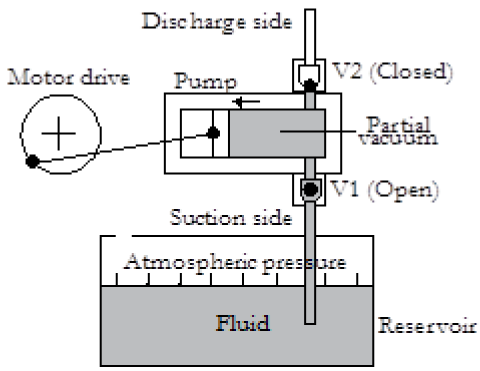
Fluidsys Training Centre Pvt Ltd
Exploring Pneumatics & Hydraulics

Fluidsys Training Centre, Bangalore offers an extensive range of skill-based and industry-relevant courses in the field of Pneumatics and Hydraulics. For more details, please visit the website: https://fluidsys.org

Hydraulic Pumps

A pump is a positive-displacement device coupled to a prime mover. It converts the mechanical energy from its prime-mover into hydraulic energy, using a fluid medium. It draws the fluid from the reservoir when driven by its prime mover and then pushes it into the system. This action creates the flow. And the system develops pressure owing to the resistance offered to the flow. The resistance to flow arises due to the fluid viscosity and the load on actuators.

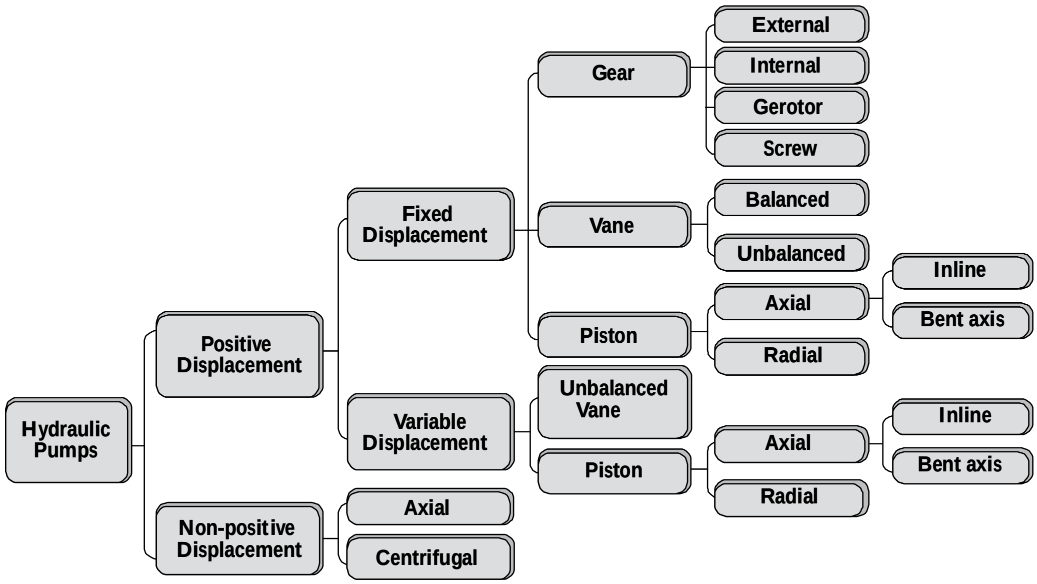


(a) Suction stroke

The pump piston is driven by a motor at a constant speed, and it acts as the pumping element as shown in the figure. It incorporates two valves V1 and V2 for drawing and containing the fluid. The suction stroke creates a partial vacuum at the suction side and draws fluid into the pump chamber through the opened valve V1. On the return stroke, the chamber is blocked from the suction side, and the trapped fluid is pushed out of the chamber to the system through the opened valve V2. The motion of the pumping element induces a force to the pumped fluid. The pump creates a flow.

Classification of Pumps

A positive-displacement pump delivers a definite amount of fluid to the system. In a non-positive-displacement pump, its internal leakage increases as the downstream pressure increases. A fixed-displacement pump delivers a fixed amount of fluid for each revolution of its drive shaft. A variable-displacement pump is designed to deliver a variable volume of fluid per cycle when running at a given speed. The pump output can be varied by changing the physical relationship of the internal pump elements. The positive-displacement pumps can further be classified according to the types of pumping elements, such as gears, vanes, and pistons, used.



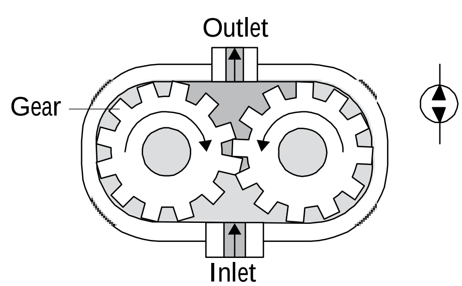
Symbols of Pumps

Gear Pumps

They are positive-displacement devices. They are simple, least expensive, and more tolerant of harmful fluid contamination. However, they are unbalanced and tend to wear disproportionately on one side, permit leakage and less efficient. Types: (1) External gear pump, (2) Internal gear pump, (3) Gerotor pump, (4) Screw pump.

External Gear Pump

It consists of two (or more) close-meshing identical gears (i.e., gear-on-gear), enclosed in a close-fitting housing. The space enclosed by the gear teeth, pump housing, and side wear plates forms the fluid chambers. A shaft supports each of the gears. One of the gears – called the drive gear - is coupled to a prime mover through its drive shaft. The second gear - called the driven (idler) gear - is driven, as it meshes with the drive gear.



The gears rotate in opposite directions. They mesh at a point between the inlet and outlet ports to provide a tight sealing. The diverging teeth at the inlet create a partial vacuum, which draws fluid. The trapped fluid then travels around the periphery of the gears as two streams. As the pump has a positive internal seal against the leakage, the fluid is positively ejected out of its delivery port. The pump displaces a fixed volume of fluid in one revolution and creates the flow.

Internal Gear Pump

This pump consists of an outer rotor gear, an inner spur gear, and a crescent-shaped spacer, all enclosed in a housing. The gears are set eccentric to each other. The gear with fewer teeth operates inside the rotor gear. The stationary crescent spacer is machined into the space between these. It acts as a seal between the suction and discharge ports. The pumping process includes drawing the fluid, trapping the fluid, moving the fluid, sealing the fluid, and discharging the fluid.

Gerotor Pump

It is similar to the internal gear pump, without the crescent-shaped spacer. It consists of an off-centre inner gear rotor (Gerotor element) and an outer female gear rotor (idler) enclosed within the housing. There is exactly one tooth difference between the gears. The tips of the teeth on the inner gear and the outer gear are always in contact. The driven inner gear rotor draws the outer gear rotor around as they mesh together. The pumping process includes drawing the fluid, trapping the fluid, moving the fluid, sealing the fluid, and discharging the fluid.

Screw Pumps

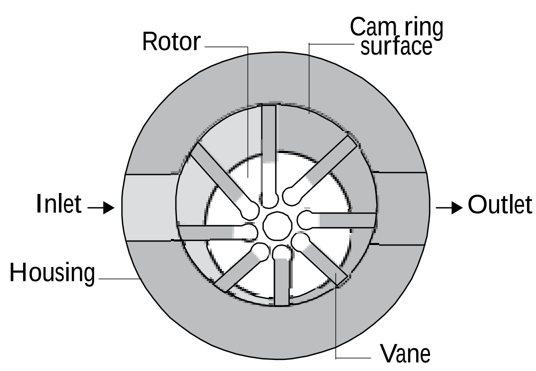
Two basic types are: single-screw pumps and multiple-screw pumps. They have multiple external screw threads (single suction/double suction type). A two-screw pump is constructed with two parallel intermeshing rotors capable of rotating in a housing machined to close tolerances. A three-screw pump consists of a central drive rotor with two meshing idler rotors rotating in a housing machined to close tolerances. The pumping process includes drawing the fluid, trapping the fluid, moving the fluid, sealing the fluid, and discharging the fluid.

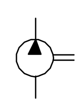
Vane Pump

Vane pumps are positive-displacement pumps. Vane pumps can be classified into two types. They are (1) unbalanced vane pumps and (2) balanced vane pumps. Vane pumps can also be classified into fixed and variable-displacement types.

Unbalanced Vane Pump

It consists of a prime-mover-driven rotor with sliding vanes in close-fitting radial slots. The rotor moves within a larger circular cavity. The centers of the rotor and the cavity are offset by a certain distance, causing an eccentricity. The vane tips bear against the casing and form an adequate seal. Side plates are used to keep the fluid confined to the space existing along the width of the rotor and vanes.





As the rotor rotates, the space between any two successive vanes at the suction side increases. This expanding volume creates a partial vacuum, which draws fluid into the chambers formed by the vanes. The fluid is trapped in these chambers, and it is then moved through the pump by the rotating vanes. As the space between the two rotating vanes decreases, the fluid is squeezed out through the discharge port and the pump creates the flow.

Balanced Vane Pump

The rotor moves inside an elliptical cam ring (casing) concentrically. The pump also consists of a set of diagonally opposite suction ports as well as a set of diagonally opposite discharge ports. This design creates two separate pumping areas on opposite sides of the rotor. The pumping action occurs in the chambers on both sides of the rotor and the shaft equally.

Variable Displacement Vane Pump

The pump displacement can be varied by modifying the degree of eccentricity between the rotor and the casing, from zero to a maximum. The variable-displacement vane pump has a movable outer casing ring that surrounds the rotor. If the rotor is dead centre with the casing, then there is no pumping action. If the centre of the rotor is offset to the maximum extent with the centre of the ring, then the eccentricity between the rotor and the ring reaches the maximum, and the pump flow tends to approach its maximum value. The pump flow can be infinitely varied by positioning the rotor in between these extremes.

Piston Pumps

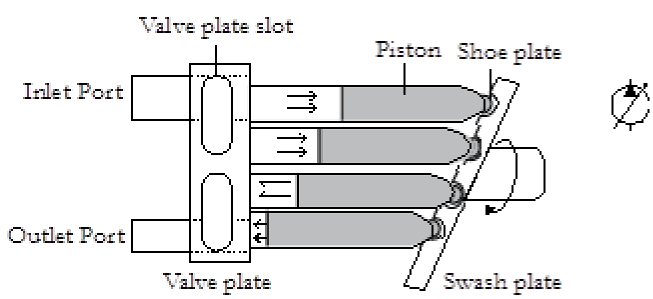
A piston pump consists of a cylinder block with pistons attached to the drive shaft. Piston pumps can be classified as axial-piston pumps and radial piston pumps according to the spatial arrangement of the cylinders. In the axial-piston pumps, a number of pistons are arranged parallel to the cylinder block in a circular array, whereas, in the radial piston pumps, the pistons are arranged radially in the cylinder block. Piston pumps are also available in fixed-displacement and variable-displacement designs.

Axial Piston Pumps

Axial-piston pumps can further be classified as in-line axial-piston pumps and bent-axis axial-piston pumps. In the in-line axial-piston pump, the centre line of its cylinder block is in-line with the centre line of its drive shaft. In the bent-axis axial-piston pump, the centre line of its cylinder block is at an angle with the centre line of its drive shaft. The fluid is then positively ejected out of its delivery port as the pump has a positive internal seal against the leakage

In-line Axial Piston Pumps

It mainly consists of (1) a group of cylinders with pistons, (2) a cam plate (swash plate), (3) a stationary valve plate, and (4) a drive shaft. The cylinders are fitted in parallel into a round block around an axis. The cylinder pistons are fitted to the cam plate through ball joint shoes. If the cam plate is not angled, the rotating pistons tend to remain stationary within their bores. If the cam plate is angled, the rotating pistons move back and forth in their respective cylinder bores.



The valve plate contains two kidney-shaped openings. The larger one is the suction port, and the smaller one is the discharge port. As the cylinder block rotates, each cylinder is connected to the suction side and the discharge side alternately by the valve plate. Any bore in the cylinder block turn past the suction port, the piston is pulled out from its bore, drawing the fluid from the reservoir. As the bore turn past the discharge port, the piston is pushed into its bore, forcing out the fluid through the discharge port.

Bent-axis Piston Pumps
It mainly consists of (1) a cylinder block, (2) a valve plate, and (3) a drive shaft. The axis of the cylinder block is set at an angle to the axis of its drive shaft. When driven, the pistons reciprocate in their respective bores. The bores in the cylinder block are connected successively to the low-pressure suction port and the high-pressure discharge port by the valve plate while rotating.

Radial Piston Pumps
A radial piston pump consists of (1) a cylinder block with seven or nine radial barrels, (2) a reaction ring, (3) a pintle, and (4) a drive shaft. The pistons are arranged in radial directions around the drive shaft. The pintle includes suction and discharge ports that connect with the inner openings of the cylinder barrels to direct fluid in and out of each cylinder. The pistons move in or out, as the cylinder block rotates. The pumping process includes drawing the fluid, trapping the fluid, moving the fluid, sealing the fluid, and discharging the fluid.

Applications
Various types of hydraulic pumps, such as gear, vane, and piston pumps, and their variants are available to meet the wide-ranging application demands. For light-duty and medium-duty industrial applications, gear pumps and vane pumps are most used, whereas, for power-intensive applications piston pumps are most suitable. For applications involving rough handling and dirty environment, as in mobile equipment and conveyor systems, external gear pumps are most appropriate. For sophisticated applications involving variable-displacement and low-noise operations, vane pumps are suitable. Piston pumps find applications in aerospace, agricultural, automotive, mobile and construction equipment, marine equipment, metal forming and stamping machines, machine tools, oilfield equipment, and mining fields.

Important Terms & Definitions Pertaining to Hydraulic Pumps

Volumetric Displacement (V_D) is the volume of fluid that is carried by the pump in one cycle of its drive shaft (m^3/rev, cc/rev).

Theoretical Flow Rate (Q_T) is the volume of fluid discharged by the pump per unit of time, provided there is no slippage.

$$Q_T\ (m^3/min) = V_D\ (m^3/rev) \times N\ (rpm)$$

Pump Slippage represents the internal leakage of the fluid in the pump from its discharge port to its suction port.

Actual Flow Rate (Q_A) is the actual fluid volume discharged by the pump per unit of time.

$$Q_A = Q_T - \text{Slippage}$$

Actual Torque (T_A) is the actual torque delivered to the pump by its prime mover.

$$\text{Actual torque, } T_A(\text{Nm}) = \frac{\text{Actual power delivered to the pump (watt)}}{\omega\ (\text{rad/s})}$$

Theoretical Torque (T_T) is the actual torque minus the torque losses on account of friction in the pump.

$$\text{Theoretical Torque, } T_T(\text{Nm}) = \frac{V_D\,(m^3/rev) \times P(Pa)}{2\prod}$$

Pump Input Power is the power delivered to the pump by its prime mover. The speed of the drive shaft and torque imparted by the motor determine the input power.

$$\text{Pump input power (kW)} = \frac{T_A\ (\text{Nm}) \times N\ (\text{rpm})}{9550} = \frac{T_A\ (\text{Nm}) \times \omega\ (\text{rad/s})}{1000}$$

Pump Output Power is the power delivered by the pump. The pressure and the actual flow rate determine the output power.

$$\text{Pump output power (kW)} = \frac{P(\text{Pa}) \times Q_A(^{\text{m}^3}/\text{s})}{1000} = \frac{P(\text{bar}) \times Q_A(\text{lpm})}{600}$$

Efficiency of Pumps

Two types of efficiencies are identified to account for the losses due to leakage and friction.

Volumetric Efficiency (η_v) represents the ratio of the actual flow rate at a given pressure and the theoretical flow rate, assuming no frictional losses.

$$\text{Volumetric Efficiency } (\eta_v) = \frac{\text{Actual flow rate}}{\text{Theoretical flow rate}} = \frac{Q_A}{Q_T}$$

Mechanical Efficiency (η_m) represents the ratio of the power delivered to the power delivered to the pump, assuming no leakage.

$$\text{Mechanical Efficiency } (\eta_m) = \frac{\text{Pump output power, assuming no leakage}}{\text{Actual power delivered to the pump}} = \frac{P \times Q_T}{T_A \times N}$$

Overall Efficiency (η_o) is the ratio of the actual power delivered to the actual power delivered to the pump.

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

Reference: JOJI PARAMBATH, Industrial Hydraulic Systems – Theory and Practice, Universal Publishers, Boca Raton, USA, 2016. Please visit: http://www.universal-publishers.com/book.php?method=ISBN&book=1627340580

Note: A comprehensive account of the topic is given in the textbook on 'Industrial Hydraulic Systems-Theory and Practice' by Joji Parambath.