MODULE – 1 Introduction to Hydraulic Power

Definition of hydraulic system, advantages, limitations, applications, Pascal's law, components of fluid power system. Pumps: Classification of pumps, theory of positive displacement pump, construction and working of Gear pumps, Vane pumps, Piston pumps, fixed and variable displacement pumps, Pump performance characteristics, pump Selection factors.

Definition of Hydraulic System

A system that uses pressurized liquid to transmit power.

- **Fluid Power:** Technology dealing with the generation, control, and transmission of power using pressurized fluids.
- **Hydraulics:** Specific application where the fluid is a liquid (petroleum oils, synthetic oils or water).
- **Primary Function:** Pressurized fluid acts upon a cylinder (linear motion) or a fluid motor (rotary motion) to perform work.

Advantages of Hydraulic Systems

- **Force Multiplication:** Small input forces can generate and control large output forces.
- **Constant Force/Torque:** Capable of maintaining constant force or torque regardless of speed changes.
- **High Power-to-Weight Ratio:** Produces high power output with components that are small and light compared to electric motors.
- **Simplicity & Safety:** Fewer moving parts than mechanical systems; built-in overload protection via relief valves.
- **Instant Reversibility:** Actuators can stop and reverse direction instantly without damage.
- **Accuracy:** "Stiff" system (incompressible fluid) allows for precise position control and accurate stopping.

Limitations of Hydraulic Systems

- **Leakage:** Fluid can leak at seals and connections, causing mess and safety hazards.
- **Fire Hazard:** Petroleum-based oils are flammable; system failure near ignition sources poses a risk.
- **Contamination Sensitivity:** Precision components are easily damaged by dirt, rust, or dust in the fluid.

- **Noise:** Pumps and fluid turbulence can generate significant operating noise.
- **Efficiency Losses:** Heat generation due to fluid friction reduces overall system efficiency.

Applications

Stationary (Industrial) Hydraulics:

- **Machine Tools:** CNC clamping, feeding, tool changing.
- **Presses:** Forging, stamping, injection molding.
- **Material Handling:** Conveyors, lifts, packaging machinery.

Mobile Hydraulics:

- **Construction:** Excavators, bulldozers, backhoes, cranes.
- **Agriculture:** Tractors, harvesters.
- **Automotive/Transport:** Power steering, brakes, aircraft landing gear, dump trucks.
- **Marine:** Steering systems, winches.

Pascal's Law

Pascal's Law states that pressure applied to a confined fluid at rest is transmitted undiminished in all directions and acts with equal force on equal areas, and at right angles to them.

$$P = \frac{F}{A}$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

P = Pressure (psi or Pa)
F = Force (lb or N)
A = Area (in² or m²)

F_1 = Input Force

A_1 = Area of Input Piston

F_2 = Output Force (Load)

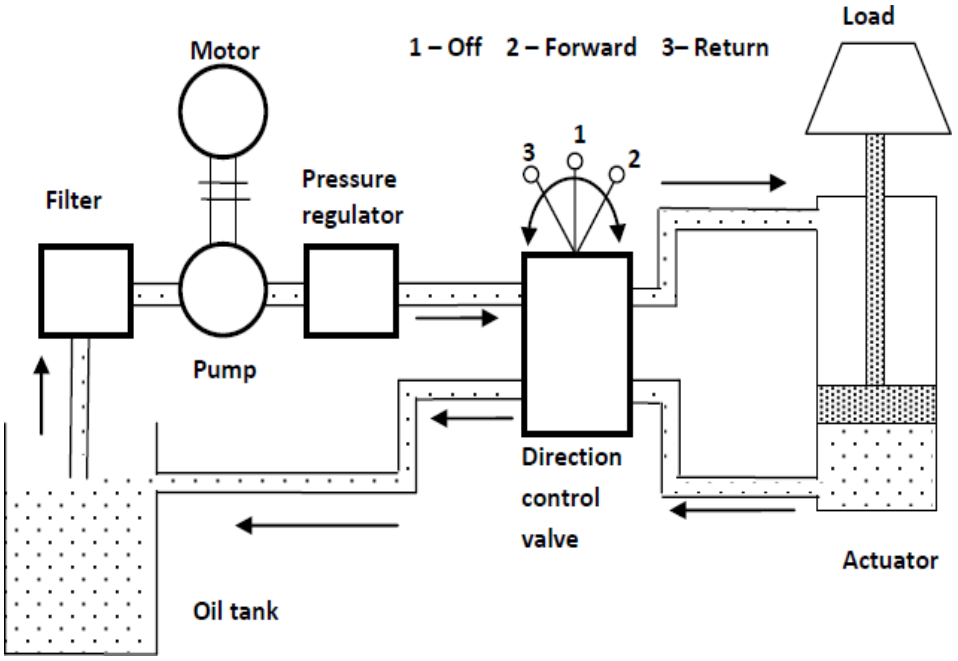
A_2 = Area of Output Piston

Introduction to Components of a Hydraulic System

1. **Hydraulic Pump**
   Converts mechanical energy into hydraulic energy by delivering pressurized fluid.
2. **Reservoir (Tank)**
   Stores hydraulic fluid and helps in heat dissipation, settling of contaminants, and deaeration.
3. **Actuators**

- *Cylinders* (linear motion)
- *Hydraulic motors* (rotary motion)

4. **Directional Control Valves (DCV)**
   Control the direction of fluid flow and movement of actuators.
5. **Pressure Control Valves**
   Maintain and regulate system pressure (e.g., relief valve, pressure-reducing valve).
6. **Flow Control Valves**
   Regulate the speed of actuators by controlling flow rate.
7. **Filters**
   Remove contamination from hydraulic fluid.
8. **Pipes, Hoses, Fittings**
   Carry fluid between components.



PUMPS

A pump, which is the heart of hydraulic system, converts mechanical energy into hydraulic energy. The diagram shows a pump driven by a motor (prime mover) that creates partial vacuum at the inlet, allowing atmospheric pressure to push the hydraulic fluid into the pump. Inside the pump, the mechanical action (depicted by the pumping element) increases the fluid's pressure, delivering it as high-pressure flow to the hydraulic system.

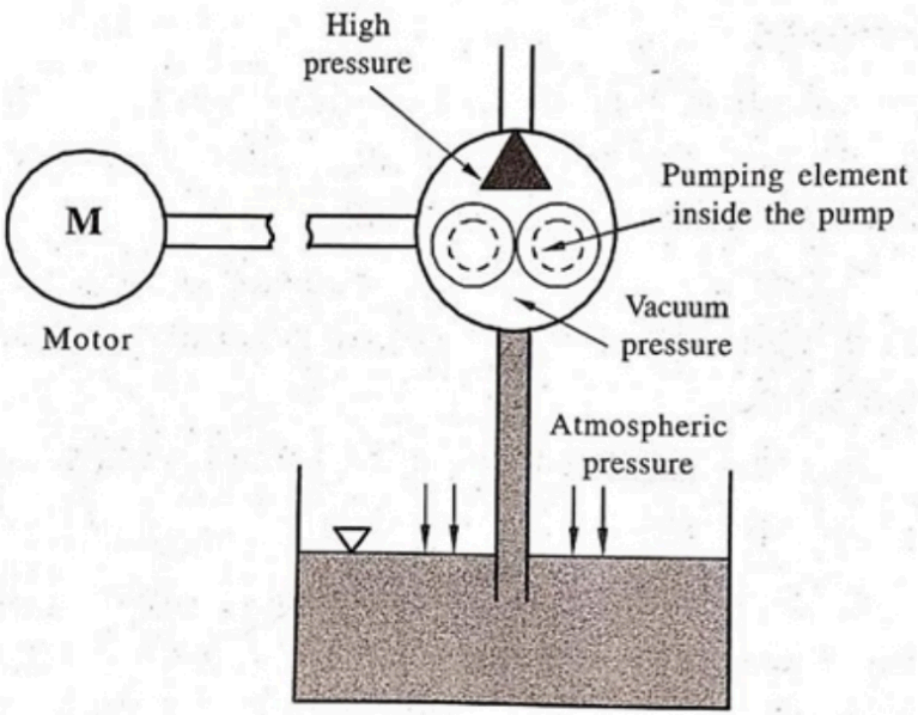


Fig. Concept of pumping principle

CLASSIFICATION OF PUMPS:

Pumps used in hydraulic systems are primarily classified into two broad categories based on their working principles:

1) Dynamic (non-positive displacement) pumps
2) Positive displacement pumps

1. **Dynamic (Non-Positive Displacement) Pumps:**
   - Used for low-pressure, high-volume applications.
   - Pump fluid by imparting velocity to the fluid (kinetic energy conversion).
   - Common types: Centrifugal pumps, Axial flow (propeller) pumps.
   - Limited pressure capability (typically up to 250-300 psi).
   - Mostly used for fluid transport, less common in hydraulic power systems.

2. **Positive displacement pumps:**
   - Widely used in hydraulic power systems.
   - Deliver a fixed volume of fluid per revolution regardless of pressure.
   - Capable of handling high pressures and precise control.
   - Types include Gear pumps, Vane pumps, and Piston pumps.

Positive displacement pumps are further classified into:

i) Fixed displacement pumps:

- The amount of fluid ejected per revolution (displacement) cannot be varied.

ii) Variable displacement pumps:

- In this type of pump, the displacement can be varied by changing the physical relationships of various pump elements.
- This change in pump displacement produces a change in pump flow output even though pump speed remains constant.

DIFFERENCE BETWEEN FIXED DISPLACEMENT AND VARIABLE DISPLACEMENT PUMPS

Feature	Fixed Displacement Pumps	Variable Displacement Pumps
Displacement Control	Fixed volume of fluid per revolution.	Displacement (flow) can be varied without changing pump speed.
Flow Output	Flow changes only with speed variation.	Flow changes by adjusting displacement (e.g., changing swash plate angle).
Typical Components	Gear pumps, fixed vane pumps, fixed piston pumps.	Variable displacement axial piston pumps, variable vane pumps.
Application	Simple hydraulic circuits requiring constant flow.	Complex circuits needing variable flow and pressure control.
Efficiency	High but constant for given speed.	High and can be optimized for operating conditions.
Control	No flow control other than speed adjustment.	Allows flow regulation without changing input speed for better efficiency.
Example	External Gear Pump	Axial Piston Pump with adjustable swashplate

THE ADVANTAGES OF POSITIVE DISPLACEMENT PUMPS OVER NON-POSITIVE DISPLACEMENT PUMPS ARE AS FOLLOWS:

1. They can operate at very high pressures, up to 800 bar (used for lifting oils from very deep oil wells).
2. They can achieve a high volumetric efficiency of up to 98%.
3. Their efficiency is high and almost constant throughout the designed pressure range.
4. They are a compact unit with a high power-to-weight ratio.
5. They can obtain smooth and precisely controlled motion.
6. By proper application and control, they produce only the amount of flow required to move the load at the desired velocity.
7. They have great performance flexibility, operating over a wide range of pressures and speeds.

PUMPING THEORY OF POSITIVE DISPLACEMENT PUMPS:

Pumps operate on the principle whereby a partial vacuum is created at the pump inlet due to the internal operation of the pump. This allows atmospheric pressure to push the fluid out of the oil tank (reservoir) and into the pump intake. The pump then mechanically forces the fluid out through the discharge line. This action can be best described by referencing a simple piston pump as shown in the figure.

1. **As the piston moves to the left**, a partial vacuum is created in the pump chamber, which keeps the outlet valve closed against its seat and induces flow from the reservoir, which is at a higher (atmospheric) pressure. As this flow is established, the inlet valve is temporarily displaced by the force of the fluid, allowing fluid to enter the pump chamber (suction stroke).
2. **When the piston moves to the right**, resistance at the valves causes an immediate increase in pressure, forcing the inlet valve against its seat and opening the outlet valve, which permits fluid to exit into the system. If the outlet port opens directly to the atmosphere, the only pressure developed is that required to open the outlet valve (delivery stroke).

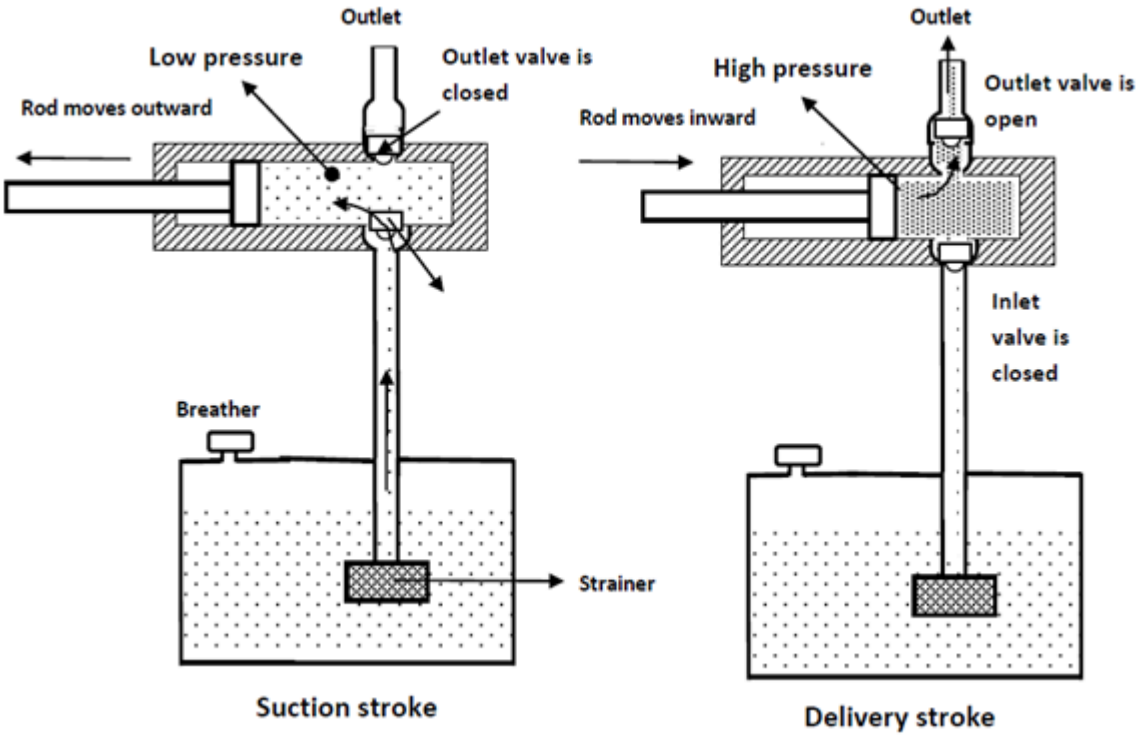


Fig. Illustration of pumping theory

CLASSIFICATION OF POSITIVE DISPLACEMENT PUMPS:

1. Gear Pumps.

2. Vane Pumps.

3. Piston Pumps:

The detailed explanations are given below

1. GEAR PUMPS:

- Gear pumps are less expensive but are limited to low pressure applications. They are noisier in operation compared to vane or piston pumps.
- Gear pumps are invariably of the fixed displacement type, which means that the amount of fluid displaced per revolution of the drive shaft is theoretically constant.

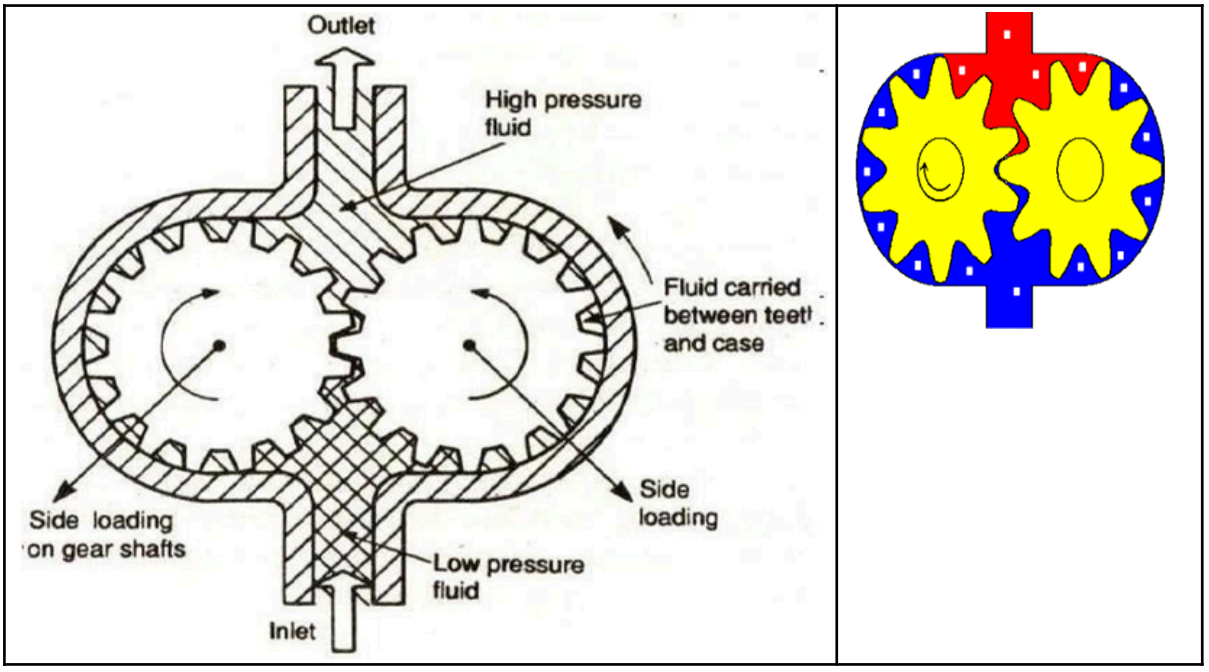


Fig. External Gear Pumps

- External gear pumps are the most popular hydraulic pumps in low-pressure ranges due to their long operating life, high efficiency, and low cost.
- They are generally used in simple machines. The external gear pump consists of a pump housing in which a pair of precisely machined meshing gears rotate with minimal radial and axial clearance.
- One of the gears, called the driver, is powered by a prime mover and drives another gear called the follower.
- As the teeth of the two gears separate, fluid from the pump inlet becomes trapped between the rotating gear cavities and the pump housing. This trapped fluid is carried around the periphery of the pump casing and delivered to the outlet port.
- The teeth of the precisely meshed gears provide almost a perfect seal between the

pump inlet and pump outlet.

Advantages of Gear Pumps

- Gear pumps are simple in construction and easy to maintain.
- They are comparatively inexpensive and compact in size.
- They provide nearly constant discharge because of fixed displacement operation.
- They have good mechanical efficiency and long operating life under low pressure conditions.
- They are suitable for handling viscous fluids and are widely used in basic hydraulic systems.

Limitations of Gear Pumps

- Gear pumps are generally limited to low and moderate pressure applications.
- They produce more noise compared to vane and piston pumps.
- They operate only at fixed displacement, so flow control requires additional components.
- Internal leakage increases with wear, which reduces volumetric efficiency over time.
- They are not suitable for high precision or high pressure hydraulic systems.

2. VANE PUMPS.

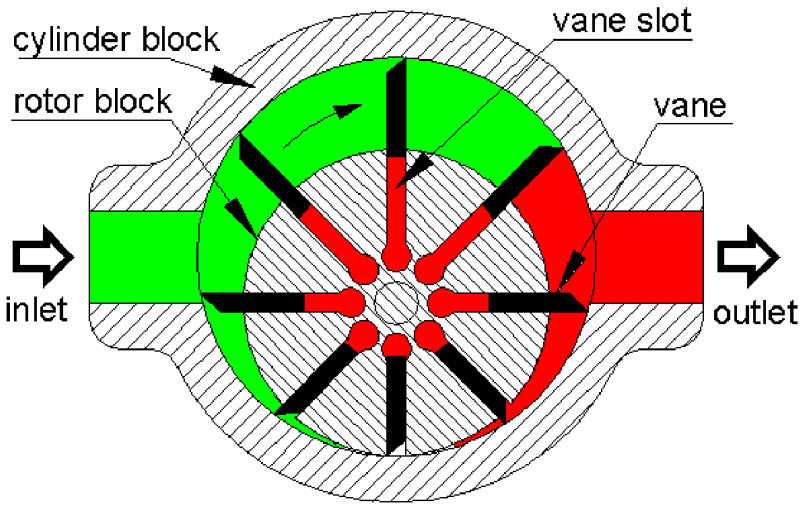


Fig. Vane Pump

- The pump consists of a cylindrical rotor mounted with an offset inside a circular casing.
- Vanes are seated in radial slots of the rotor and are held against the casing by spring or hydraulic force.
- There is no leakage of oil between the vane tips and the casing.

- As the rotor rotates, the vanes carry the liquid from the inlet port to the outlet port.
- The difference in pressure between the inlet and outlet ports creates a side thrust on the rotor shaft, which consequently loads the bearings.
- During half of the rotor's rotation, the volume of the chambers increases while the pressure of the liquid decreases. During the other half of the rotation, the volume of the chambers decreases and the pressure increases.

Advantages of Vane Pumps

- Self-priming, robust, and supply a constant delivery at a given speed.
- Provide uniform discharge with negligible pulsations.
- Self-compensating for wear, and vanes can be replaced easily.
- Do not require check valves.
- Light in weight and compact.
- Can handle liquids containing vapors and gases.
- Volumetric and overall efficiencies are high.
- Discharge is less sensitive to changes in viscosity and pressure variations.

Disadvantages of Vane Pumps

- Relief valves are required to protect the pump in case of sudden closure of the delivery line.
- Not suitable for abrasive liquids.
- Require good seals.
- Require good filtration systems, and foreign particles can severely damage the pump.

3. PISTON PUMPS:

AXIAL PISTON-TYPE PUMP. (SWASH PLATE PISTON PUMPS)

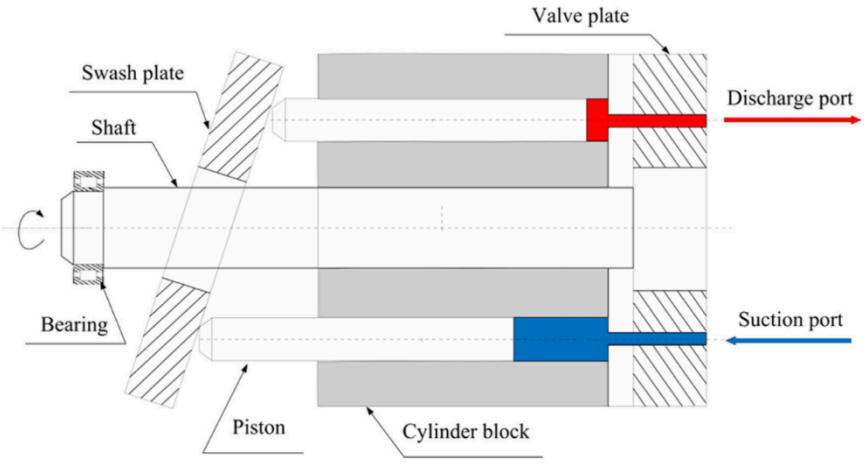


Fig.1 Axial piston pump

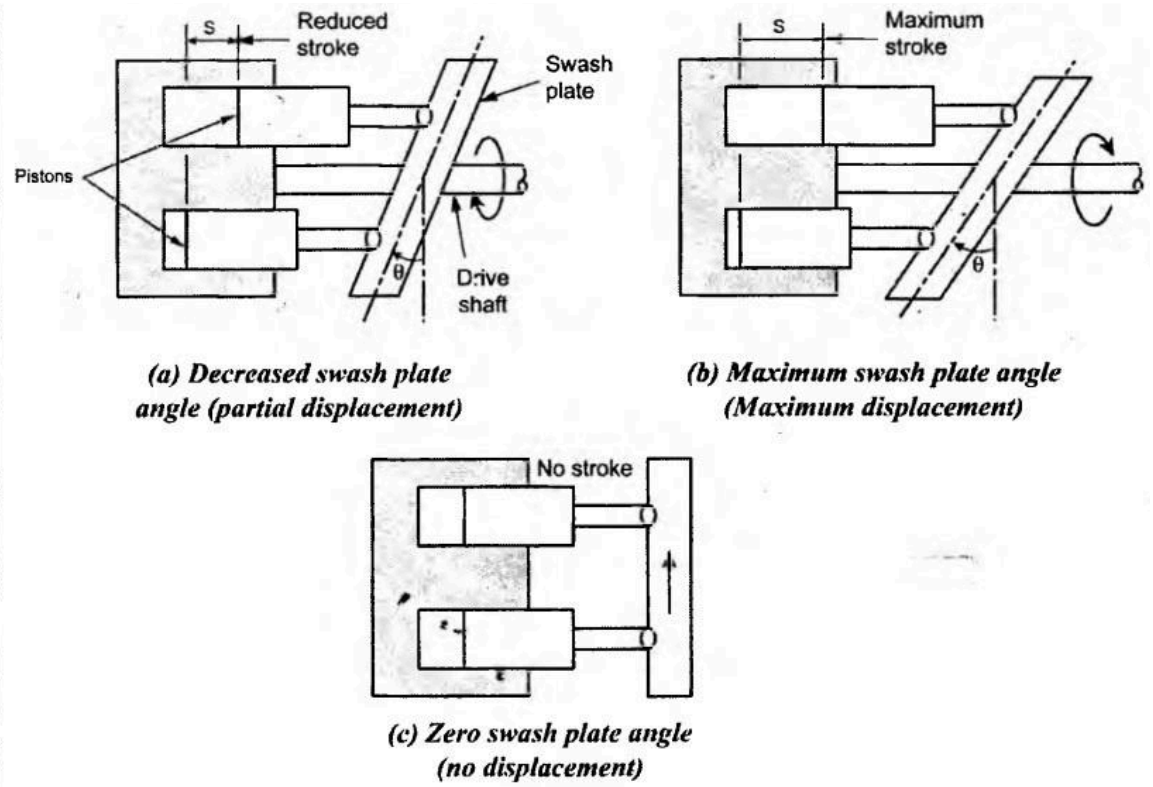
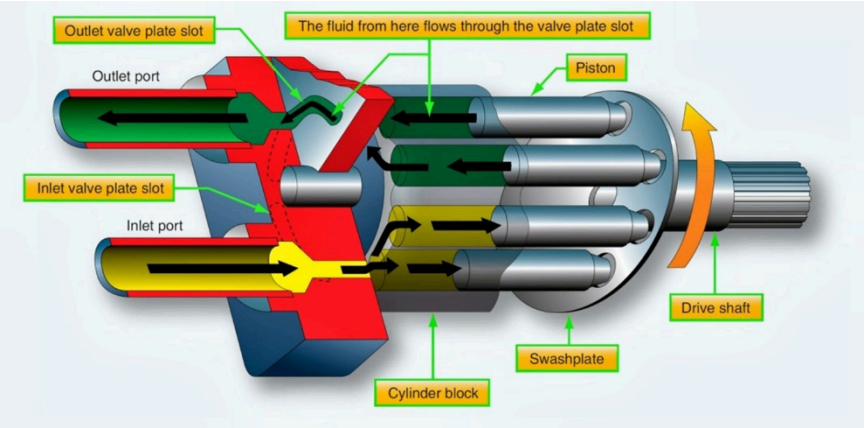


Fig.2 Variation in pump displacement with swash plate angle

- Swash plate pumps have a rotating cylinder block containing pistons.
- A spring pushes the pistons against a stationary swash plate, which is set at an angle to the cylinder. As shown in Fig. 1
- Each piston sucks in fluid during half a revolution (suction stroke) and pushes fluid out during the other half (delivery stroke).
- The stationary disk, shown at the far right, acts as a valve plate with two semi-circular ports, visible in both edge and head-on views.
- These ports allow the pistons to draw in fluid during movement toward the swash plate and to discharge fluid as they move away.
- For a given speed, swash plate pumps can be either fixed displacement (with a constant swash plate angle) or variable displacement (with an adjustable swash plate angle).
- Increasing the swash plate angle increases piston stroke and thus the amount of fluid transferred, while decreasing the angle reduces displacement. At zero angle, no fluid is pumped. As shown in Fig. 2



RADIAL PISTON-TYPE PUMP

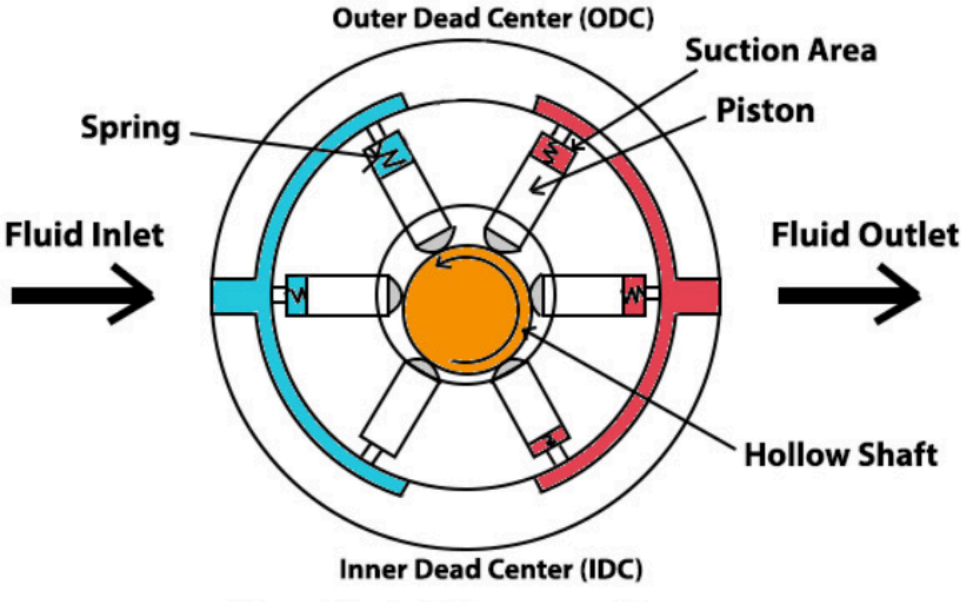


Fig. Radial piston pump

A radial piston pump, as illustrated, consists of several pistons arranged radially around a hollow shaft within a circular cylinder block.

- Fluid enters through the fluid inlet and fills the suction area, where each piston moves from the inner dead center (IDC) toward the outer dead center (ODC).
- Springs push the pistons outward against the cylinder block during the suction phase. As the pump rotates, pistons at the suction area draw fluid in.
- As the pistons pass the fluid outlet zone, they move inward from ODC to IDC due to the shaft profile and spring force, compressing and expelling fluid through the outlet.
- The movement is precisely synchronized; the longer the piston stroke (from IDC to ODC), the more fluid is pumped per cycle.
- The hollow shaft in the center enables rotary movement and transmits drive force to

the piston mechanism.

This configuration provides a smooth and continuous flow, supporting efficient high-pressure hydraulic applications with excellent volumetric efficiency and precise flow control.

Pump performance characteristics

Pump Performance

The performance of a pump mainly depends on the material quality, precision of the manufacturing, and component accuracy.

Types of Pump Efficiency

1. Volumetric Efficiency (η_{vol})

Volumetric efficiency measures how effectively a pump delivers the expected flow rate:

$$\eta_{vol} = \frac{Actual\ discharge\ of\ the\ pump}{Theoretical\ discharge}$$

or,

$$\eta_{vol} = \frac{Q_{act}}{Q_{th}} \times 100$$

Where:

- Q_{act} = Actual flowrate delivered by the pump (measured output)
- Q_{th} = Theoretical (ideal, expected) flowrate without losses

High volumetric efficiency indicates little leakage and strong sealing within the pump.

2. Mechanical Efficiency (η_{mech})

Mechanical efficiency considers how effectively power supplied to the pump is converted into fluid power (without losses due to friction, heat, etc.):

$$\eta_{mech} = \frac{Output\ power\ of\ pump\ (assuming\ no\ leakage)}{Input\ power\ to\ the\ pump} \times 100$$

It can also be defined using torque:

$$\eta_{mech} = \frac{Theoretical\ torque\ developed\ by\ the\ pump}{Actual\ torque\ supplied\ to\ the\ pump} \times 100$$

or,

$$\eta_{mech} = \frac{T_{th}}{T_{act}} \times 100$$

Where:

- T_{th} = Theoretical torque required (from fluid output)
- T_{act} = Actual torque input (from the driver or motor)

Overall Efficiency

Overall efficiency combines volumetric and mechanical efficiencies, representing total energy conversion from input torque to fluid output, accounting for internal losses:

$$Overall\ Efficiency = \frac{\eta_{vol} \times \eta_{mech}}{100}$$

PUMP SELECTION FACTORS

Main Parameters Affecting Pump Selection:

1. Maximum operating pressure
2. Maximum delivery (flow rate)
3. Type of control required
4. Pump drive speed
5. Type of fluid (clean, viscous, abrasive, corrosive, etc.)
6. Pump contamination tolerance
7. Noise level of the pump
8. Size and weight of the pump
9. Pump efficiency
10. Cost (initial and operating)
11. Availability and interchangeability of parts
12. Maintenance requirements and spare parts availability

1. **Maximum operating pressure** This dictates the pump's ability to withstand the system's load without failure; the rating must exceed the system's peak pressure to prevent leakage or bursting.

2. **Maximum delivery (flow rate)** This determines the speed at which hydraulic actuators can move; the pump must be sized to supply the volume required for the system's maximum velocity.

3. **Type of control required** Refers to the need for fixed versus variable displacement; complex applications may demand load-sensing or electronic controls to vary flow and pressure dynamically.

4. **Pump drive speed** The pump's rated RPM must match the prime mover (motor/engine); exceeding the maximum speed rating causes cavitation, excessive noise, and rapid wear.

5. **Type of fluid** The pump's internal materials (seals and metals) must be compatible with the fluid's viscosity and chemical properties (corrosiveness) to prevent erosion or seal failure.

6. **Pump contamination tolerance** Some pumps (like gear pumps) handle dirty oil well, while precision pumps (like piston pumps) require strict filtration; this dictates the filtration cost and reliability.

7. **Noise level of the pump** Critical for indoor or operator-proximate applications; high noise levels indicate vibration or cavitation and may require expensive sound-dampening enclosures.

8. **Size and weight of the pump** Essential for mobile applications (robotics, aerospace) where space is limited; a heavy or bulky pump reduces the machine's payload capacity and fuel efficiency.

9. **Pump efficiency** A measure of volumetric and mechanical losses; higher efficiency pumps reduce input power requirements and heat generation, lowering operating costs.

10. **Cost (initial and operating)** A trade-off between the upfront purchase price and long-term energy costs; cheaper pumps often have lower efficiency and durability, increasing the total cost of ownership.

11. **Availability and interchangeability of parts** Ensures that the pump uses standard, off-the-shelf components; this minimizes downtime by guaranteeing that replacements can be sourced quickly.

12. **Maintenance requirements and spare parts availability** Considers the ease of servicing and frequency of repairs; pumps designed for easy maintenance with readily available spares reduce costly system downtime.