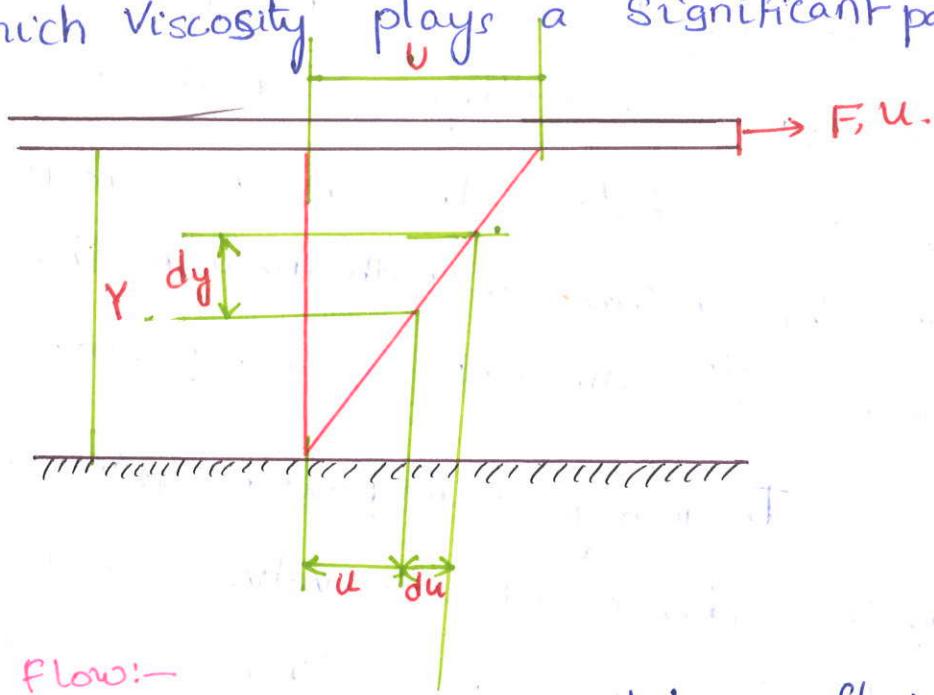
$\mu$  = Absolute Viscosity

There are two types of flows in pipes:-

### Laminar Flow:-

This is also known as stream line flow

Viscous flow. In stream line flow, the fluid appears to move by sliding of laminations of infinitesimal thickness relatively adjacent layer; that is, the particles move in definite and observable paths (or) stream lines. The characteristic of a viscous fluid is one in which viscosity plays a significant part.



### Turbulent Flow:-

It is characterized by a fluid flowing in random way. The movement of particles fluctuates up and down in a perpendicular direction as well as parallel to mean flow.

In mixing action generated turbulence due to juddering fluid particles. This causes ~~a~~ considerable more resistance to flow and thus, greater energy losses than those produced by laminar flow. A distinguishing characteristic of turbulence is its irregularity. There being no definite frequency as in wave motion and no considerable

## → Energy losses in hydraulic Systems.

Liquid such as petrol or water much easily flows <sup>than</sup> other oils. The resistant to flow is essentially a measure of viscosity of a fluid. The greater viscosity of a fluid, the less readily it flows and more energy required to move it. The energy lost because its dissipated as heat.

Energy losses occurs in Valves and fittings. Various types of fitting, such as bends, couplings, tees, elbows, filter, strainers etc are used in hydraulic systems. The nature of path through the valve fittings determine ~~the~~ amount of energy losses.

In many fluid power applications, the energy loss due to flow in valves and fittings exceed those due to flow in pipes. Therefore a proper selection of fitting is essential. In general the smaller size pipe fittings the greater the losses.

The Energy Equation and the continuity equation can be used to perform the complete analysis of a fluid system. This includes calculating pressure drops, flow rates, and power losses for all components of fluid power systems.

Friction is the main cause of energy losses in fluid power systems. The prediction of this friction loss is one of the important problems in fluid power.

Head losses in a long pipe in which the velocity distribution has become fully established or uniform along its length can be found by Darcy's equation as.

$$H_L = f \left[ \frac{L}{D} \right] \left[ \frac{V^2}{2g} \right]$$

Where

$f \rightarrow$  Darcy friction factor.

$L \rightarrow$  Length of the pipe. (m)

$D \rightarrow$  Diameter of the pipe. (m)

$V \rightarrow$  average Velocity (m/s)

$g \rightarrow$  Acceleration due to gravity [m/s<sup>2</sup>]

Actual dependence of  $f$  on  $Re$  has to be determined experimentally. Friction factor determined do not apply near the entrance portion of a pipe where the flow can change quickly from one cross section to next or to any other flow in which acceleration terms are not negligible.

## Friction losses in laminar flow:

Darcy's equation can be used to find head losses in pipes by noting that laminar flow, the friction factor equals the constant 64 divided by Reynold's Number.

$$f = \frac{64}{Re}$$

Substituting this in Darcy's equation gives Hagen - poiseuille Equation.

$$\boxed{H_L = \frac{64}{Re} \left[ \frac{L}{D} \right] \left[ \frac{V^2}{2g} \right]}$$

## Friction losses in turbulent flow:

Darcy's Equation can be used to find head losses in pipes experiencing turbulent flow. However the friction factor in turbulent flow is function of Reynold's Number and the relatively roughness of the pipe.

## Effect of Pipe Roughness:

The relative roughness of the pipe is defined as the ratio of inside surface roughness ( $\epsilon$ ) to the diameter.

$$\boxed{\text{Relative Roughness} = \frac{\epsilon}{D}}$$

Type of the pipe	$\epsilon$ (mm).
Glass (or) plastic.	
Drawn tube	0.0015
wrought iron	0.046
Commercial steel	0.046
Asphalted cast iron	0.12
Galvanized iron.	0.15
Cast iron	0.26
Riveted steel.	1.8

To determine the values of the friction factor for use in Darcy's we use the Moody diagram. If we know the relative roughness and Reynolds number, the friction can be determined easily. No curves drawn in the critical zone.  $Re$  lies between 2000 and 4000 because it is not possible to predict whether laminar (or) turbulent in this region.

$$f = \frac{64}{Re}$$

## Frictional losses in Valves and fittings

The majority of the energy losses occurs in Valves and fittings in which there is a change in the cross-section of flow path and a change in direction of the flow.

$$H_L = K \left[ \frac{V^2}{2g} \right]$$

$K$  = Loss coefficient of Valve (or) fitting.

Table for fittings.

Valve (or) fitting	K factor.
Globe valve	wide open      10
	$\frac{1}{2}$ open      12.5
Gate valve	Wide open      0.20
	$\frac{3}{4}$ open      0.90
Return bend	$\frac{1}{2}$ open      4.5
	$\frac{1}{4}$ open      24.
Standard tee	2.2
Standard elbow	1.8
45° elbow	0.90
90° elbow	0.42
Ball check Valve	0.75
Union socket	4
	0.04

## Equivalent length technique:

We can find a length of pipe that for the same flow would produce the same head loss as a valve (or) fitting. The length of the pipe which is called the equivalent length of the valve (or) fitting, can be found by equating head losses across the valve (or) fitting and the pipe.

$$K \left[ \frac{V^2}{2g} \right] = f \left[ \frac{L_e}{D} \right] \left[ \frac{V^2}{2g} \right]$$

$$L_e = \frac{K D}{f}$$

de- Equivalent length of a valve or fitting



## -: Hydraulic pumps:-

The function of hydraulic pump is to Convert mechanical Energy into hydraulic Energy . It is the heart of any hydraulic system because it generates the force necessary to move the load. Mechanical Energy is delivered to the Pump by using a prime mover such as an electric motor. Partial Vacuum is created at the inlet due to the mechanical rotation of pump shaft. The pump then pushes the fluid mechanically into the fluid power actuated devices such as a motor or a cylinder.

Pumps are classified into 3 different ways and must be considered in any discussion of fluid power equipment.

1. Classification based on displacement.

- a. Non-positive displacement pumps [Hydrodynamic Pumps]
- b. Positive displacement Pumps. [Hydrostatic pumps]

2. Classification based on delivery:

- a. Constant delivery pumps.
- b. Variable delivery Pumps.

### 3. Classification based on motion:-

a. Rotary Pump

b. Reciprocating Pump.

### Non-Positive displacement Pumps:

These pumps are generally used for low pressure and high discharge applications. Therefore these pumps are primarily used for transferring fluid from one location to another location. Most of these pumps operated by Centrifugal force. Fluid entering the center of the pump housing is thrown out by a rotating impeller. There is no positive sealing between inlet and outlet ports, hence these pumps are not self primed. Though these pumps are able to provide smooth and continuous flow, the output decreases with external circuit resistance.

As the resistance buildup in the discharge side, the fluid slips back into the clearance spaces, or in other words, follows the path of least resistance. When the resistance gets to a certain value, no fluid get delivered to the system and the volumetric efficiency of the pump drops to zero for a given speed. These pumps are not used in fluid power industry as they are not capable of withstanding high pressure. Their max. capacity

the maximum capacity is limited to 17-20 bar<sup>(1)</sup>

These types pumps are primarily used for transporting fluids such as water, petroleum etc to one location to another.

Most commonly used hydrodynamics pumps are Centrifugal and the axial flow propeller pumps.

Advantages of Non-displacement pumps:-

- These pumps have fewer moving parts.
- Initial Maintenance cost is low.
- They give smooth and continuous flow.
- They are suitable for handling almost all types of fluid including slurries and ~~sugars~~ sledges.
- Their operation is simple and reliable.

Disadvantages:-

- Non-displacement pumps are not self priming and hence they must be positioned below the fluid level.
- Discharge is a function of output resistance.
- low volumetric efficiency.

## Positive displacement pumps:-

These pumps are most commonly used in hydraulic system. In these pumps a specific quantity of fluid is delivered per stroke per revolution. The pressure built-up by these pumps rapidly increase with External Circuit resistance. A pressure relief valve is usually provided to protect the pump against over pressure diverting the fluid flow back to reservoir.

These pumps can be classified according to

### (i) Type of motion of internal elements

#### a) Rotary Pumps.

Ex: Gear pumps, lobe pumps,

Screw pumps, Vane pumps.

#### b) Reciprocating Pump:

Ex: Piston pumps

### (ii) Displacement

#### (a) Fixed displacement pumps.

The discharge (or) volume of flow rate is constant

Ex: Gear pumps, lobe pumps, Vane pumps

#### (b) Variable displacement pumps.

The discharge (or) volume of flow rate is not

Ex: Piston pumps can be fixed or variable displacement

(20)

Advantages of positive displacement pumps over non-Positive displacement pumps.

- They can operate at very high pressures of upto 800 bar. [used to lifting oils from very deep oil well.]
- They can achieve a high volumetric efficiency of up to 98%.
- They are highly efficient and almost constant through out the designed pressure range.
- They are a compact unit, having a high Power to weight Ratio.
- They can obtain smooth and precisely controlled motion.
- By Proper application and control, they produce only the amount of flow required to move the load at desired Velocity.
- They have a great flexibility of performance.
- They can be made to operate a wide range of pressures and speeds.

## Classification based on Delivery:

### Constant Delivery Pumps:

Constant Volume pumps ~~are~~ always deliver the same quantity of the fluid in given time at the operating speed and temperature. These pumps are used with relatively simple machines, such as saws or drill presses (or where a group of machines are operated with no specific relationship among their relative speeds). Power for reciprocating actuators is most often provided by Constant Volume Pumps.

### Variable Delivery Pumps:

The output of Variable volume pumps may be either manually (or) automatically with no change in the input speed to the pump. Variable volume pumps are frequently used for rewinds, constant tension devices (or) where a separate driver has an integrated speed relation such as a conveyor system continuously processing equipment.

## Classification Based on motion

(21)

This classification concerns the motion that may be either rotary or reciprocating. It was of greater importance when reciprocating pumps consisting only of a single or a few relatively large cylinders and the discharge had a large undesirable pulsation.

Differences b/w Positive and Non-positive displacement Pumps:

### Positive displacement Pumps

The flow rate does not change with head

The flow rate is no much affect by the viscosity of fluid

Efficiency is almost constant with head

High volumetric efficiency

Can operate at very high pressure

### Non-positive displacement Pumps

The flow rate decrease with head.

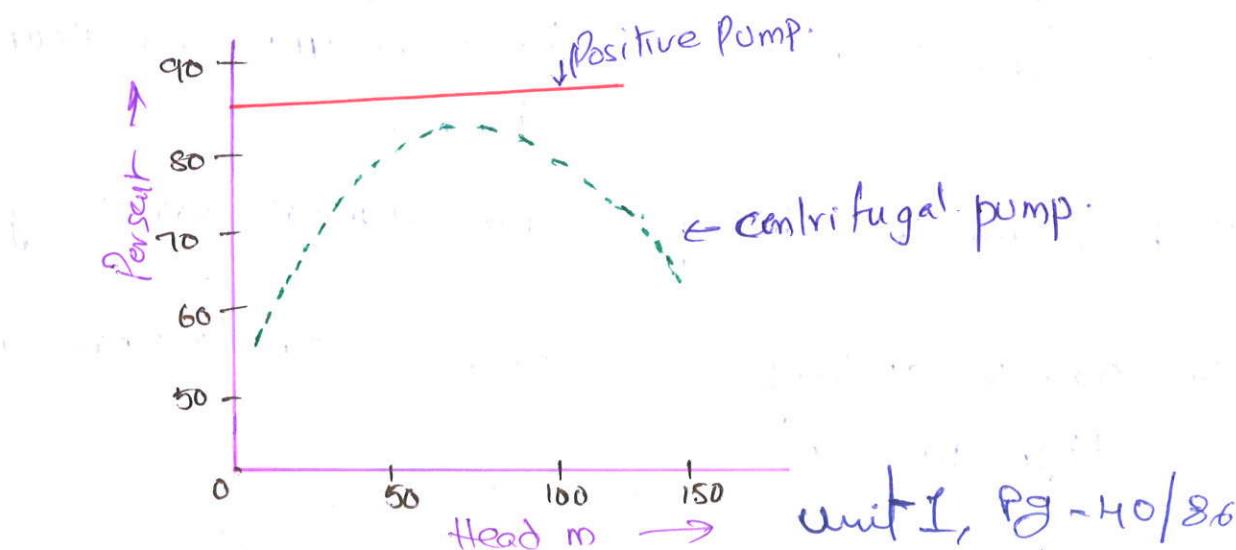
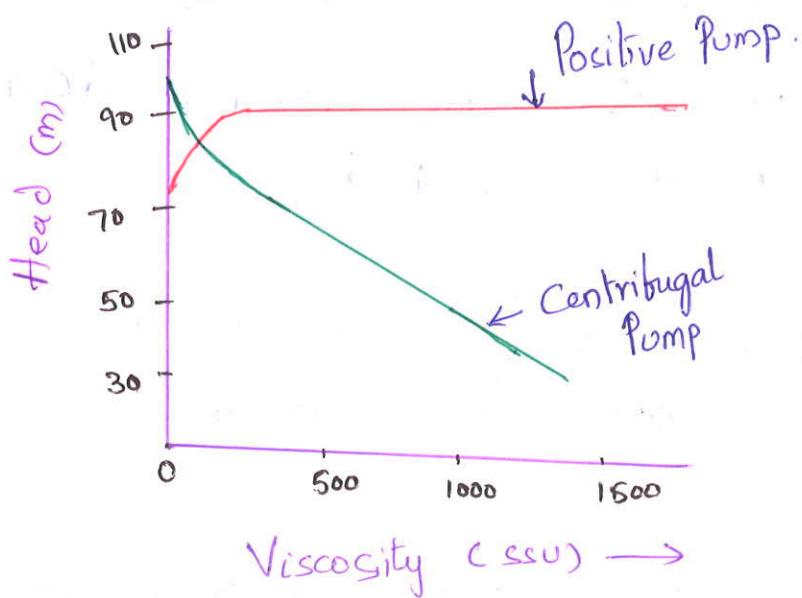
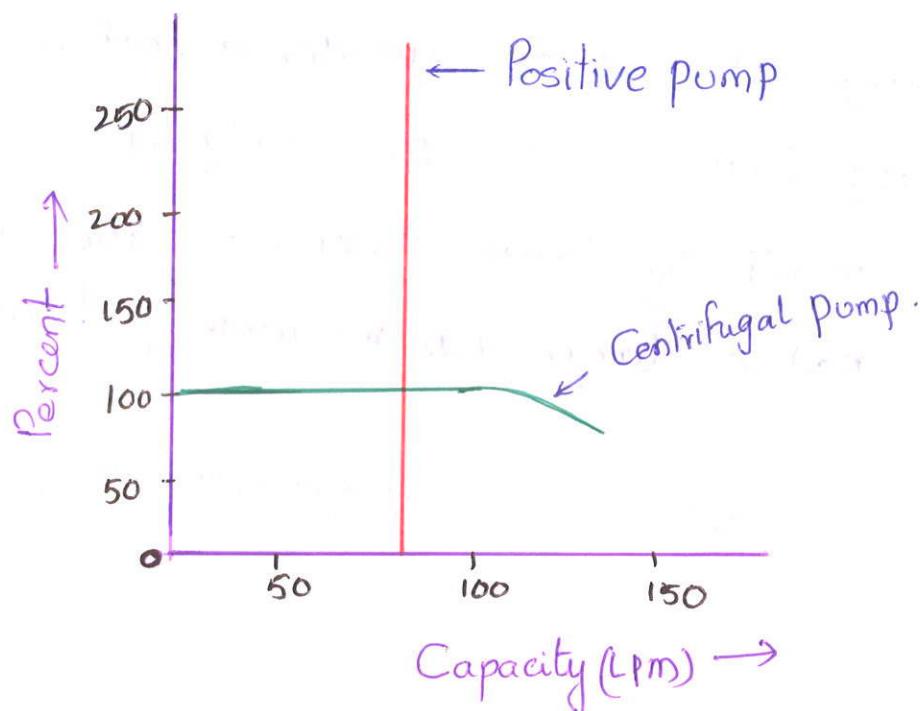
The flow rate decreases with the Viscosity

Efficiency increases with head at first and then decreases.

Low volumetric efficiency

operated at low pressures.

## Performance Curves for positive and non-positive displacement pumps.

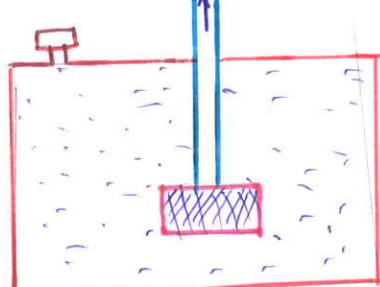
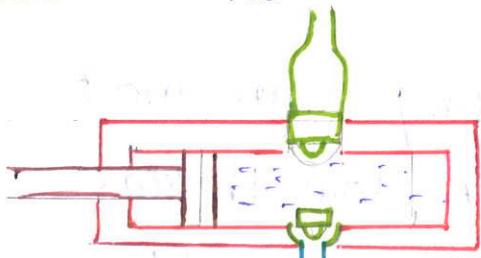


## Pumping theory:-

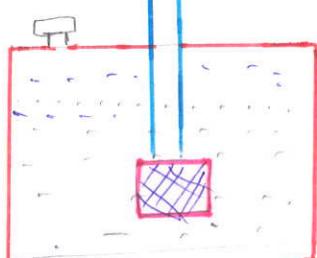
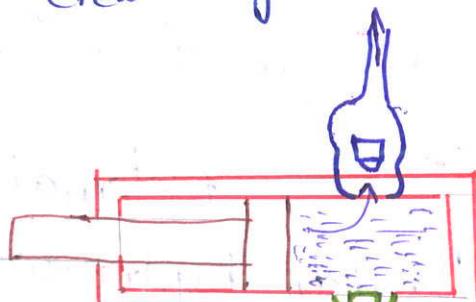
(22)

A Positive displacement hydraulic Pump is a device used for Converting mechanical energy into hydraulic Energy . It is driven by prime mover Such as, electric motor. It basically performs two functions first it creates a partial Vacuum at the pump inlet port. This vacuum enables atmospheric pressure to force the liquid from the reservoir into the pump. 2. The Mechanical action of the pump traps this fluid within the pumping cavities, transport it through the Pump and forces into the hydraulic System.

It is important to note that pumps create flow not Pressure. Pressure created by resistance to flow



Suction stroke



unit 1, Pg - 11 / 86

## Gear Pumps:-

Gear Pumps are very less expensive but limited to 140 bar. It is noisy in operation than either Vane or Piston pumps.

Gear Pumps are invariably of fixed displacement type which means that the amount of fluid displaced for each revolution of the drive shaft is theoretically constant.

Gear Pumps are classified into two types

1. External Gear pumps.

2. Internal Gear pumps

## External Gear Pumps:-

External Gear pumps are most popular hydraulic pumps in low-pressure range due to their long operating life, high efficiency and low cost.

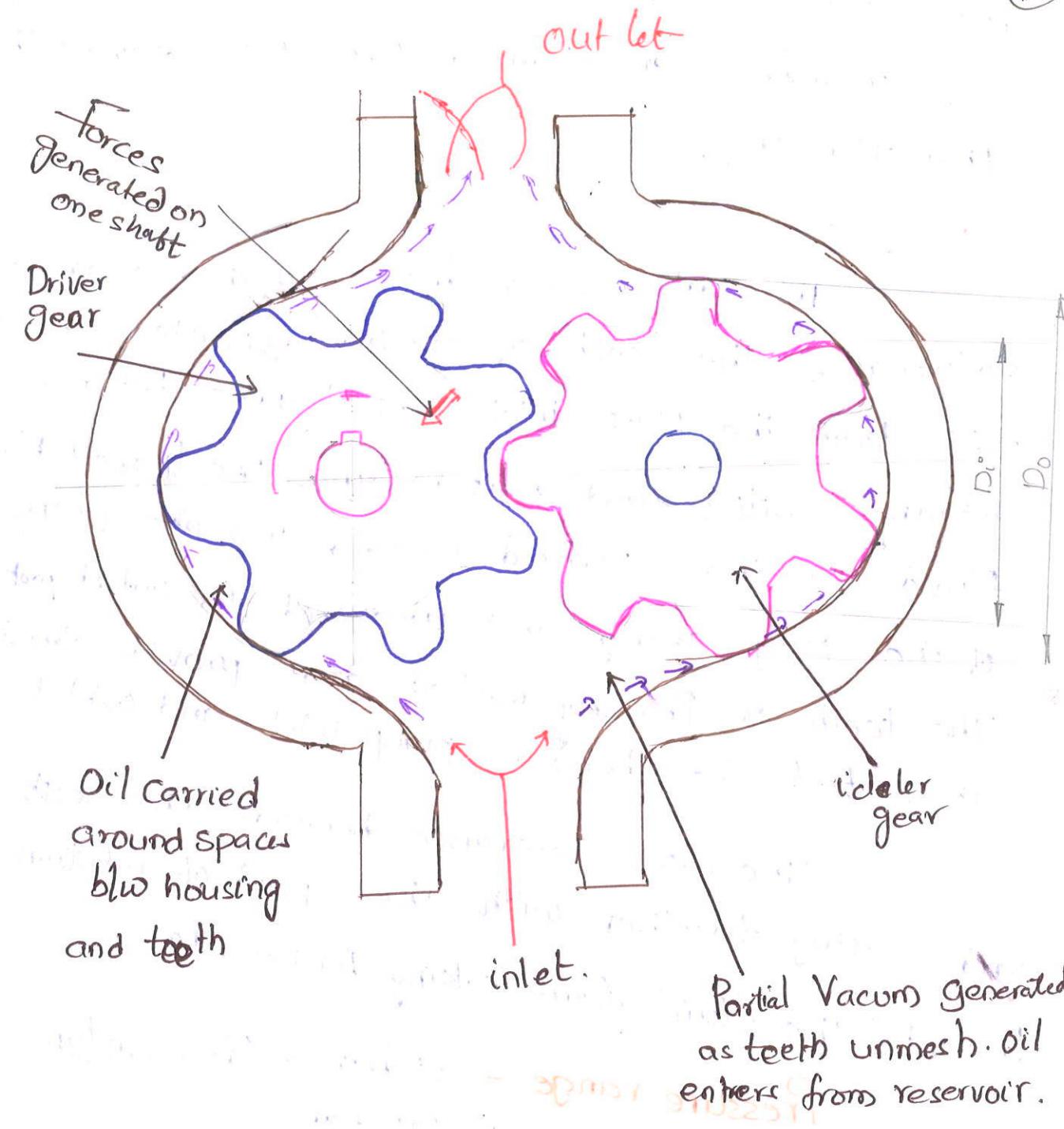


Fig:- External Gear Pump.

### Construction:-

The ~~consist of~~ <sup>←</sup> An External gear pump consists of two intermeshing gears of size and form mounted on separate spindles. The gears are housed in a close fitting casing. One gear on shaft connected to the



# (24)

## Expression for the theoretical flowrate of an

External pump:

Let:

$D_o$  - The outside diameter of the gear teeth.

$D_i$  - The inside diameter of the gear teeth

$l$  - The width of the gear teeth

$N$  - The speed of the pump in RPM.

$V_D$  - Displacement of the pump.

$M$  - module of the gear

$Z$  - no. of gear teeth

$\alpha$  - Pressure angle

volumetric Displacement

$$V_D = \frac{\pi}{4} [D_o^2 - D_i^2] L$$

$$D_i = D_o - 2 [\text{Addendum} + \text{dedendum}]$$

Theoretical Discharge

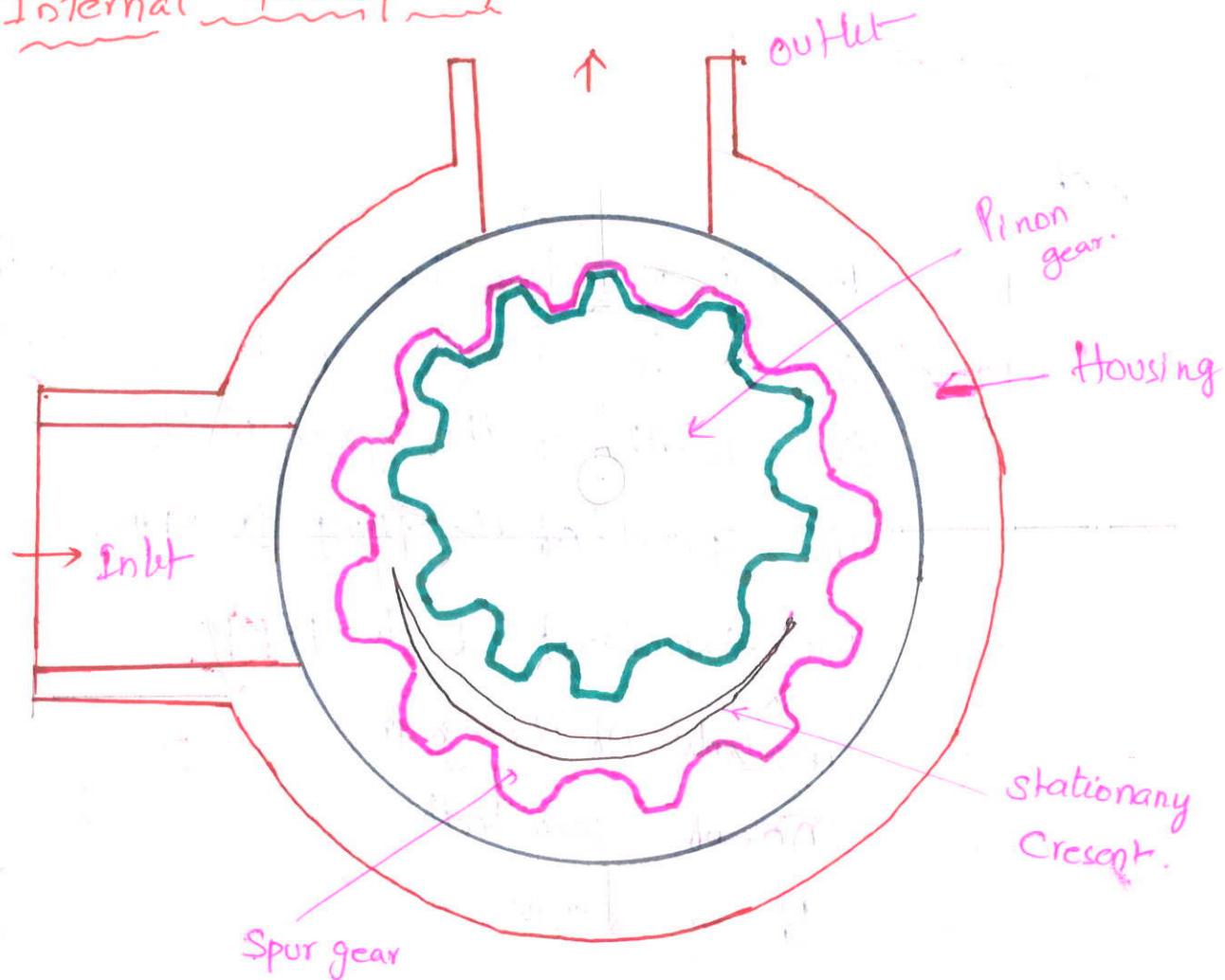
$$Q_T = V_D \times N = \frac{m^3}{rev} \times \frac{Rev}{min}$$

$$= m^3/min.$$

If the Gear is specified by no. of gear and  
no. of teeth then the theoretical discharge can  
be

$$Q_T = 2\pi L m^3/min \left( Z + \left[ 1 + \frac{\pi \cos 20^\circ}{12} \right] \right) m^3/min$$

## Internal Gear pumps:-



Internal Gear pump Comprises an internal gear, a regular Spur gear, a crescent-shaped seal and external housing. The internal gear is eccentrically located within the outer spur gear ring, the tooth from being selected such that correct meshing of two gears is to occurs. Rotation when the teeth engage on side opposite to the crescent seal, the fluid is forced to enter the discharge side of the pump.

The fluid volume is directly proportional to the degree of separation and these units may be reversed without difficulty.

Internal gear Pump. Compared to External Pump, reduces the intensity of pressure generated and decreases the shear force on the fluid. It is also operated at much lower noise levels. These pumps have higher pressure capability than external gear pumps. This pump generally fixed displacement type.

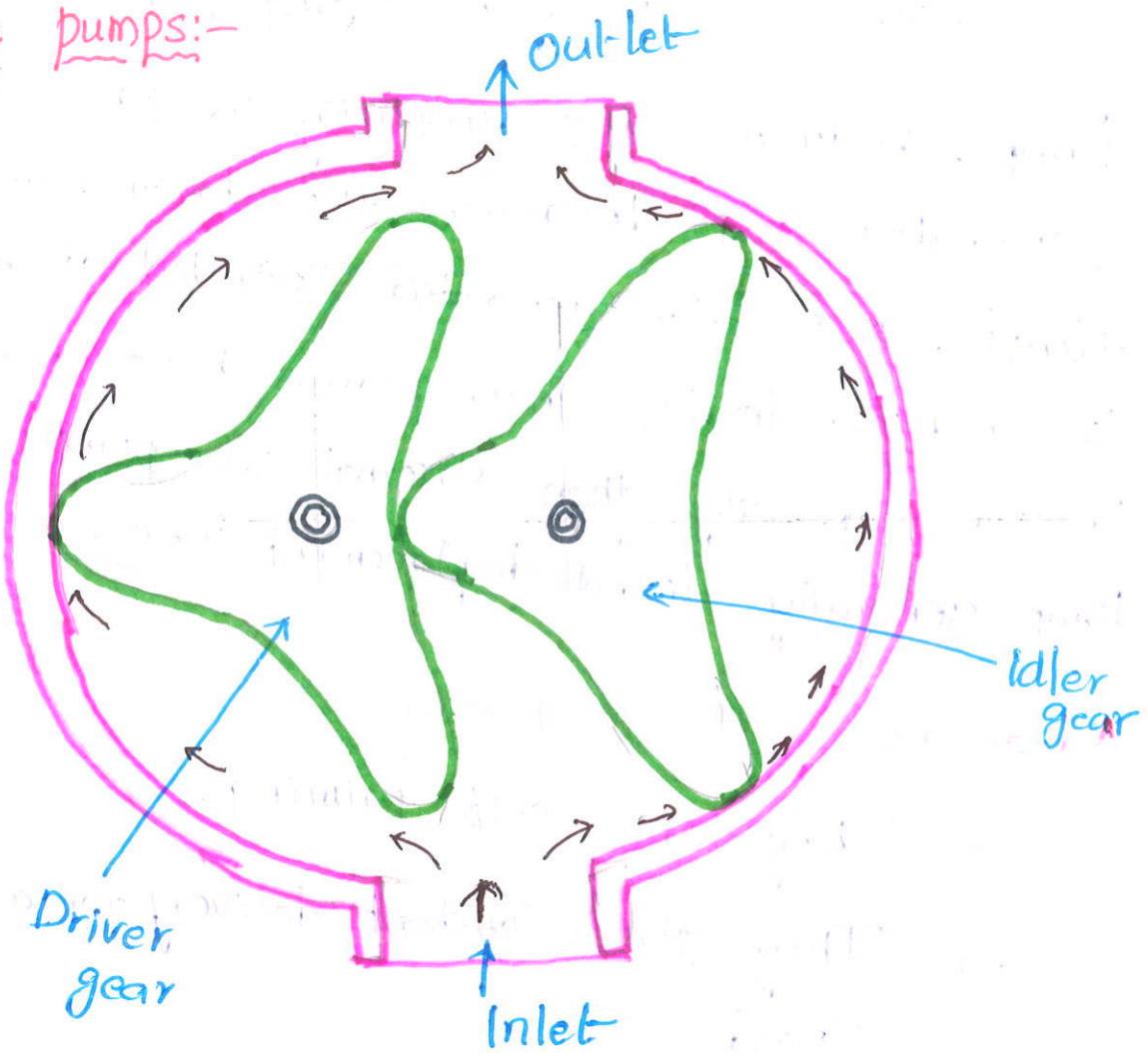
### Advantage of Gear pumps:-

- They are self priming.
- They give constant delivery for a given speed.
- They are compact and light in weight.
- Volumetric efficiency is high.

### Disadvantage of Gear pumps:-

- Liquid to be pumped must be clean, otherwise it will damage pump.
- Variable speed drive are required to change the delivery.
- If they run dry, parts can be damaged because the fluid pumped is used as lubricant.

## Lobe pumps:-



The operation of lube pump is similar to that of external gear pump, but generally they have high volumetric efficiency. Two lobes are enclosed in a chamber and drive externally so that they do not actually contact each other. As they rotate fluid caught between two lobes and the wall of the pump chamber carries around from suction to discharge. Lobe pump is used for pumping fluid with low pressure and high flow rate.

## Advantages of lube pumps:-

(26)

- Can handle many types of liquids including slurries.
- Non-metal to metal contact.
- Quieter in operation.
- Long-term dry run. (with lubrication seal)
- Volumetric displacement is greater than other types of gear pumps.

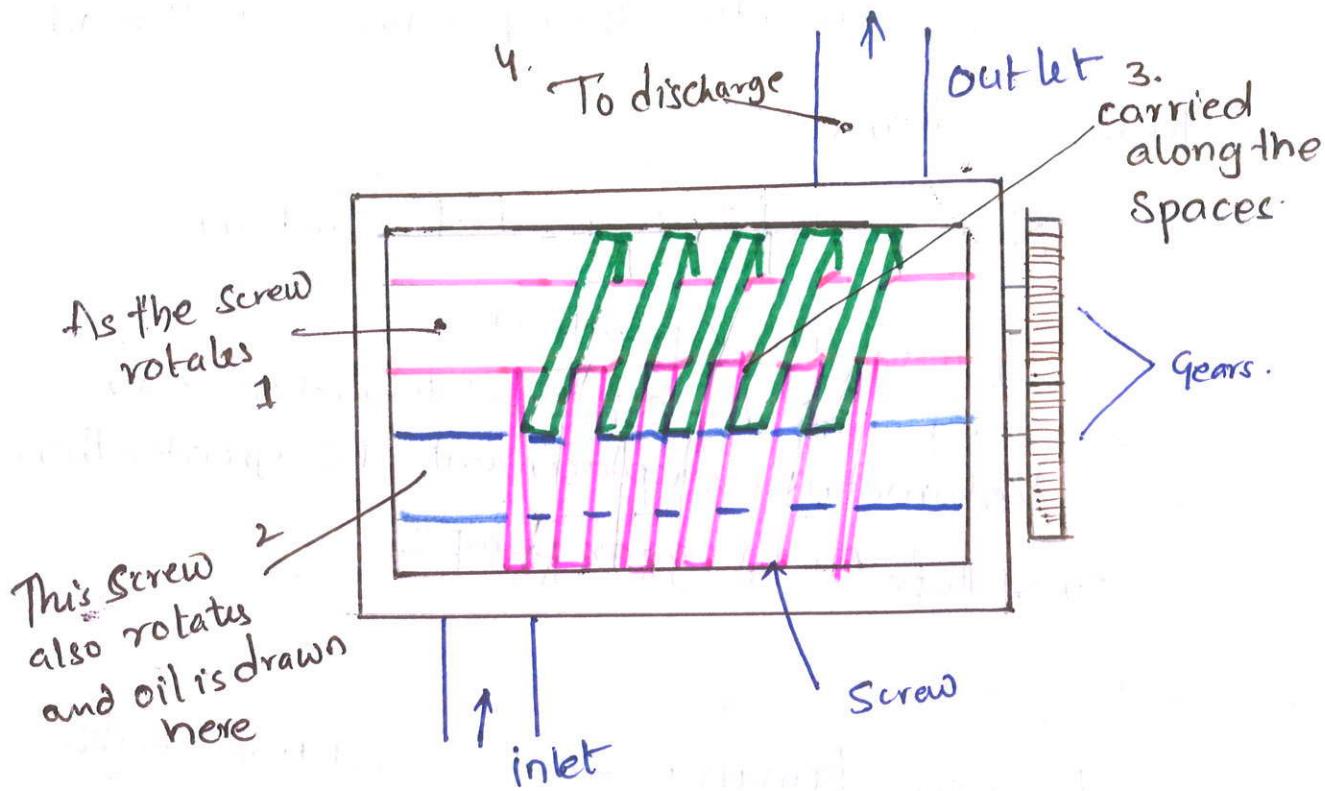
## Disadvantages:-

- Require timing gears and two seals.
- Reduced lift within thin liquid.

## Applications:-

- Polymers
- Paper Coatings
- Soaps and Surfactants
- Paints and dyes
- Rubber and adhesives
- pharmaceuticals
- food applications

## Screw pump:-



Screw pump is suitable for handling large volumes of oil. It is an axial flow Positive displacement pumps.

These pumps have one drive shaft connected to prime mover (driving rotor) and one or two idle shafts (driven rotor) all having helical screws with the same pitch. Partial vacuum is created at inlet when the teeth of screw disengages. Oil flows from the sump and enters the inlet of the pump. During the rotation of the screw the spaces between threads divided into compartments from the ends. The oil carried out by these compartments is pushed

towards the along the axis towards the  
Centre of the pump from where it is discharged  
to the outlet at high Pressure.

A two screw pump consisting of  
rotors with intermeshing threads. The screws  
are enclosed in a casing. A fluid tight  
seal is formed between screws and casing  
Screws having left hand threads one side and  
right hand threads on other.

These pumps deliver non-pulsating  
flow quietly and efficiently and are suitable  
for high speed operations. Capacities range from  
5 lit/min to 7200 lit/min with pressure upto 140  
bar.

### Advantage of Screw pumps:-

- They are self priming and more reliable.
- They are quiet due to rolling action of screw spindles.
- They can handle liquids containing gases and vapours.
- They have long service life

## Disadvantages:-

- They are bulky and heavy.
- They are sensitive to viscosity changes of the fluid.
- They have low volumetric and mechanical efficiency.
- Manufacturing cost of Precision screw is high.

## Vane pump

### Applications :-

- Lifts
- elevators.
- hydraulic press.
- In machine tools for actuating the slides.

## Vane pump:-

(28)

The pump consists of rotor mounted eccentrically in the cam ring. The rotor contains radial slots. each slot comprises a vane which is free to slide. The rotation of rotor causes the vane slides in and out of the slots. These vanes are kept constant with the surface of the cam ring due to centrifugal force. The vanes divide the spaces between the rotor and cam ring into number of small chambers (pumping chambers). Rotor rotation causes increase in volume of the chambers near inlet and decrease at outlet. The increase in volume at inlet creates vacuum (or) suction, drawing oil in. The decrease in volume at outlet compresses the oil and delivers it to the delivery side.

Vane pumps are suitable for medium pressure and medium speed duties. The main limitation of the pump is that the sealing at low speeds may be poor because the radial pressure exerted on the vane is directly proportional to the speed of rotation. This can be overcome by spring loaded vanes. These pumps can deliver

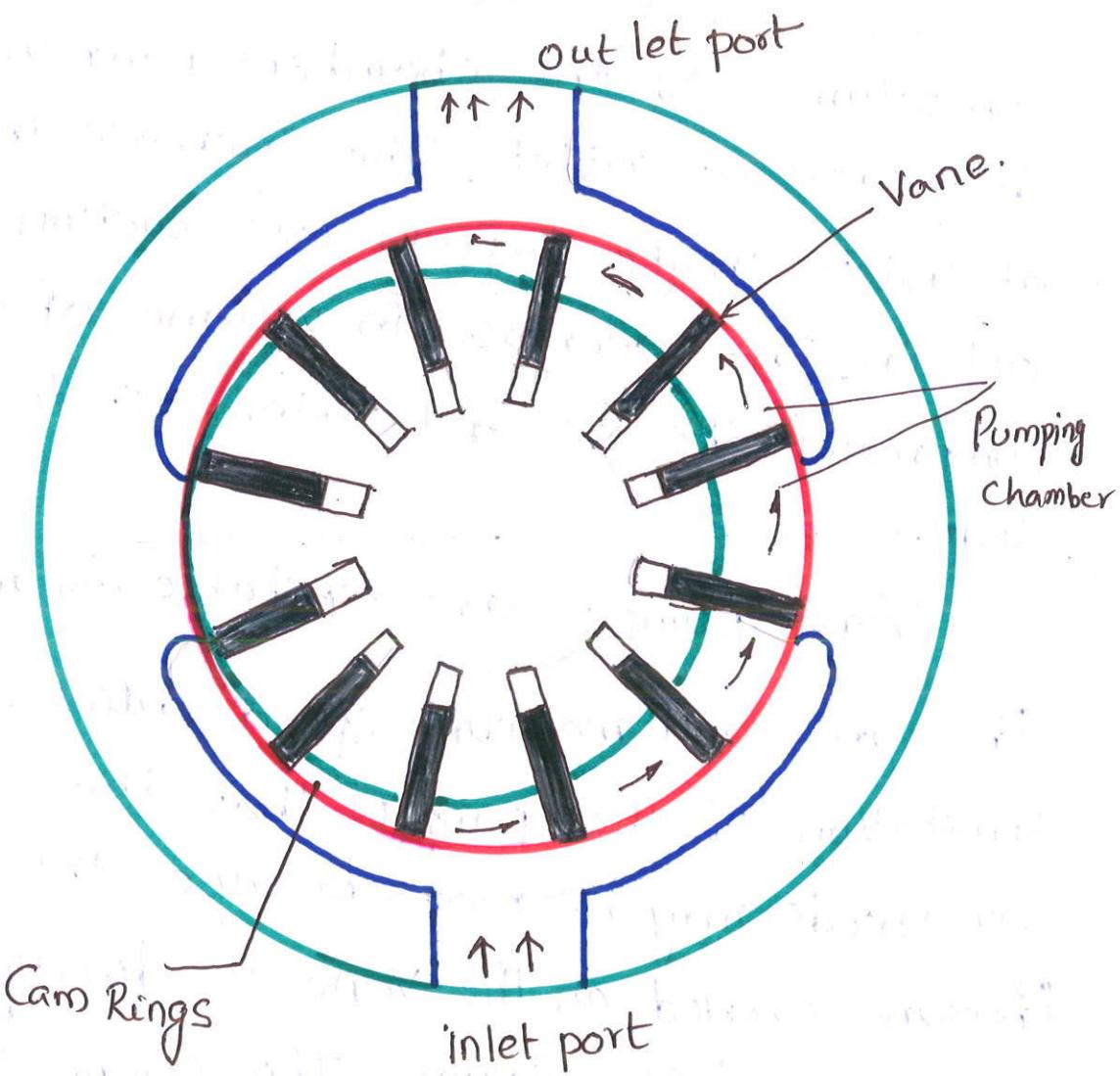
develop pressures upto 70-100 bar with speed upto 2500 rpm. with max. delivery upto 410-455 lit/min. Minimum speed of Vane pump is of the order 200-450 Rpm.

### Types of Vane pumps

There are two types of Vane pumps.

1. Un balanced Vane pumps.

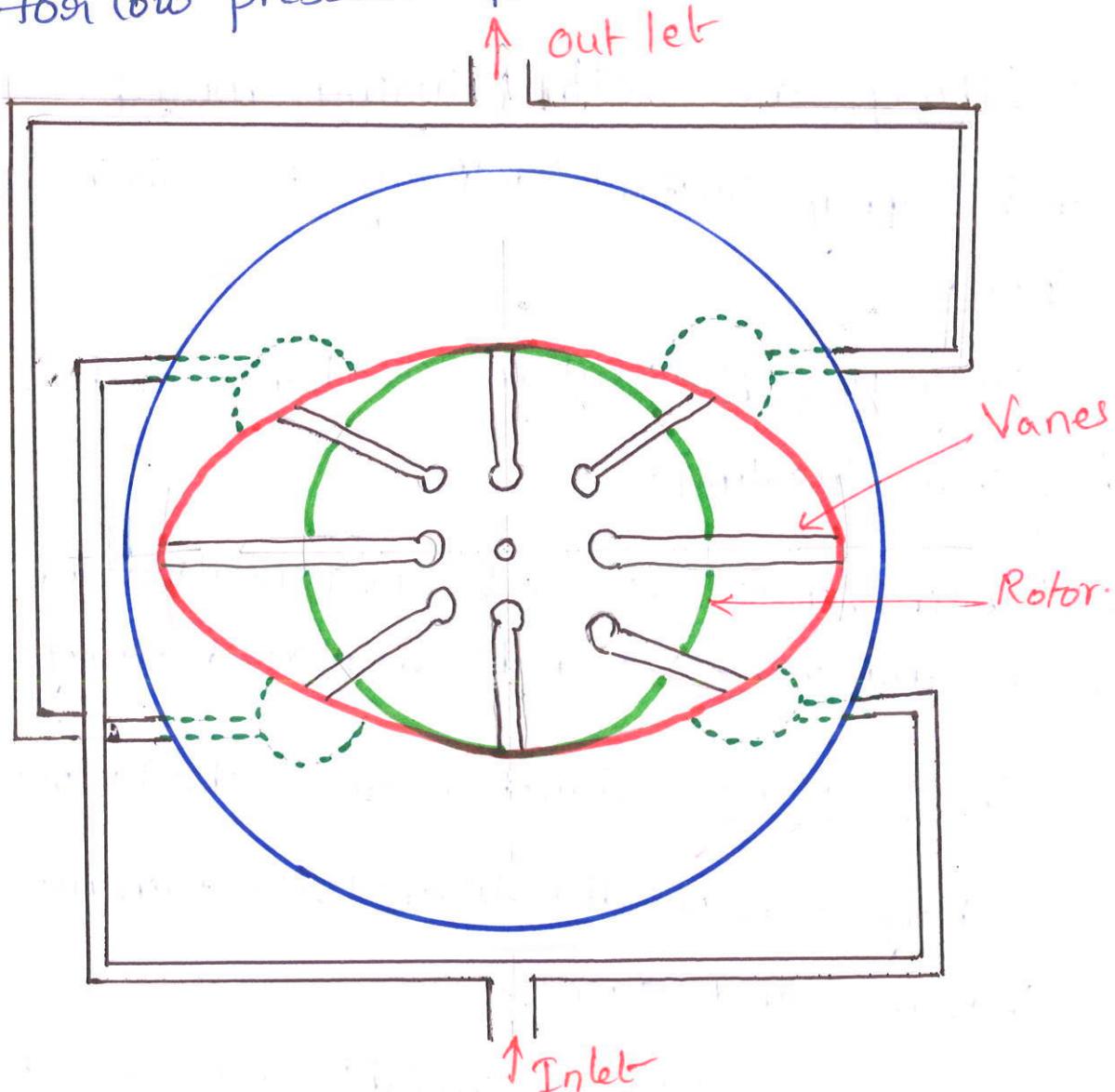
2. Balanced Vane pumps.



unbalanced Vane pump

(29)

In unbalanced Vane pump, the Pressure Chambers are located on only one side of the drive shaft. The outlet port at the top ~~is the Pressure~~ ~~outlet~~ under pressure, while the inlet port at the bottom is at Vacuum. This condition results in a net force on the pump shaft bearing that can cause excessive vibration and wear at high speed or pressures. Therefore these pumps are suitable for low pressure applications.



Balanced Vane pumps:

Unit 1, Pg - 55/86

## Advantages

In balanced Vane pump, two inlet ports and two outlet ports are located diametrically opposite each other. It has elliptical housing which forms two separate chambers on opposite side of the rotor. This eliminates the bearing side loads ~~thrust~~. Permit higher operating pressure.

## Advantages of Vane pump:

- They are self-priming, robust and supply constant delivery at a given speed.
- They provide uniform discharge with negligible pulsations.
- Their vanes are self-compensating for wear and vanes can be replaced easily.
- These pumps do not require check valves.
- They can handle liquids containing vapours and gases.
- They are light in weight and compact.

→ Volumetric and overall efficiencies are  $\textcircled{D}$  high.

→ Discharge is less sensitive to changes in Viscosity and pressure variations.

### Disadvantages :-

- Relief Valves are required to protect the Pump in case of sudden closure of delivery.
- They are not suitable for abrasive liquids.
- They require good seals.
- They require good filtration system and foreign ~~practical~~ particle can severely damage pump.

### Advantages of balanced Vane pumps:-

- The balanced Vane pumps eliminates the bearing side loads therefore high operating Pressure can be used.
- The service life is high compared to unbalanced type due to less wear and tear.

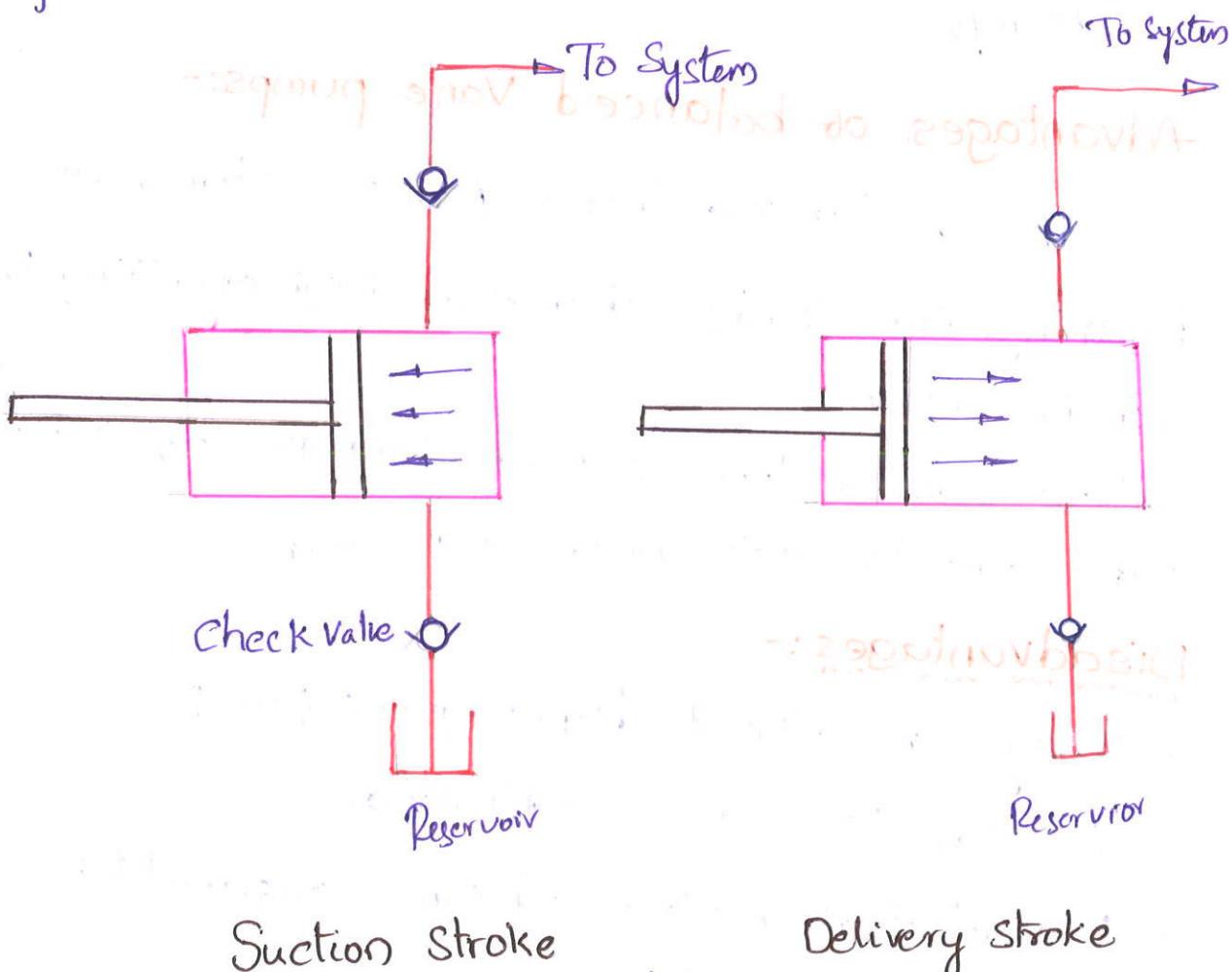
### Disadvantages :-

- They are fixed displacement pumps.
- Design is more complicated.
- Manufacturing cost is high compared to unbalanced type.

## Piston Pumps:-

A piston pump consists of a cylinder and a reciprocating piston. When piston retracts (moves towards the rod end) creates suction at inlet - drawing the fluid in. When piston extends (moving towards the cover end) compressing the fluid and delivered it to the system. The action of the piston pump. The check valves of a piston pump allows flow in only one direction.

Piston pumps have high volumetric efficiency combined with a wide range of delivery outputs.



There are basically two types of piston pumps:

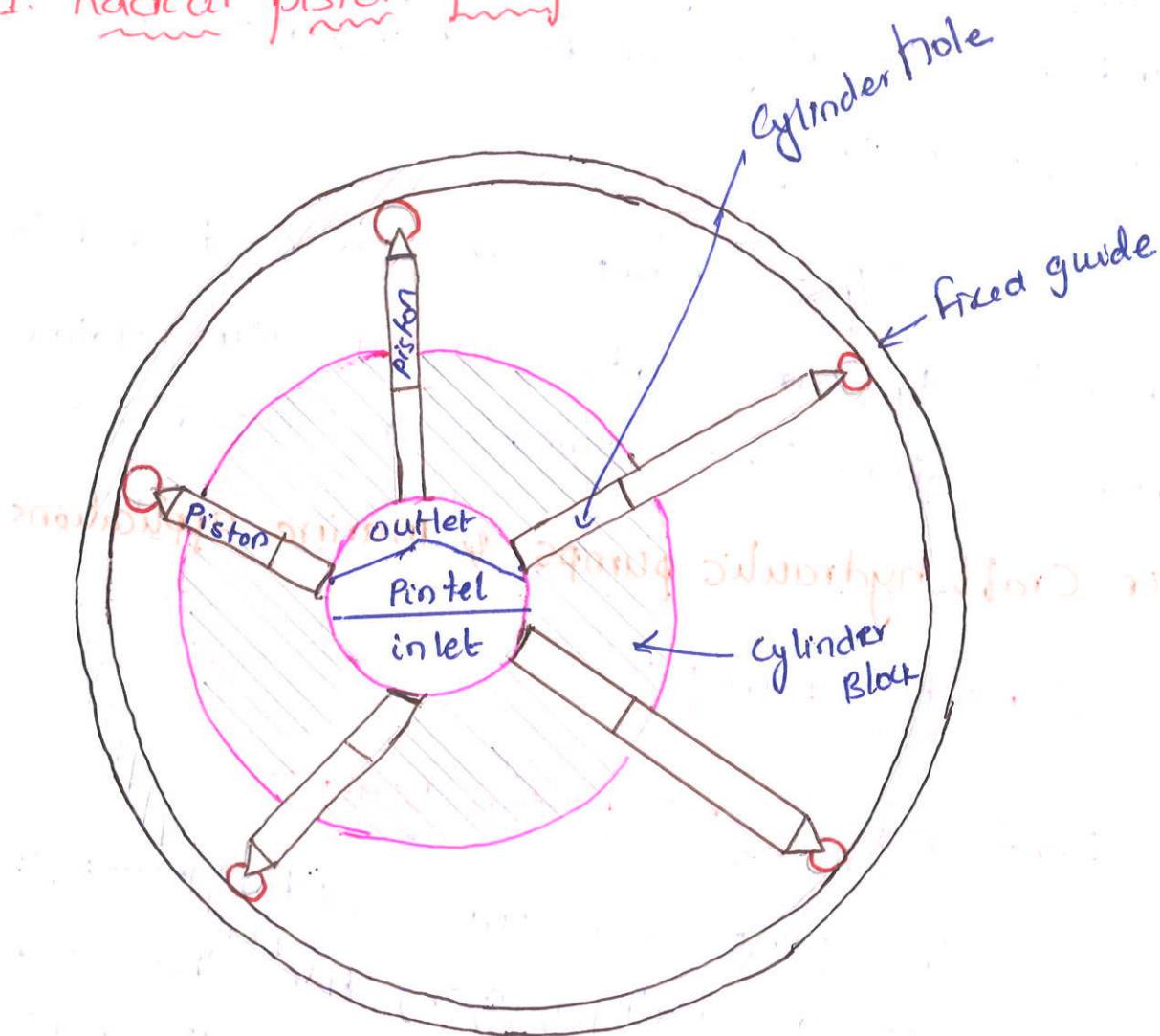
1. Radial piston pump

2. Axial piston pump.

(i) Bent axis type piston pump.

(ii) Swash plate type piston pump.

### 1. Radial piston pump:-



It consists of a cylinder block with pistons, a stationary pintel a fixed guide on reaction ring. The valve ports are located in the pintel. The cylinder block is mounted eccentric to the cam surface forming more space on one side of cylinder block and less space on other side.

The cylinder block keyed to the drive shaft. As the cylinder block rotates, the piston moves in and out radially. The outward stroke of piston draws the fluid in from the inlet port and inward stroke delivers fluid to discharge port. The eccentricity between the cylinder block and reaction ring can be changed to give variable delivery.

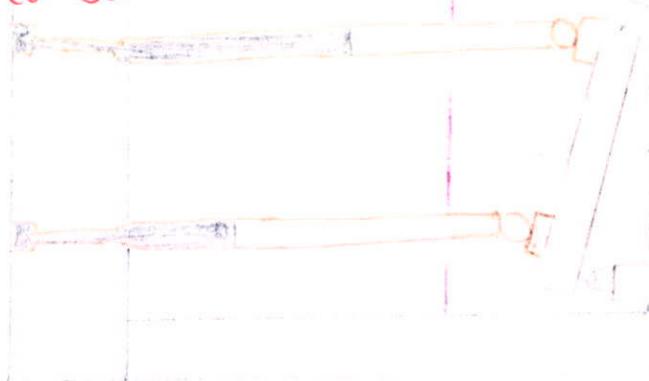
These pumps are compact and can generate pressure upto 210 bar can rotates upto 3000 rpm. These pumps are used as air craft hydraulic pumps & marine applications

### Axial piston pumps:-

#### i) Bent axis-type piston pump:-

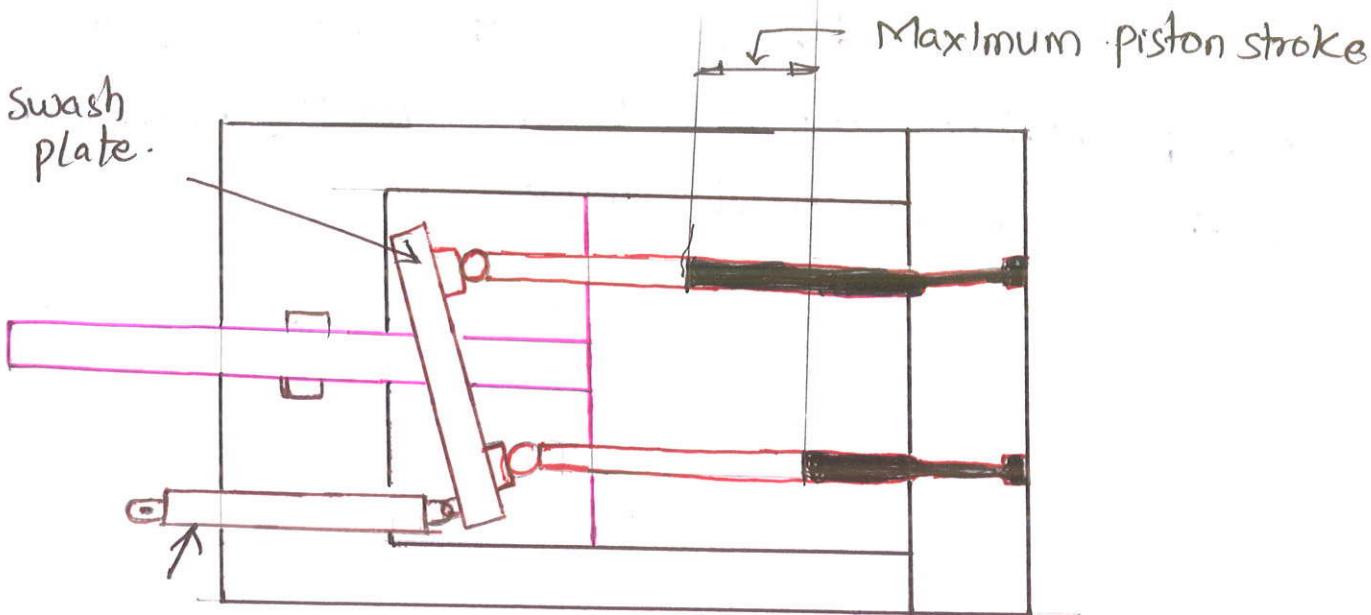
In bent-axis type piston pump, the cylinder at an angle rather than the swash plate. The cylinder block rotates with a drive shaft. Thus the rotation of drive shaft causes rotation of the cylinder bore block and pistons reciprocating inside the bore of cylinders. The cylinder block bores are open inlet and outlet ports of the valve plate. The volumetric displacement is  $\frac{60}{86}$ .

of the Pump depends on the offset angle. Fixed displacement units are usually provided with  $23^\circ$  to  $30^\circ$  offset angles.



Swoash plate Type piston pump <sup>(equally suitable for positive negation)</sup>  
In this type the cylinder block and drive shaft located on the same centerline. The Pistons are connected to a shoe plate that bears against angled swoash plate. As the cylinder rotates, the pistons reciprocate, because the piston shoes follow the angled surface of the swoash plate. The outlet and inlet ports are located in the valve plate so that the piston pass the inlet as they are being pulled out and pass the outlet as they are <sup>being</sup> forced back in. The type of pump can also be designed to have a variable displacement capability. The swoash plate angle is limited to  $17.5^\circ$  by construction.

Swash  
plate.



Displacement  
Piston.

Swash plate type piston pump:

Comparison of Hydraulic pumps:

	Pressure [bar]	Discharge (lpm)	Maximum speed (lpm)	Overall efficiency
Gear pump	20 - 175	7 - 570	1800 - 7000	75 - 90
Vane pump	20 - 175	2 - 950	2000 - 4000	75 - 90
Axial pump	70 - 1350	2 - 1700	600 - 6000	85 - 95
Radial piston pump	50 - 250	20 - 700	600 - 1800	80 - 92

Hydraulic pumps Graphic Symbols.



fixed displacement



Variable  
displacement



Bi-Directional.

unit 1, Pg - 62/86

## Pump Performance :-

(33)

The performance is the function of the precision of its manufacture. An ideal pump is one having zero clearance between all mating parts. Because this is not possible, working clearance should be as small as possible while maintaining proper oil films for lubrication between mating parts.

### i. Volumetric efficiency:-

It is the ratio of actual flow rate of the pump to the theoretical flow rate of the pump.

$$\text{Volumetric Efficiency} = \frac{\text{Actual flow rate of the pump}}{\text{Theoretical flow rate of the pump}}$$

Volumetric efficiency  $\eta_v$  indicates the amount of leakage that takes place within the pump. This is due to manufacture tolerance and flexing of the pump casing under designed operating conditions.

Gear pumps — 80% - 90%

Vane pumps — 92%

Piston pumps — 90 - 98%

Mechanical Efficiency :- [ $\eta_m$ ]

It is the Ratio of the pump output Power assuming no leakages to actual Power delivered to pump.

Mechanical efficiency =

Pump output power assuming no leakage  
Actual power delivered to the pump.

$$\eta_m = \frac{P \cdot Q_T}{T_A \cdot 2\pi N}$$

$T_A$  = Actual Torque

$N$  = Speed of the pump

$P$  = Pump discharge pressure  $N/m^2$

$Q_T$  - Theoretical discharge of pump.  
 $m^3/sec.$

In terms of Torque:

$$\eta_m = \frac{T_T}{T_A} \times 100$$

$T_T$  = Theoretical torque.

$$= \frac{\sqrt{P \times P}}{2\pi} \cdot Nm.$$

$T_A$  = Actual torque

unit :-  $\frac{\text{Actual Power delivered by pump}}{Pg - 64/862\pi N}$

Mechanical efficiency indicates the amount of energy losses that occurs for reasons other than leakage. This includes friction in bearings and mating parts. This includes energy losses due to fluid turbulence. Mechanical efficiencies are about 90-95%.

Overall efficiency :- It is defined as the ratio of actual power delivered by the pump to actual power delivered to the pump.

$$\text{Overall efficiency} = \frac{\text{Actual power delivered by the pump}}{\text{Actual power delivered to the pump}}$$

$$\eta_o = \frac{Q_A}{Q_T} \times \frac{P Q_T}{TAN}$$

$$\eta_o = \eta_v \times \eta_m$$

## Pump Performance Curves:-

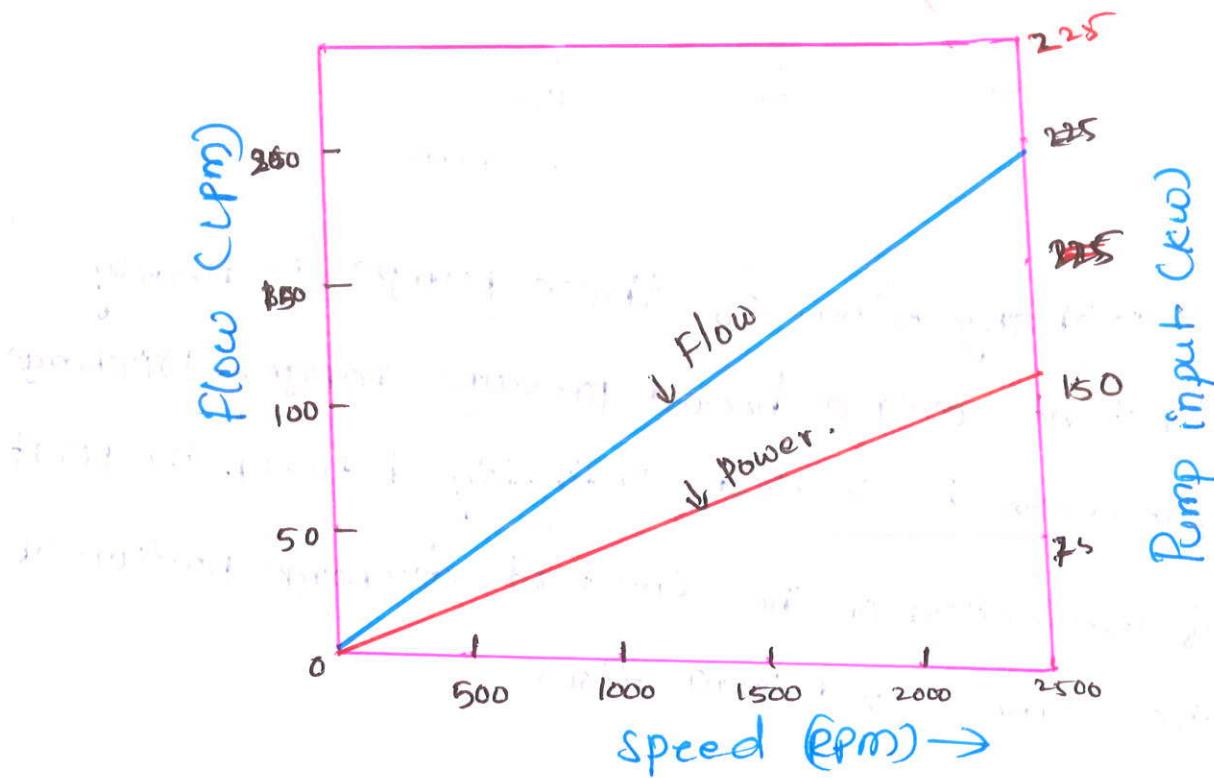
Pump Performance characteristics are first analyzed independently of the rest of the hydraulic system. and as part of the system. Both sets of data valuable to designer analyzing Pump by itself gives an indication of its capabilities and performance based on the speed of rotation internal geometry, cost factors etc. whereas analyzing the Pump Performance in the system essentially determines the Pump system compatibility.

In the first case the designer may observe the curves of performance to see if a specific Pump has the pressure and volume flowrate to operate a given set of ~~operates~~ actuators

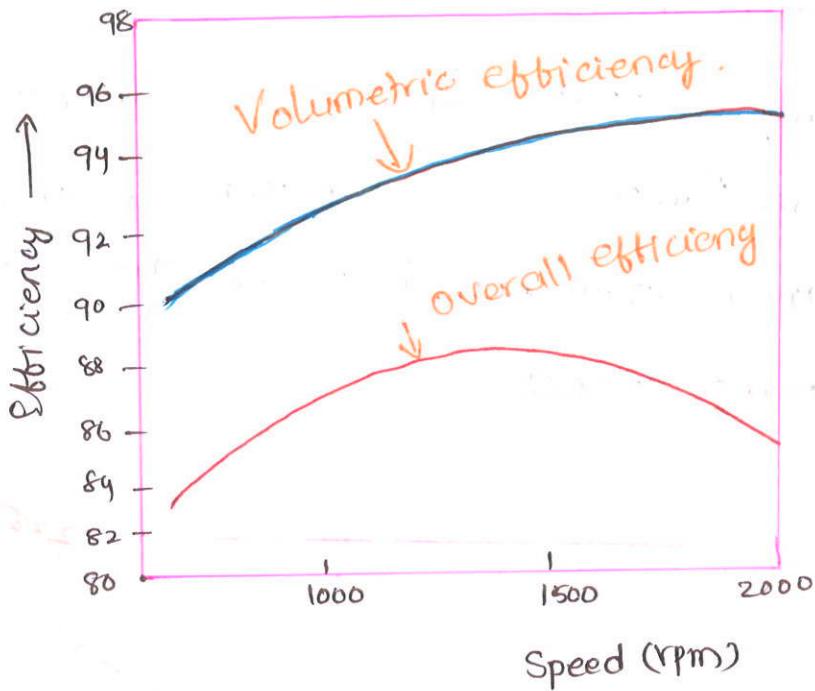
In second instance the system designer may be computing the Noise, Vibration, cavitation and flow characteristics of a specific pump before and after installation to determine if the pump and existing system are compatible.

The Pump ~~pump~~ performance characteristics are interpreted from data in tabular form and then graphed.

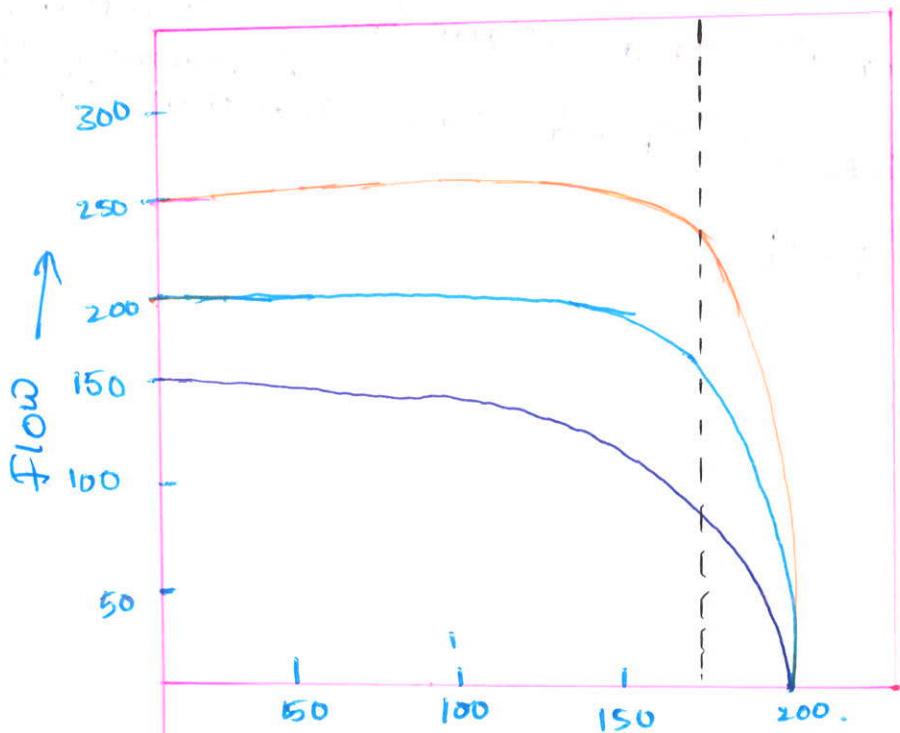
The relationship between input power and the Pump output flow of a Variable displacement Piston Pump as a function of speed of the Pump. Linear relationship between the discharge flow and pump speed.



\*→ Overall and volumetric efficiencies as a function of speed. The ~~function~~ <sup>Performance curve</sup> of the radial piston pump.



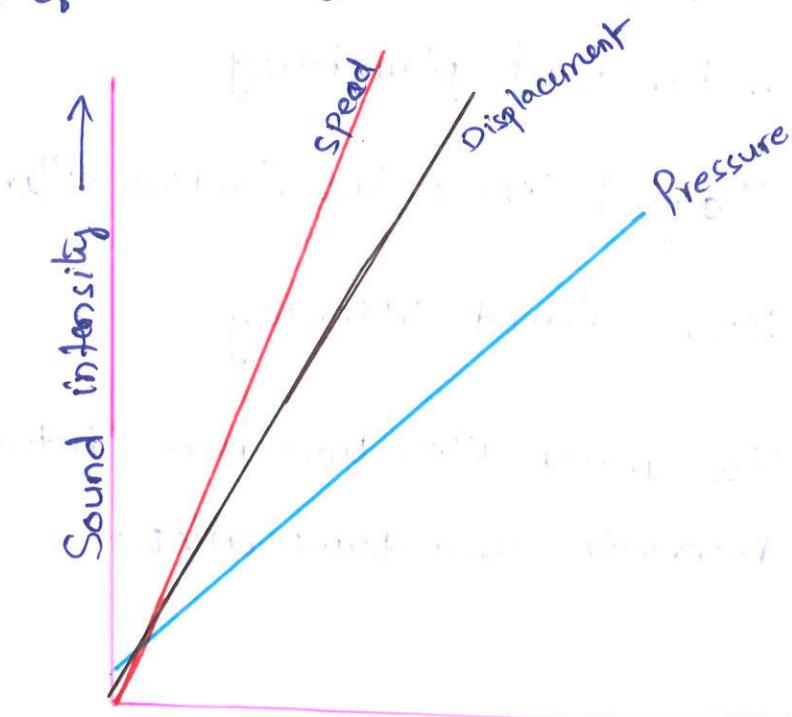
\* Discharge flow of these pumps is nearly constant over a broad pressure range. Discharge flow can be varied infinitely between the point of inflection on the constant discharge portion of the curve and zero flow.



## Pump Noise:-

(36)

Pump Noise is an important parameter used to determine the performance. An increase in noise indicates the increased wear and eventually pump failure. Pumps are good generators but poor radiators of noise. Noise is not just the sound coming directly from the pump, but also from the vibration and the fluid pulsation produced by pump. Pumps are small in size and hence they are poor radiators of noise. Reservoirs, electric motors and piping being large in size are better radiators. Hence, a pump induced vibration can cause audible noise greater than that coming from the pump. Fixed displacement pumps are less noisy than variable displacement pumps because of their rigid construction.



Operating Parameters →

unit 1, Pg - 69 / 86

## Pump Cavitation

Cavitation is the form of oil vapour bubbles due to a very low pressure (high vacuum) on the inside of the pump. The pressure also causes air, which is dissolved in the oil to come out of the solution and form bubbles. These air and oil vapor bubbles collapse when they reach the outlet side of the pump which is under high pressure. The collapsing oil vapour bubbles cause extremely localized pressure and velocity. These pressures are high that they cause pitting of metal and consequently decrease the life and efficiency of the pump.

### Factors Causing Cavitation:

- Undersized plumbing
- Clogged lines (or) Suction filters
- High fluid viscosity
- Too much elevation head between the reservoir and pump inlet.

## Rules to eliminate cavitation .

- Keep suction line velocities below 1.2 m/s.
- keep the pump inlet line as short as possible.
- Minimize the number of fittings in the inlet line
- Mount the pump as close as possible to the reservoir.
- Use low-pressure drop inlet filters.
- Use proper oil recommended by the pump manufacturer.

## Parameters of the pump:-

- Max operating pressure.
- Max. delivery
- Type of control.
- Pump drive speed
- Type of fluid
- Pump contamination tolerance
- Pump Noise.
- Size and weight of a pump.
- Pump efficiency.
- Cost
- Availability and interchangeability.
- Maintenance and spares.

## Hydraulic Motors:-

Hydraulic motor converts hydraulic power into mechanical power in the form of rotational motion. Hence, the motor performs the opposite function of pumps. Pressurized fluid enters the motor inlet and motor converts it into rotational motion and torque. The speed of the motor depends on the flow rate at inlet and torque is dependent on the operating pressure.

Many hydraulic pumps can be operated as motors. Gear, vane, piston motors are widely used in the industry. All these motor constructions are similar to the hydraulic pump of same type.

## Applications of Hydraulic Motors:-

Hydraulic motors are widely used in many applications that require smooth and heavy rotational motion.

→ Material Handling Equipment

→ Form machinery

→ Railway locomotives

→ Automobiles

→ Machine tools.

# Differences between Hydraulic pump & Motor

## Hydraulic motor

It is a device used for delivering torque at a given pressure. The main emphasis is on mechanical efficiency and torque that can be transmitted.

Motors are operated over a wide range of speed, from a low RPM to high RPM.

Most motors are designed for bidirectional application such as braking loads, rotary tables.

Motors may be idle for long time

Motors are subjected to high side loads. [from gears chains, belt driven pulley]

## Hydraulic Pump

It is a device delivering flow at a given pressure. The main emphasis is on volumetric efficiency and flow.

Pumps usually operated at high RPM.

In most situations pumps usually operated in one direction.

Pumps usually operate continuously

Majority of pumps are not subjected to side loads, usually pumps are pad mounted on power pack top and shaft is connected to the prime mover directly.

## Comparision between Hydraulic motors and Electric motor:

Electric motor has appeal due to its universal use but has certain limitations over hydraulic motor.

Electric Motor	Hydraulic Motor.
Electric motor cannot be stopped instantly and direction of rotation cannot be reversed instantly	Hydraulic motors can be stalled for an indefinite period without damage, and direction of rotation can be instantly reversed.
Electric motors are heavy and bulky and can occupy more space	Hydraulic motors are very compact and occupy less space.
Moment of inertia-to-torque ratio is high	Moment of inertia to torque is less.

## Advantages of hydraulic motor over electric motor:

- hydraulic motors responds quickly to speed and direction changes.
- hydraulic motors can be stalled under full load without any damage.
- hydraulic motors are very compact and occupy less space.

## Classification of Hydraulic motors:-

### High torque motors :-

These motors are designed to provide high torque and these are normally low speed machines.

Ex:- Radial - Piston (or) axial - Piston motor

### High speed Motors:-

These motors have high operating speeds with low torque.

Ex:- Gear ~~Pumps~~<sup>motor</sup>, axial - piston motor and Vane motor.

### Medium Torque and medium speed motors:-

These motors providing good torque with operating speeds greater than high torque motors.

Ex: Radial-piston, Axial-Piston, Vane and gear motor.

### High moment motors:-

These motors provide high start up torque with greater speed of operation than high - torque motor.

Ex:- Radial - Piston type.

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Based on construction, hydraulic motors can also be classified as:

1. Gear motors

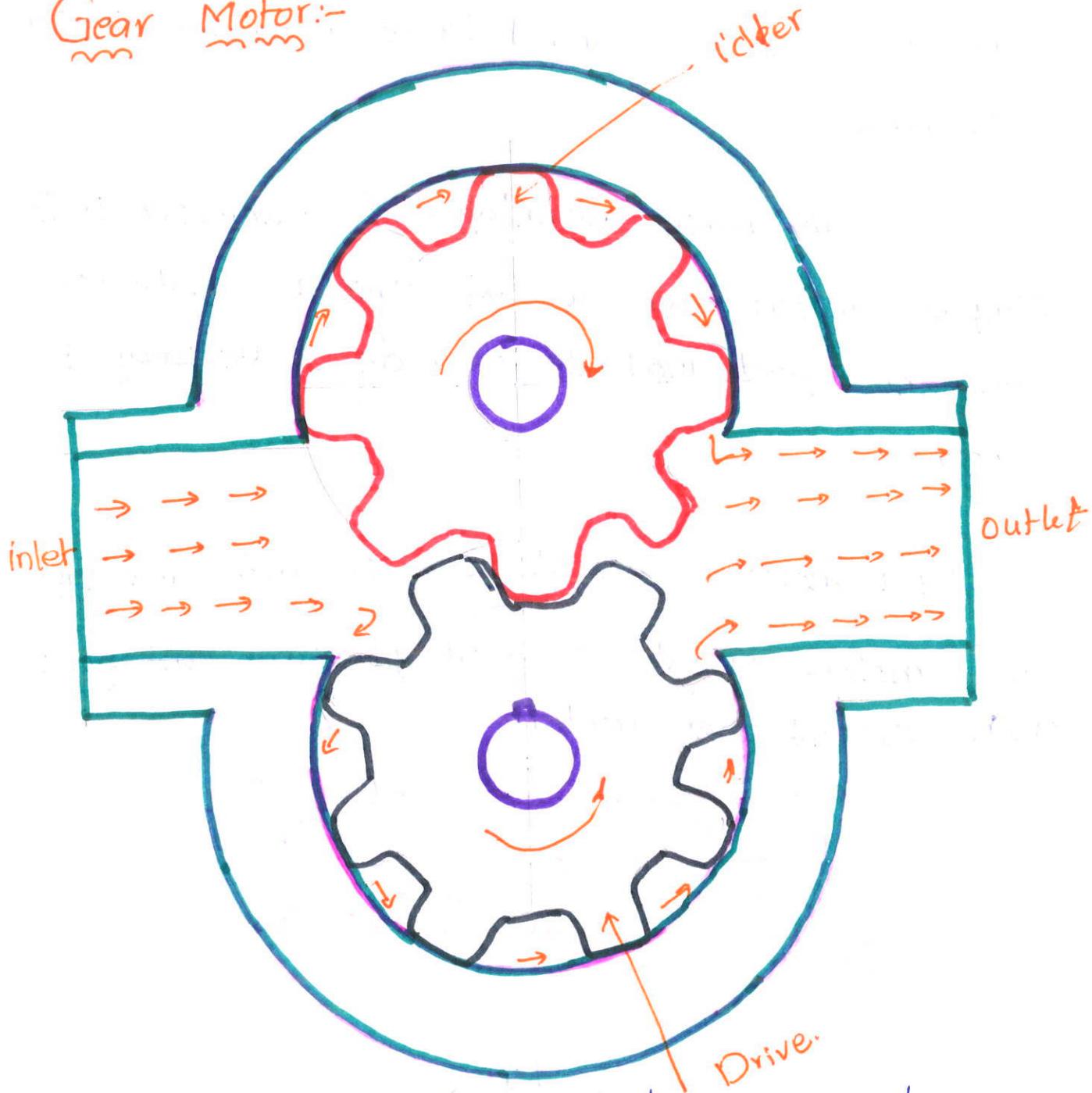
2. Vane motors.

3. Piston motors

(a) axial piston type motors

(b) Radial piston type motors.

Gear Motor:-



The gear motor consists of two gears are equal in diameter and form. One gear keyed on the output shaft and another is idle gear. Thus pressurised fluid enters the inlet of the ~~motor~~<sup>motor</sup> pump. This fluid pushes the gear tooth, causing them to rotate. The inlet pressure must be sufficient to rotate the output shaft against the load. Most of the gear motors are irreversible. The direction of the rotation can be changed by reversing the direction of flow.

The main advantage of gear motor is its simple design and low cost. This is suitable for constant speed, moderate power drives efficiency upto 90%.

Gear motors can also be internal gear type. These motors operate at high pressures and speeds than external gear motor.

Operating pressure - 150 bar

Operating speed - 2500 rpm

Max flow capacity - 600 lpm

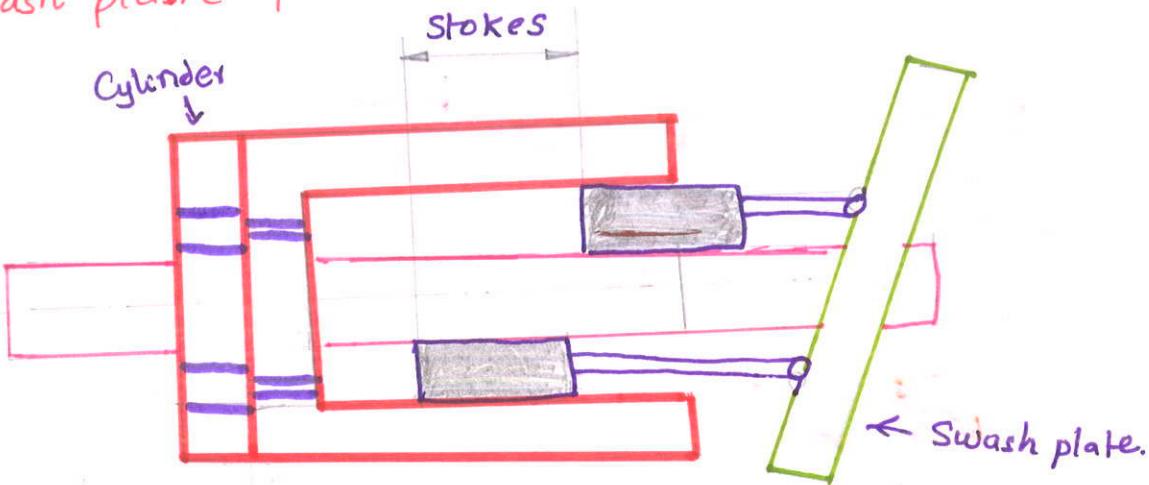
## Piston motors

### Axial motors :-

→ Swash plate piston motor.

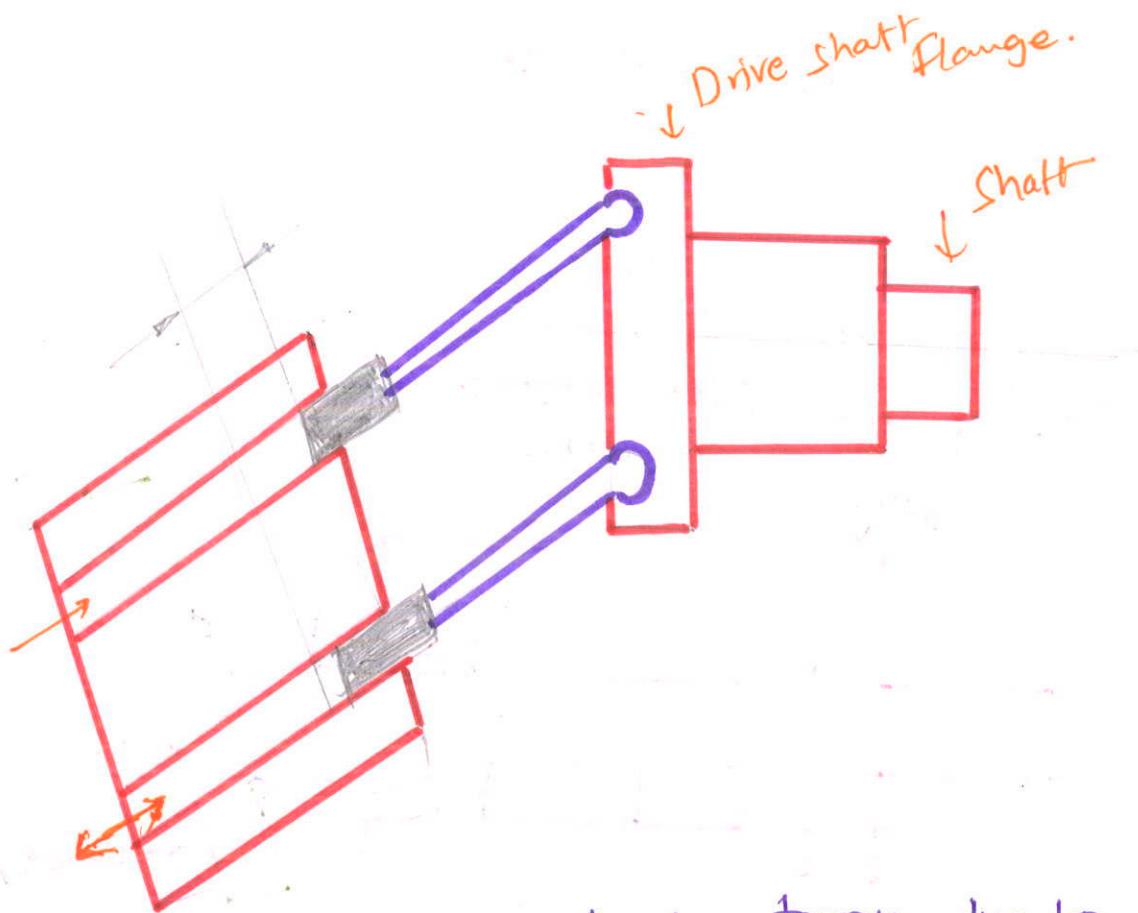
→ Bent axis piston motor.

### Swash plate piston motor:-



In this motor, driving shaft, cylinder block mounted on same axis. Pressure acting on the ends of the generator a force against the angled swash plate. This cause the cylinder block to rotate with the same a torque that is proportional to area of the piston. The torque is also a function of the swash plate angle. In variable displacement on the swash plate mounted on the swing ingyoke the angle can be varied by various means such as lever, hand wheel (or) servo control. If the offset angle is increased, the displacement and torque capacity increases but the speed of the drive decreases. Vice versa.

## Bent axis piston motor

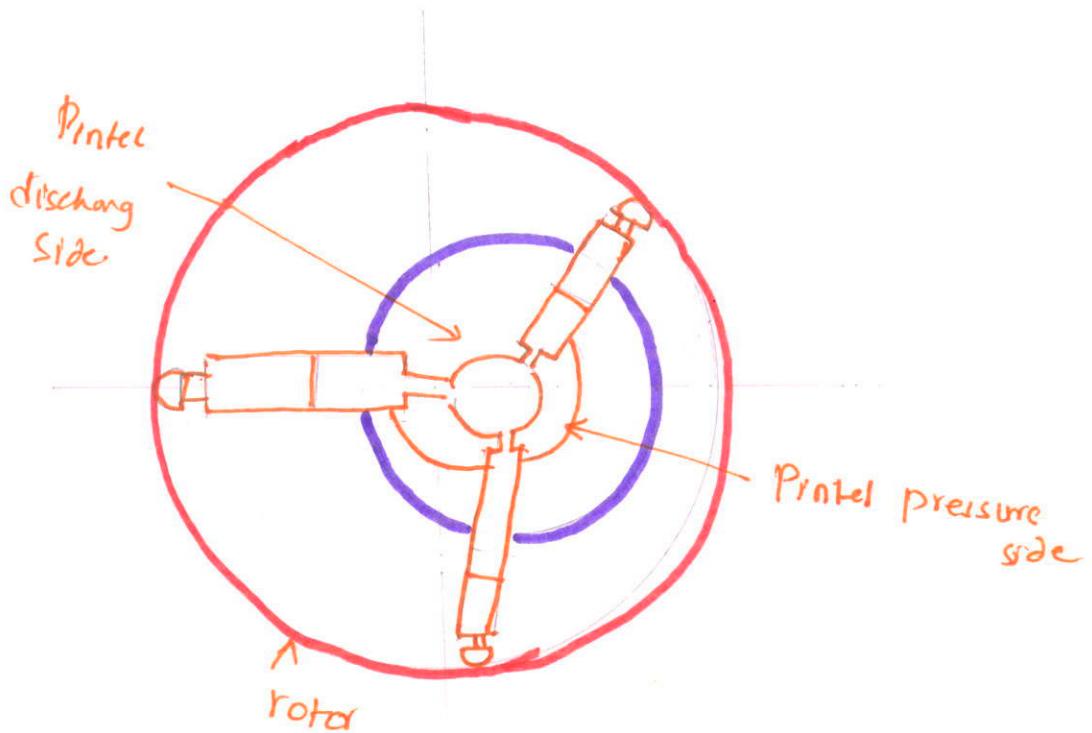


In Bent axis piston motor develop torque due to Pressure acting on the reciprocating pump. In this motor cylinder block and drive shaft mount at an angle to each other so that the force exerted on the drive shaft flange.

Speed and Torque depends on the angle between cylinder block and the drive shaft. The larger the angle , the greater displacement and Torque and the smaller speed . The angle varies from (min)  $7.5^\circ - 30^\circ$  (max)

## 2. Radial piston motor:

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In Radial piston motors, the piston reciprocates radially or perpendicular to the axis of the output shaft. The basic principle of operation is shown in fig. Radial motors are low speed high torque motors which can address the multifarious problem in diverse power transfer applications.



## Performance of the Motor.

### Theoretical Torque:

The Torque delivered by friction less hydraulic motor is called theoretical torque.

$$T_T = \frac{\nu_D \times P}{2\pi} \text{ N.m.}$$

$\nu_D$  - volumetric displacement,  $\text{m}^3/\text{rev.}$

$P \rightarrow$  Pressure -  $\text{N/m}^2$

### Theoretical power:

The power developed by frictionless hydraulic motor is called Theoretical power.

$$P_T = 2\pi N \cdot T_T$$

$$= \omega T_T$$

$$P_T = \frac{\omega \times \nu_D \times P}{2\pi} \text{ watts}$$

$N \rightarrow$  speed in  $\text{rev/sec.}$

$$\omega = 2\pi N$$

### Theoretical flowrate:

The flow rate a hydraulic motor would consume if there were no leakage is called theoretical flow

$$Q_T = \nu_D \times N \text{ m}^3/\text{s}$$

$v_D \rightarrow$  volumetric discharge  $\text{m}^3/\text{rev}$

$N \rightarrow$  speed rev/sec.

$$\frac{\omega}{2\pi}, \omega \text{ rad/sec.}$$

## Motor Efficiencies

### 1. Volumetric Efficiency :-

Motor uses more flow than it should theoretically due to leakage. The volumetric efficiency defined as the ratio of theoretical flow rate to actual flow rate.

$$\text{Volumetric Efficiency} = \frac{\text{Theoretical flowrate should supplied}}{\text{Actual flowrate supplied}}$$

$$\eta_v = \frac{Q_T}{Q_A} \times 100$$

## Mechanical Efficiency:

It is defined as the ratio of torque delivered by the motor to theoretical torque that motor should deliver.

$$\text{Mechanical Efficiency} = \frac{\text{Actual torque developed by a motor}}{\text{Theoretical torque developed by a motor}}$$

$$\eta_m = \frac{T_A}{T_T} \times 100$$

$$\text{Theoretical Torque } T_T = \frac{V_D \times P}{2\pi}$$

$$\text{Actual Torque } T_A = \frac{P}{2\pi N}.$$

$$= \frac{P}{\omega}$$

P = Power in watts.

N = Speed of motor rev/sec.

Overall efficiency:-

It is defined as the ratio of actual power delivered by motor to the Actual power delivered to motor.

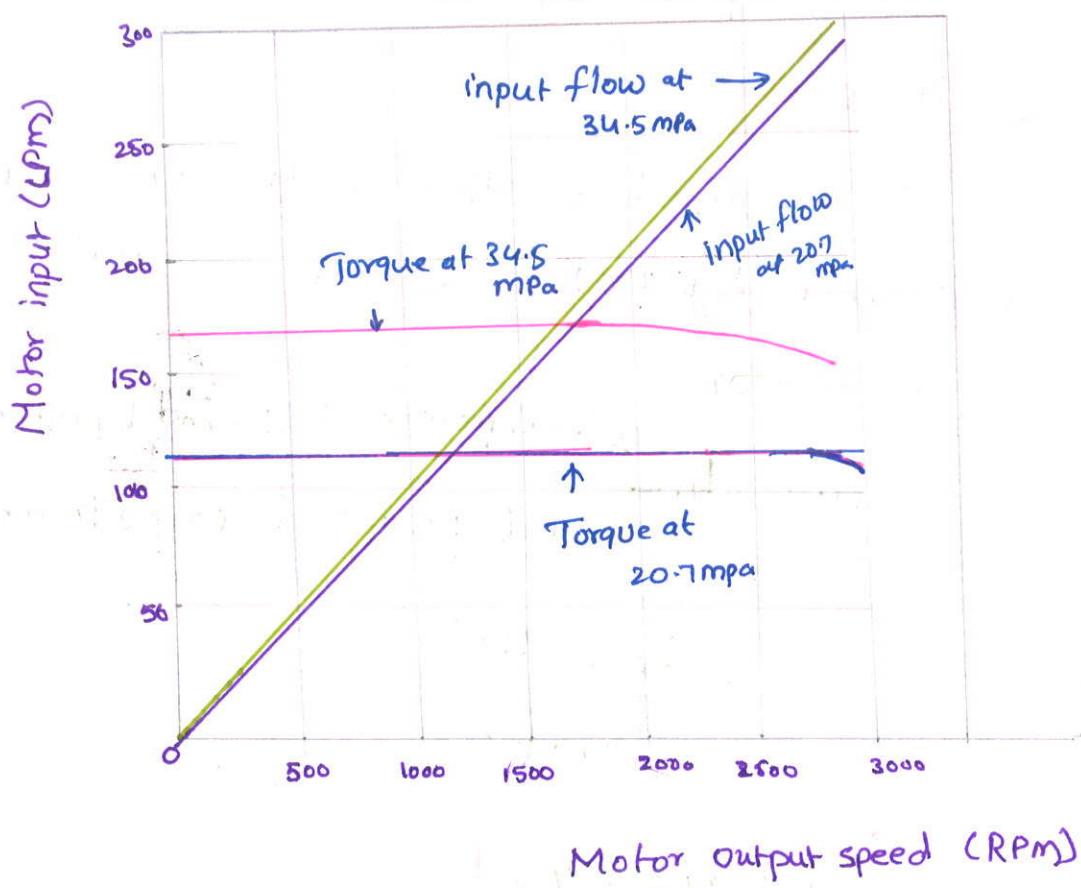
$$\eta_v = \frac{\text{actual power delivered by motor}}{\text{actual power delivered to motor}}$$

$$= \frac{T_A \times 2\pi N}{Q_A \cdot P}$$

$$\boxed{\eta_v = \eta_m \times \eta_r}$$

# Performance Curves for a Variable displacement motor:

The following curves represents typical performance obtained for a  $100 \text{ cm}^3$  variable displacement motor at full displacement gives the motor input flow [LPM] and motor output torque as a function of motor speed (rpm) at two pressure levels.



Answers There

The Curve of overall efficiency and volumetric efficiency as a function of motor speed RPM

