HYDRAULICS AND PNEUMATICS

Chapter - 4

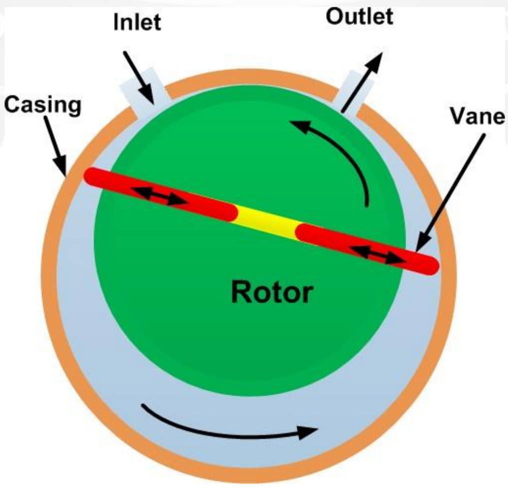
UNIT I FLUID POWER PRINICIPLES AND HYDRAULIC PUMPS

VANE PUMPS, Selection criteria of Linear and Rotary – Fixed and Variable displacement pumps –Problems.

Vane Pumps

In the previous lecture we have studied the gear pumps. These pumps have a disadvantage of small leakage due to gap between gear teeth and the pump housing. This limitation is overcome in vane pumps. The leakage is reduced by using spring or hydraulically loaded vanes placed in the slots of driven rotor. Capacity and pressure ratings of a vane pump are generally lower than the gear pumps, but reduced leakage gives an improved volumetric efficiency of around 95%.

Vane pumps are available in a number of vane configurations including sliding vane, flexible vane, swinging vane, rolling vane, and external vane etc. Each type of vane pump has its own advantages. For example, external vane pumps can handle large solids. Flexible vane pumps can handle only the small solids but create good vacuum. Sliding vane pumps can run dry for short periods of time and can handle small amounts of vapor. The vane pumps are known for their dry priming, ease of maintenance, and good suction characteristics. The operating range of these pumps varies from -32 °C to 260 °C.



Schematic of working principle of vane pump

The schematic of vane pump working principle is shown in above figure. Vane pumps generate a pumping action by tracking of vanes along the casing wall. The vane pumps generally consist of a rotor, vanes, ring and a port plate with inlet and outlet ports. The rotor in a vane pump is connected to the prime mover through a shaft. The vanes are located on the slotted rotor. The rotor is eccentrically placed inside a cam ring as shownin the figure. The rotor is sealed into the cam by two side plates. When the prime mover rotates the rotor, the vanes are thrown outward due to centrifugal force. The vanes track along the ring. It provides a tight hydraulic seal to the fluid which is more at the higher rotation speed due to higher centrifugal force. This produces a suction cavity in the ringas the rotor rotates. It creates vacuum at the inlet and therefore, the fluid is pushed intothe pump through the inlet. The fluid is carried around to the outlet by the vanes whose retraction causes the fluid to be expelled. The capacity of the pump depends upon the eccentricity, expansion of vanes, width of vanes and speed of the rotor. It can be noted that the fluid flow will not occur when the eccentricity is zero. These pumps can handle thin liquids (low viscosity) at relatively higher pressure. These pumps can be run dry fora small duration without any failure. These pumps develop good vacuum due to negligible leakage. However, these pumps are not suitable for high speed applications and for the high viscosity fluids or fluids carrying some abrasive particles. The maintenance cost is also higher due to many moving parts. These pumps have various applications for the pumping of following fluids:

- Aerosol and Propellants
- Aviation Service - Fuel Transfer, Deicing
- Auto Industry - Fuels, Lubes, Refrigeration Coolants
- Bulk Transfer of LPG and NH3
- LPG Cylinder Filling
- Alcohols
- Refrigeration - Freons, Ammonia
- Solvents
- Aqueous solutions

Unbalanced Vane pump

In practice, the vane pumps have more than one vane as shown in figure 1.4.1. The rotor is offset within the housing, and the vanes are constrained by a cam ring as they cross inlet and outlet ports. Although the vane tips are held against the housing, still a small amount of leakage exists between rotor faces and body sides. Also, the vanes compensateto a large degree for wear at the vane tips or in the housing itself. The pressure difference between outlet and inlet ports creates a large amount of load on the vanes and a significant amount of side load on the rotor shaft which can lead to bearing failure. This type of pump is called as unbalanced vane pump.

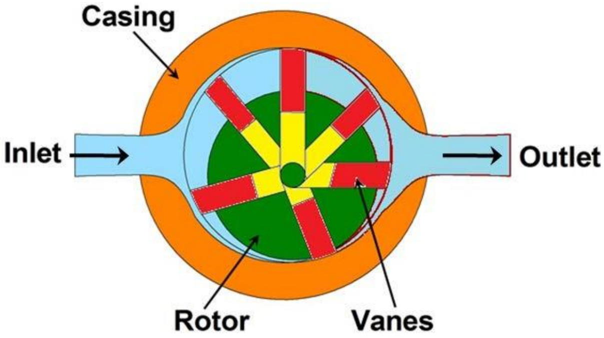


Figure 1.4.1 Unbalanced vane pump

BALANCED VANE PUMP

Figure 1.4.2 shows the schematic of a balanced vane pump. This pump has an elliptical cam ring with two inlet and two outlet ports. Pressure loading still occurs in the vanes butthe two identical pump halves create equal but opposite forces on the rotor. It leads to the zero net force on the shaft and bearings. Thus, lives of pump and bearing increase significantly. Also the sounds and vibrations decrease in the running mode of the pump.

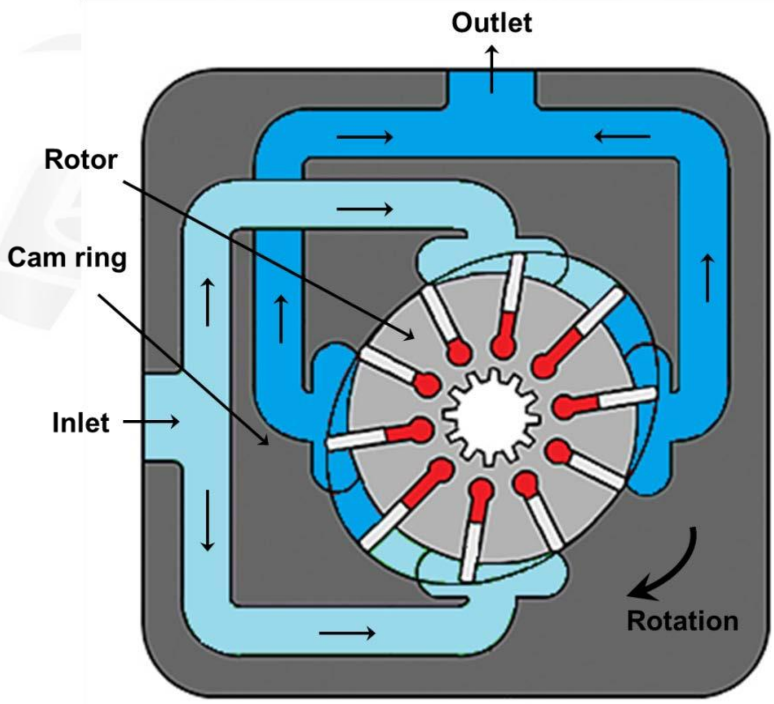


Figure 1.4.2 Balanced vane pump

ADJUSTABLE VANE PUMP

The proper design of pump is important and a challenging task. In ideal condition, the capacity of a pump should be exactly same to load requirements. A pump with larger capacity wastes energy as the excess fluid will pass through the pressure relief valve. It also leads to a rise in fluid temperature due to energy conversion to the heat instead of useful work and therefore it needs some external cooling arrangement. Therefore, the higher capacity pump increases the power consumption and makes the system bulky and costly. Pumps are generally available with certain standard capacities and the user has to choose the next available capacity of the pump. Also, the flow rate from the pump in most hydraulic applications needs to be varying as per the requirements. Therefore, some vane pumps are also available with adjustable capacity as shown in figure 1.4.3. This canbe achieved by adjusting a positional relationship between rotor and the inner casing by the help of an external controlling screw. These pumps basically consist of a rotor, vanes, cam ring, port plate, thrust bearing for guiding the cam ring and a discharge control screwby which the position of the cam ring relative to the rotor can be varied. In general, the adjustable vane pumps are unbalanced pump type.

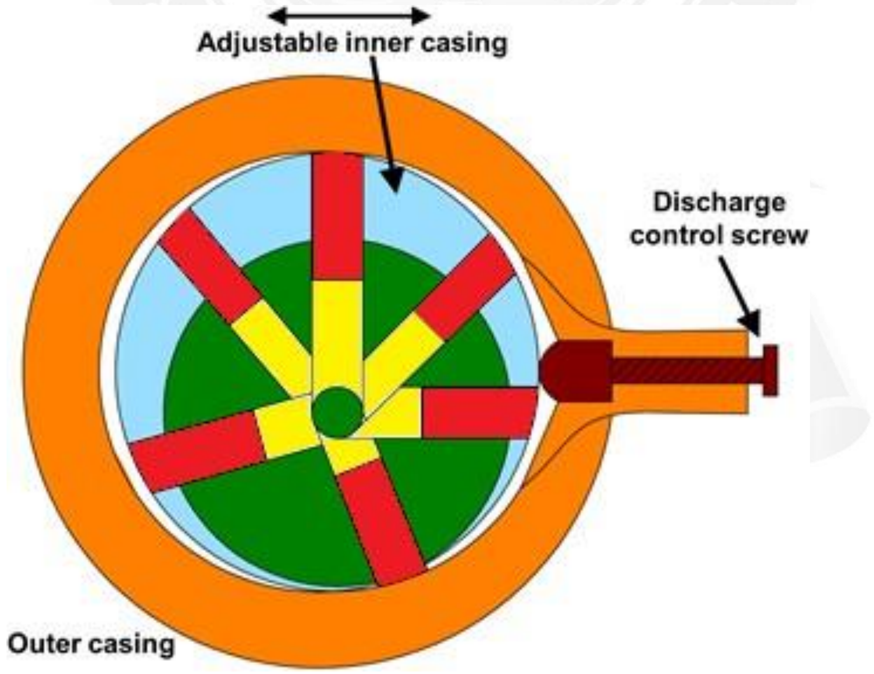


Figure 1.4.3 Adjustable vane pump

In general the applications of Hydraulic Pumps can be summarized as,

- Hydraulic pumps are used to transfer power via hydraulic liquid. These pumps have a number of applications in automobiles, material handling systems, automatic transmissions, controllers, compressors and household items.
- The hand operated hydraulic pump is used in a hydraulic jack where many strokesof the pump apply hydraulic pressure to lift the ram.
- A backhoe uses an engine driven hydraulic pump to drive the articulating parts of the mechanical hoe.
- The hydraulic pumps are commonly used in the automotive vehicles especially in power steering systems.
- The lift system of tractor is operated by the hydraulic pumps. These are used in automatic transmissions and material handling systems in industries.
- Many precise controllers are developed by using hydraulic pumps. The commonlyused compressor is operated by reciprocating pumps.
- The hydraulic pumps are also used in routine household systems like power lift and air-conditions. Therefore, it can be said that the hydraulic pumps have significant applications in industries as well as ones routine life.

Pump technology systems

Most pumps used in industrial settings can be divided into flow pumps and positive displacement pumps according to their underlying working principle.

Centrifugal pumps, a type of flow pump, are the most widely used pump type. In this type, the fluid flows through the machine continuously.

Displacement pumps are differentiated into rotary and reciprocating positive displacement pumps. Here, individual volumes of equal size flow through the machine discontinuously.

Rotary positive displacement pumps

In positive displacement pumps, the mechanical energy of a displacer in a closed space is transferred to the conveyed medium and increases its potential energy. In the case of a rotary positive displacement pump, the displacer, as the name suggests, carries out a rotating movement. There are a diverse range of shapes for displacers, including screws, gears and rotary pistons.

Reciprocating positive displacement pumps

This description is given by the reciprocating movement of the displacer, in the form of aplunger or a diaphragm, which alternately increases and decreases the working space. In order to prevent return flow of the conveyed medium, the working space has to be closed by two valves.

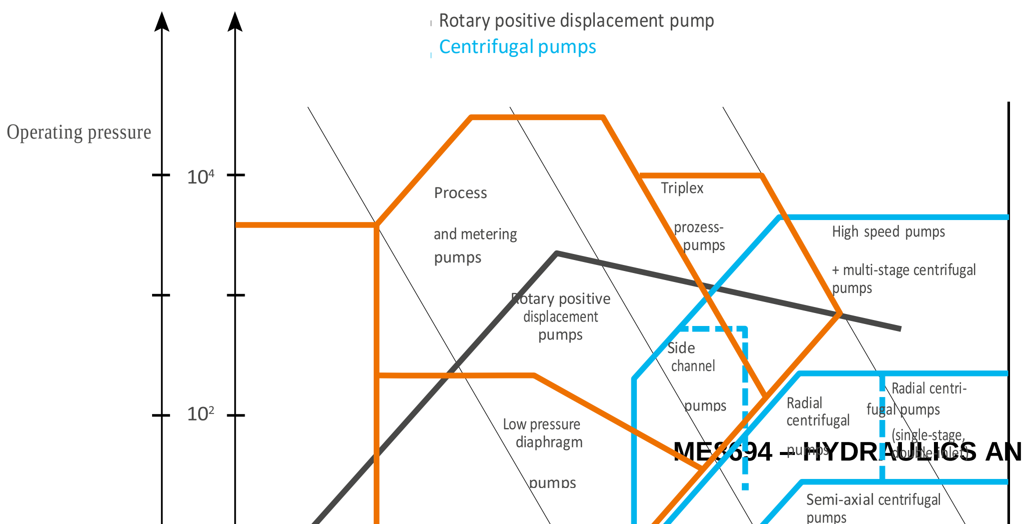
Comparison or Selection of the different pump types.

As already mentioned, reciprocating positive displacement pumps have an extremely rigid pressure characteristic curve. With rotary positive displacement pumps, the flow rate depends more on the pressure, as the leakage losses through the sealing gaps are directly depending on the differential pressure. Due to their operating principle, the flow rate of centrifugal pumps directly depends on the discharge pressure.

When it comes to selecting a suitable pump, it is generally correct that centrifugal pumps are used primarily at high flow rates and low pressures, while displacement pumps are suitable for high pressures and low flow rates. The exact application area with respect to pressure and flow rate depends on the design, as illustrated by Figure 1.5.1

Certainly, there are overlaps, some application areas are covered by different pump designs. Other selection criteria have to be taken into account. Application areas that require precise metering call for displacement pumps. If hermetic sealing is required, diaphragm pumps are the right choice. Here, however, it should be mentioned that other pump designs can also be constructed to be hermetically tight, using canned motors.

However, technically feasible application areas are often abandoned due to economic aspects or predetermined infrastructure, e.g. an existing pump pool.



Flow rate in m^3/h

Fig 1.5.1 - : Pressure/flow rate diagram for various pump designs

Diaphragm pumps are suitable for pumping different fluids. The safe transport of toxic, highly acidic or basic substances as well as abrasive, combustible and environmentally hazardous materials opens up numerous application options for diaphragm pumps in the chemical industry. In this industry, systems and chemical pumps for critical processes need to be safe and reliable.

In practice, diaphragm pumps are used both for manufacturing various chemicals, often under extreme conditions such as high temperatures and pressures, as well as for precisely metering micro flows in laboratory environments

Diaphragm pumps are frequently used in the oil and gas industry. In oil production, for example, for chemical injection to treat oil, gas or water, and also for gas drying, diaphragm pumps ensure reliable operation and high process safety. Depending on the discharge pressure and flow rate, various materials can be used for the diaphragm. Elastomers and thermoplastics such as PTFE or metal diaphragms are common.

Diaphragm pumps are also used in gas odorizing systems. In these systems, the pumps meter a strong-smelling gas into odorless natural gas or into LNG/LPG/CNG (liquefied natural gas, liquefied petroleum gas, compressed natural gas). This is done for safety reasons, since escaping gas is highly dangerous. Leaks must be detected early to avoid explosions and accidents. For example, the diaphragm pumps are operated in odorizing systems at gas pressure regulation stations, "gate stations" or junction points in the natural gas distribution grid and in LPG odorizing at gas stations and filling stations.

Operators in refineries and downstream applications also benefit from low-maintenance diaphragm technology. For special applications a remote head design can be used, a special design where the drive unit is spatially separated from the pump head, eg for manufacturing biofuels, since temperatures up to 400 °C occur in these applications.

Multiplex diaphragm pumps are suitable for mixing various components into one end product. A process called "recipe metering" allows ingredients to be mixed together in various proportions. Thanks to the modular design, drive elements with different reduction ratios and stroke lengths can be combined. This allows the individual pump elements of the multiplex pump to run at different speeds and flow rates. Thus, various fluids, which may have drastically different viscosities, can be conveyed and mixed efficiently and cost-effectively.

In general, diaphragm metering and process pumps are used when hazardous or high-viscosity media need to be pumped or when dry running is a concern due to process conditions. Because the separating diaphragm ensures mutual shielding for the pumped fluid and drive, the diaphragm pump guarantees that the respective fluid is pumped safely, reliably and without leaks, thus solving one of the main problems with plunger pumps.

Design consideration of pumps

In order to select the right metering pump, a series of fluid properties and process parameters must be taken into account. The most important are the necessary flow rate and the hydraulic power. The following sections address the way these values are calculated and the influence of the design criteria.

Flow rate

The theoretical flow rate $\dot{V}_{th}$ of a reciprocating positive displacement pump is calculated by multiplying the stroke volume V_S by the number of strokes n and the number of pump cylinders i The stroke volume is calculated by multiplying the plunger surface area A_p with the stroke length s :

$$\dot{V}_{th} = V_s * n * i = A_p * s * n * i$$

Due to the compressibility of fluids in the pump working space, the elasticity of the pump housing, backflow losses during the valve closing process as well as minor leakages through the plunger seal, the actual flow rate $\dot{V}$ is less than the theoretical flow rate $\dot{V}_{th}$ These losses are represented by the volumetric efficiency ηv

The actual flow rate can be calculated as follows:

$$\dot{V} = \dot{V}_{th} * \eta_v$$

The mass flow It can be calculated by multiplying the volume flow rate by the density ρ:

$$\dot{m} = \rho * \dot{V}$$

Hydraulic power

The hydraulic power P_{hyd} is calculated from the differential pressure Δp between the inlet and outlet sides and the flow rate $\dot{V}$:

$$P_{hyd} = \Delta p * \dot{V}$$

During the initial design steps for a reciprocating positive displacement pump, the hydraulic power can be used to come up with a rough estimate for the pump size.

Head

The head is generally used for designing centrifugal pumps. Due to the prevalence of centrifugal pumps, the term "head" is also used for other pump types, although it is more common to design reciprocating positive displacement pumps based on the dis- charge pressure. Thus, the following explains the definition of head and how it is converted into pressure:

The head H is defined as the usable mechanical work transferred from the pump to the pumped fluid with respect to the weight force of the pumped fluid. It is possible to calculate the head from the discharge pressure p using the density of the fluid ρ and the gravitational acceleration g as follows:

$$H = \frac{p}{\rho g}$$

The unit of head is the meter m. The SI unit for the pressure is the pascal Pa. When de- signing pumps, the *bar* or *psi* is usually used as the unit of pressure.

Selection Criteria of Pump depends on Fluid Characteristics:

Fluid Temperature:

Fluid temperatures determine the design of the pump head. Depending on the diaphragm material (PTFE, stainless steel, Hastelloy etc), temperatures in a range of -20 °C to 200 °C are permitted without any additional constructional measures. This temperature range can be expanded using remote head solutions, as doing so decouples the process fluid from the drive unit. As a result, critical process conditions such as extreme temperatures or even radioactive radiation can be kept from affecting the displacement system, guaranteeing high system safety. Using this technology, temperatures up to 500 °C can be implemented.

If there is a major temperature difference between the fluid and the environment, a constant fluid temperature can be maintained in the pump heads using a heating or cooling jacket and/or insulation. High fluid temperatures result in increased heat transfer from the pump head to the drive unit. To ensure that this does not negatively impact the service life of the drive unit, cooling coils are built into the hydraulic oil reservoir.

The fluid temperature has a critical influence on the fluid properties themselves, Viscosity, density, vapor pressure and compressibility are dependent on temperature. The definition of a wide temperature range results in the corresponding ranges for the listed fluid parameters. The most unfavorable operating point has to be evaluated, considering the entire range of all fluid parameters.

Fluid Viscosity:

The viscosity affects the selection of the valve and the stroke frequency. At high viscosities, the closing delay of the valves must be taken into account in order to avoid a drop in flow rate. At the same time, to compensate for high viscosities, a moderate pump speed can be selected, which reduces the inlet pressure loss created by the inflow of the fluid flowing at the suction valve and inside the pump head. However, investment costs must also be considered. These costs can be reduced by selecting a smaller and more cost-effective pump that runs at a higher stroke frequency. At viscosities less than 1 mPa, occurring for instance with liquefied gases, there are suitable valve variants. This increases the service life of these wear parts.

Fluid Density:

The density is needed when a mass flow is being specified. The volume flow rate is al- ways used to design pumps and, as a result, it must be determined from the mass flow.

Vapour pressure:

The vapor pressure has to be taken into account in the context of suction pressure as well as the pressure losses in the pump head and suction line. This is vital to avoid cavitation in the suction line and in the pump. For vapor pressures close to the suction pressure, it is necessary to optimize the inlet pressure loss through the selection of the valves and stroke frequency. Pump heads with heating/cooling jackets are used to cool the fluid in order to take advantage of the fact that the vapor pressure heavily depends on the temperature, For example, in CO_2 applications, cooling by 5K in the temperature range above 0 °C makes it possible to reduce the vapor pressure by 5 bar or more. As an alternative, booster pumps can be used if necessary.

Compressibility:

The compressibility of a fluid determines the flow rate of the pump. If there is a large pressure increase, its influence is significant, again, especially in the case of liquefied gases. As the fluid temperature decreases, the compressibility decreases as well. Knowing about this relationship allows for smaller pumps to be designed. At the same time, the fact that the heat of compression results in heating of the pump head must be taken into account in liquefied gas applications. A cooling device in the form of a heating/cooling jacket can be installed in these cases.

Solidification point:

The solidification point determines whether or not a heated pump head is required. Melts are not in the liquid phase at ambient temperature. Therefore, the head must be brought to the right temperature before the pump is started up so that the fluid is flowable.

Common Parameters for the Selection of hydraulic pump in hydraulic system

1) Pressure:

It is the basic selection criteria. Pump pressurizes the hydraulic oil to the level required by actuator. When pressures up to 150 bars are required then gear pumps can be selected. For pressure of 150 to 250 vane pump is suitable and for above 500 bar pressure piston pumps are useful.

2) Flow of pressurized oil:

Volumetric output of pump is measures in LPM. The flow of oil decides the speed of actuator. The displacement can also be changed for variable displacement pumps.

3) Speed of pump:

The speed of pump is decided by rated capacity of the manufacturer. If wrong speed is selected for pump, then efficiency and working of hydraulic system may get hamper.

4) Efficiency of the pump:

The selected pump must have good efficiency. We can consider following efficiencies: 1) Volumetric 2) Mechanical 3) Overall 5) Oil compatibility: The oils used in pump should be compatible with the material of the pump. If wrong oil gets selected then pump will not work to its rated performance.

Problems and Calculations on Pumps

1. A gear pump has a 75mm outside diameter, a 50mm inside diameter, and a 25mm width. If the actual pump flow at 1800rpm and rated pressure is 0.106m3 /min, what is the volumetric efficiency?

Volume $V = \frac{\pi}{4}(D_o^2 - D_i^2)L$

$= \frac{\pi}{4} \times (0.075^2 - 0.050^2) \times 0.025$

$= 0.0000614\ m^3/rev$

Theoretical flow rate, $Q_T = V_D N = 0.0000614 \times 1800 = 0.115\ m^3/min$

The volumetric efficiency, $\eta_v = \frac{Q_A}{Q_T}$

$= \frac{0.106}{0.115} = 0.921 = 92.1\%$