Hydraulic Drive

Er. H. S. Dhingra
Dr. S. S. Dhami

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Hydraulic Drive & Controls

-: Course Content Developed By :-

Er. H. S. Dhingra

Associate Professor

Department of Farm Machinery and Power Engg., PAU, Ludhiana

-:Content Reviewed by :-

Dr. S. S. Dhami

Associate Professor

NITTTR, Chandigarh

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Module 1. Hydraulic Basics

LESSON 1. HYDRAULIC BASICS

Introduction

Electrical motors can provide rotary motion, which if required can be converted into linear motion by devices such as screw jack or rack and pinions etc. For very short stroke, say upto 10 mm, a solenoid may be used to obtain linear motion directly.

Enclosed fluids (both liquids and gases) can also be used to produce rotary or linear motion or apply a force. Fluid based systems using liquids as transmission medium are called hydraulic systems, whereas gas based systems are called pneumatic systems.

A comparison of main features of electrical, hydraulic and pneumatic systems is given in Table 1.1.

Table 1.1 Comparison of Electrical, Hydraulic and Pneumatic Systems

	ELECTRICAL	HYDRAULIC	PNEUMATIC
ENERGY SOURCE	Electrical power station	Electric motor or Diesel engine	
ENERGY STORAGE	Limited (batteries)	Limited (accumulator)	Good (reservoir)
DISTRIBUTION SYSTEM	Excellent with minimum losses	Limited	Good (plant wide)
ENERGY COST	Lowest	Medium	Highest
ACTUATOR	AC motors cheap, Good speed control in DC motors, Short linear motion with solenoids	Low speed with good control	Wide speed range, speed control difficult
FORCE AVAILABLE	Low	High	Medium
HAZARDS	Electric shock	Oil leakage dangerous and unsightly	Noise

1.2 Hydraulics

When a force is applied on a liquid in an enclosed vessel, a uniform pressure is exerted on the liquid throughout the enclosed volume. Any leak in the vessel will decrease the pressure.

Hydraulics is the science of transmitting force or motion or both through the medium of confined liquid. In hydraulic devices, power is transmitted from one location to another by applying a force on a confined liquid, to produce rotary or linear motion or to apply a force. To operate liquid-powered systems, it is required to have knowledge of the basic nature of liquids as the basic principles of hydraulics are based on certain characteristics of liquids

- Liquids have no shape of their own. However, they have definite volume.

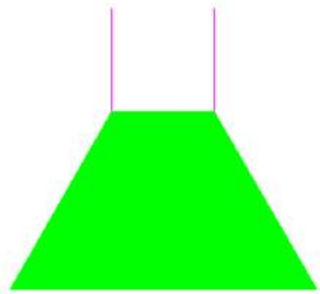

Fig 1.1 Liquids have no definite shape

- Liquids acquire the shape of the container they are put in.
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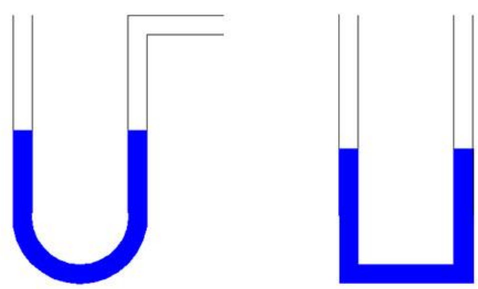

Fig 1.2 Liquids acquire shape of container

- Liquids always seek a common level.
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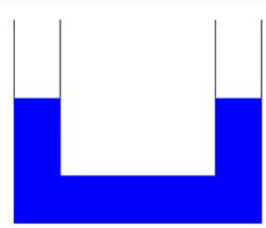


Fig 1.3 Liquid seek common level

Therefore, oil in a hydraulic system will flow in any direction and through any passage, regardless of size or shape. Liquids are basically incompressible, which gives them the ability to transmit force. The pressure applied to a liquid in a sealed vessel is transmitted equally in all directions and to all areas of the system. Since force equals pressure times area, liquids can provide great increases in the force available to do work by getting larger area to system pressure.

1.3 Brief History

Humans recognized fluids as a source of power long ago. Water is available in nature and water flowing under pressure has two forms of energy – kinetic and potential energy. This natural source of energy has been harnessed by humankind since early ages for irrigation and to drive simple machines.

Joseph Bramah (1748 -1814), an inventor and locksmith of England, got a patent for his invention of the hydraulic press in 1795. William George Armstrong (1810 – 1900), a successful industrialist of England, developed hydraulic accumulator, a cast-iron cylinder fitted with a plunger supporting a very heavy weight. Both Bramah and Armstrong are considered fathers of hydraulic engineering.

In the early stages of industrial development, mechanical linkages had been used along with prime movers, like electric motors and engines, for handling loads. But, the mechanical efficiency of linkages is very low and these often fail under certain working conditions. With the advent of fluid power technology, several applications, where motion and/or force are primary requirements, started using hydraulic power.

Common examples of applications of hydraulic systems which we come across now-a-days are shown in Fig. 1.4.

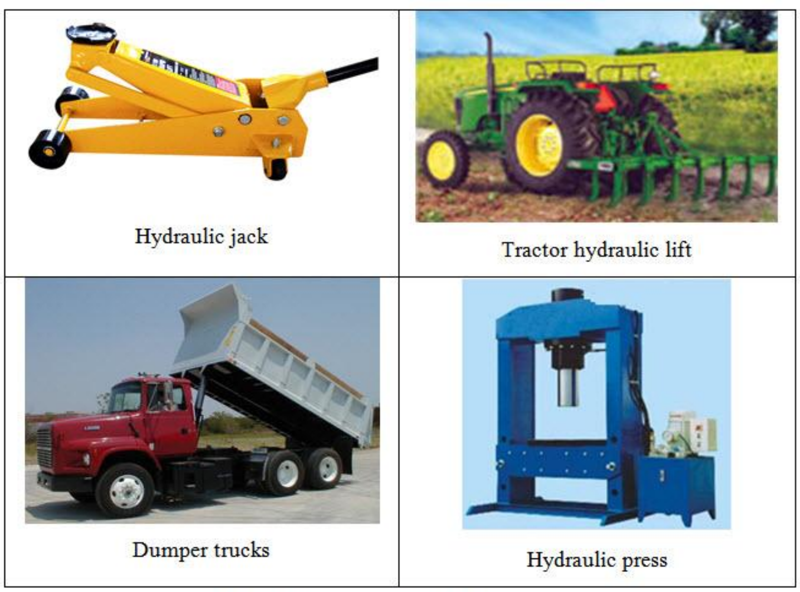


Fig. 1.4 Common Hydraulic Systems

1.4 Advantages of Hydraulic Systems

The advantages of hydraulic systems over other methods of power transmission are:

Automation: Complete automation in many cases is possible with the use of hydraulics

Power to Weight Ratio: A high power to weight ratio is available in comparison with electrical and pneumatic systems.

Simpler design: In most cases, readily available components, such as cylinders and valves, can be used to build a hydraulic system.

Flexibility: Hydraulic components can be located with considerable flexibility. Pipes and hoses in place of mechanical elements reduce location problems.

Smoothness: Hydraulic systems are smooth and quiet in operation. Vibration is kept to a minimum.

Lubrication: Since oil is used as working medium, separate lubrication of various components is not required.

Bidirectional: Hydraulic systems or devices can be operated in forward (clockwise) or backward (anticlockwise) directions easily.

Control: Control of a wide range of speed and forces is easily possible.

Responsive: Since the medium used for power transmission in hydraulic systems is incompressible, they exhibit a quick response.

Transmission Efficiency: Hydraulic systems exhibit high efficiency due to minimum friction loss.

Overload protection: Automatic valves guard the system against a breakdown from overloading.

1.5 Disadvantages of Hydraulic Systems

The following disadvantages are associated with hydraulic systems:

Initial Cost: The initial cost of hydraulic systems is high.

Leakage: Oil leakage in hydraulic systems results in unsightly and slippery conditions.

Protection against Dirt / Water: Protection is required against dirt and water entering hydraulic system.

Maintenance: Frequent maintenance in terms of gaskets, seals and packagings etc. is required.

Hazardous: Oil leakage is a fire and environment hazard.

1.6 Hydraulic Systems Fundamentals, Operation and Control

The knowledge of the following is necessary for understanding the working of hydraulic systems, their operation and control:

- Physical units for fluid power
- Principles of fluid power

- Fluids used in hydraulic systems
- Hydraulic power packs
- Hydraulic system components
- Fittings and connectors
- Basic hydraulic circuits
- Design of hydraulic circuits
- Maintenance and troubleshooting

In the next lecture, the physical units for fluid power and units of measurement will be discussed. Also the basic hydraulic system and its terminology will be introduced.

LESSON 2. HYDRAULIC BASICS

2.1 INTRODUCTION

Transmission of motion can be done easily with liquids. Consider a simple hydraulic device used for lifting a load as shown in Fig. 2.1. It consists of an L-shaped cylinder filled with hydraulic oil and fitted with two pistons at the two extremes. The pistons can move in the cylinder. Piston 'A' is used for applying force and piston 'B' is used for lifting a load. Piston A is called the apply piston and piston B is called the output piston.

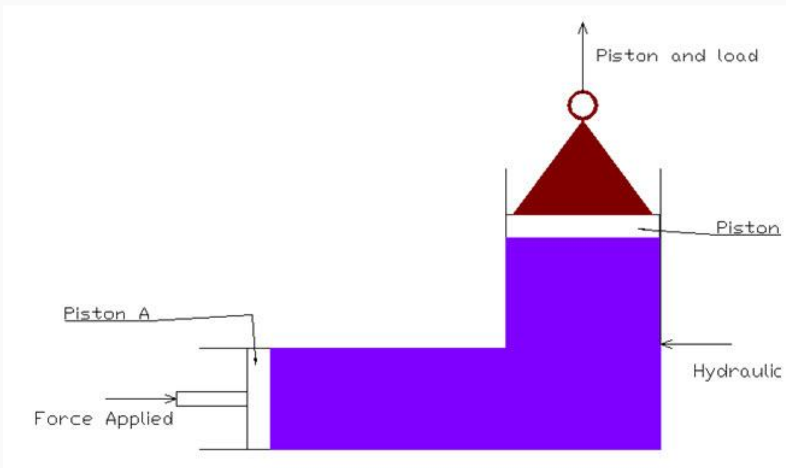


Fig. 2.1 : A simple hydraulic device

In a hydraulic device power is transmitted by pushing on a confined liquid. The transfer of energy takes place because the confined liquid is subjected to pressure due to the push. This pressure acts equally in all directions. Therefore, when apply piston 'A' is pushed towards right a pressure is created in the hydraulic oil, which acts throughout the system equally in all directions. This results in a force on output piston 'B' equal to pressure multiplied by area of the piston 'B'.

For example if a pressure 'P' = 20 kgf/cm^2 is acting on output piston having area 'A_p' = 10 cm^2, then the force 'F' acting on the piston is calculated as:

$F = P \times A_p = 20\ kgf/cm^2 \times 10\ cm^2 = 200\ kgf.$

Due to this force, the piston 'B' will move in upward direction along with the load. The displacement and speed of the output piston will depend upon a number of factors such as combined mass of piston 'B' and load, dimensions of cylinder and pistons, fluid characteristics etc. A hydraulic engineer may require to calculate the output piston displacement for a given force on the apply piston or calculate the force required on apply piston for desired displacement of the output piston. For this purpose familiarity with various physical units of fluid power is essential.

2.2 Physical Units for Fluid Power

Hydraulic engineers are concerned with the following three fundamental units:

(a) Length

(b) Mass

(c) Time

Other units such as area, volume, velocity, force and pressure etc. can be defined in terms of the above mentioned fundamental units.

The fundamental units used in hydraulics are measured in various systems of units. British Imperial System also known as FPS system uses foot, pound and second. Metric system uses centimetre, gram and second (the CGS system) or metre, kilogram and second (the MKS system). The MKS system has evolved into SI system which uses is a logical method for defining derived units such as force and pressure, as compared to MKS system.

Now, we will discuss the fundamental and derived units which are significant for understanding hydraulics.

The unit of **length** is foot (ft) in FPS system, centimetre (cm) in CGS system and metre (m) in MKS and SI systems.

The unit of **time** is second (s) in CGS, MKS, SI and FPS systems.

Mass is the quantity of matter contained in a body. It's unit is pound (lb) in FPS system, gram (gm) in CGS system and kilogram (kg) in MKS and SI systems. Mass of a body is always a constant, irrespective of the location where it is measured.

Weight of an object is the *force* due to gravitational attraction between the object and the earth. Thus weight of an object is a force which is not constant for the object. It's value depends upon the force of gravity at the location where weight is measured. Thus the weight of an object will be different on the moon than on earth, but the mass of the same object will be same on moon and earth.

When a **force** 'F' is applied to a body having mass 'm', acceleration 'a' (or deceleration) is produced in the body, given by Newton's second law of motion:

$$F = ma \tag{2.1}$$

The unit of force is pound-force (lb-f) in FPS system, dyne in CGS system, kilogram-force (kg-f) in MKS system and Newton (N) in SI system.

A Newton is defined as the force which produces an acceleration of 1 ms^{-2} when applied to a mass of 1 kg. Here, it may be noted that the value of acceleration due to gravity is taken as 9.81 ms^{-2} i.e. 1 g = 9.81 ms^{-2}.

However, when force is taken in lb-f and mass in lb in the relation (2.1), acceleration is measured in g. Thus if a force of 10 lb-f acts on a body having mass of 5 lb, an acceleration equal to 2 g is produced in it.

Similarly, when force is taken in kg-f and mass in kg in the relation (2.1), acceleration is measured in g. Thus if a force of 10 kg-f acts on a body having mass of 5 kg, an acceleration equal to 2 g is produced in it.

Pressure is defined as the normal force acting per unit area. In FPS system the unit of pressure is pound-force per square inch (psi). In metric system, the unit of pressure is taken as kilogram-force per square centimeter (kg-f/cm^2).

The SI system defines pressure as the force in Newton per square metre (Nm^{-2}). Further 1 Nm^{-2} is called 1 Pascal (Pa). One Pascal of pressure quantifies a very low pressure from practical point of view. Therefore kilo Pascal (kPa i.e. 10^3 Pa) or mega Pascal (MPa i.e. 10^6 Pa) are more commonly used.

Pressure is exerted due to weight of a fluid. This is usually called pressure **head** and depends upon height 'h' of the fluid. In FPS and metric systems, head (P) is given by:

$$P = wh \qquad (2.2)$$

where head 'P' is measured in psi or kg-f/cm^2, 'w' is the specific weight of the fluid.

In SI system, expression (2.2) is written as:

$$P = \rho gh \qquad (2.3)$$

where 'g' is acceleration due to gravity (9.81 ms^{-2}). The head 'P' is measured in Pascal, 'ρ' is the density of the fluid and 'g' is the acceleration due to gravity.

Pressure in a fluid can also be defined in terms of equivalent head pressure. Common units are millimeter of Mercury (mm of Hg) and centimetre, inches, feet or metre of water.

Pressure is generally measured either with reference to atmospheric pressure or vacuum. When atmospheric pressure is used as reference, the measured pressure is called gauge pressure. When vacuum is used as reference, the measured pressure is called absolute pressure.

2.3 Conversion between Units

The conversion between units for various fundamental and derived quantities is given in Table 2.1.

Table 2.1 Conversion between Units

Mass
1 kg = 1000 gm
Length
1 m = 100 cm = 1000 mm
Volume
1 litre = 1000 ml
Force
1 N = 10^5 dynes
Pressure
1 bar = 100 kPa = 0.9872 atm (atmosphere) = 750 mm Hg 1 atm = 1.013 x 10^5 Pa = 1.013 bar

2.4 A Hydraulic System

The physical components and their layout for a typical hydraulic system are shown in Fig. 2.2. The basic components are pump, strainer, oil reservoir, filter, pressure gauge, pressure relief valve, control valves, actuator (cylinder or motor) etc. These components are joined together by means of pipes, tubes or hoses.

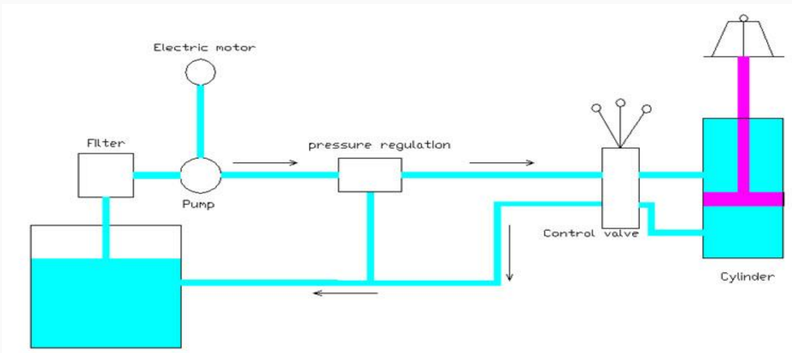


Fig. 2.2: A typical hydraulic system

Hydraulic pump

It converts the mechanical energy into hydraulic energy by forcing hydraulic fluid, under pressure, from the reservoir into the system. It may be called heart of the hydraulic system. The pumps used in the hydraulic circuit are generally of three types - piston type, gear type or vane type. A pump normally creates a partial vacuum, which causes the fluid to move through the pump and hence it keep on moving the fluid in the components.

Electric motor and coupling

These are used for running the hydraulic pump. An electric motor of suitable power rating is fitted as per the size of pump, pressure requirements etc. The pump and motor are connected with the help of a flexible coupling. The coupling absorbs the shocks and slight misalignment between the pump and the motor.

Oil sump or reservoir

It acts as a storehouse for the fluid and a heat dissipater. The hydraulic fluid stored in the sump is pumped into various components of the hydraulic system with the help of a pump. The capacity of the sump should be kept large, around three to four times the pump delivery, so that pump can move the fluid through the components continuously.

Strainer or filter

It filters the hydraulic oil circulating in the system. A strainer is required to have a filter in the system because the same oil is utilized again and again which makes the oil contaminated. The filters can be placed in the pump line, pressure line or return line. It collects the particles and prevents them from recirculation in the circuit.

Pressure gauge

It is used for measuring pressure in the hydraulic system. System pressure is required to be measured at the outlet of the pump and hence a pressure gauge is mounted. It indicates the pressure in the lines which is an indicator of the safe working of the system. The pressure gauge may be of dial type or digital type.

Relief valve

It is used to protect the system from damage by releasing excess pressure in the system. Pressure relief valve limits the pressure of the circuit. As the system pressure exceeds the set operating pressure, the relief valve discharges oil directly to return line thereby protecting the system from any damage.

Hydraulic valves

These are provided to control pressure, direction and flow rate of the fluid in the hydraulic system.

Fluid lines

These transport the fluid to and from the pump through the hydraulic system. These lines can be rigid metal tubes, or flexible hose assemblies. Fluid lines can transport fluid under pressure or vacuum (suction).

Fluid

It can be almost any liquid. The most common hydraulic fluids contain specially compounded petroleum oils that lubricate and protect the system from corrosion.

Actuators

It convert hydraulic energy into mechanical energy to do work. A linear actuator gives force and motion outputs in a straight line. It is more commonly called a cylinder. A rotary actuator produces rotational motion like an electric motor.

Module 2. Hydraulic Systems

LESSON 3. PASCAL'S LAW, FLOW, ENERGY, WORK AND POWER

3.1 INTRODUCTION

Hydraulics plays a significant role in the industrial and agricultural sectors. Hydraulic devices are perhaps amongst the greatest inventions which help human beings in performing complicated and heavy tasks. It is quite wonderful that how a small jack can lift tons and tons of weight with just the pressing of a handle or a hydraulic press can easily cut thick metal sheets. In a tractor or other automobiles hydraulic brake stop a vehicle by overcoming huge momentum of the vehicle using force applied by the driver on brake pedal. All these tasks are possible due to certain principles of hydraulic theory. The fundamental principle of hydraulics was discovered by Blaise Pascal, a French mathematician in 17th century. The law is known as Pascal's law or principle of transmission of fluid-pressure.

3.2 Pascal's Law

Pascal's law states that that pressure exerted anywhere in a confined incompressible fluid is transmitted equally in all directions with equal force on equal areas and acts normal to the surface. The law is illustrated in Fig. 3.1. A force of 'P' kgf is exerted on a piston having cross sectional area of 'A' cm^2. This results in a pressure of magnitude 'P/A' kgf/cm^2 act on the liquid exactly underneath the piston. Since the liquid is confined, the same pressure is transmitted throughout the liquid and acts on all the surfaces normally with equalmagnitude

i.e. 'P/A' kgf/cm^2.

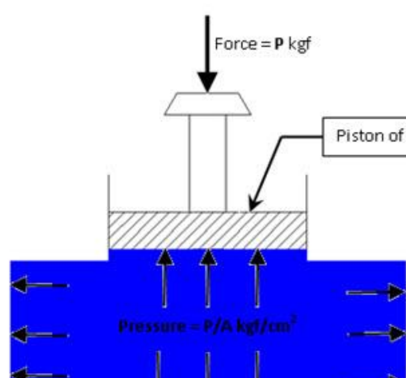


Fig. 3.1 : Pascal law illustration

3.3 Application of Pascal's Law

The principle of Pascal's law was successfully applied by an English Engineer Mr. Joseph Bramah in 1795 to develop a hydraulic press, in which by applying a small input force a large output force was generated. The Bramah's press principle may be understood by considering the two piston system shown in Fig. 3.2. A force of 100 kilogram is applied on the smaller cylinder having cross-sectional area of 1 cm^2. This creates a pressure of 100 kg/cm^2 in the liquid under the cylinder. According to Pascal's Law, this pressure is transmitted undiminished throughout the fluid acting normal in every direction. The 100 kg/cm^2 pressure acts on the larger diameter piston having an area of 5 cm^2. This results in a force of 100 kg/cm^2 x 5 cm^2 i.e. 500 kg acting perpendicularly on the piston. Thus the 500 kg force applied on the larger piston in the downward direction is balanced by the 500 kg force on the piston due to fluid pressure in the upward direction. Thus the applied force has been multiplied 5 times – a mechanical advantage of 5 to 1.

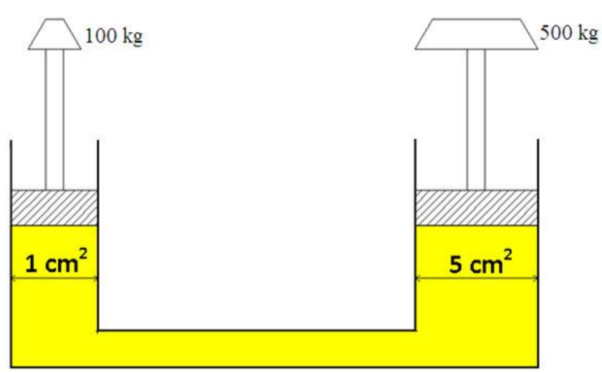


Fig. 3.2 : Pascal's law – Principle of Bramah's hydraulic press

Similarly, the distance moved by larger piston due to movement of smaller piston, in Fig. 3.2, can also be determined. Since hydraulic oil is incompressible, if the small piston moves down it displaces a volume of oil equal to the product of cross-sectional area of the cylinder and the distance traveled by the piston. For example, if the smaller piston is pushed down through a distance of 10 cm it will displace 1 cm^2 x 10 cm i.e. 10 cm^3 of oil. This will cause the larger piston to move up through a distance equal to 2 cm i.e. displaced oil volume of 10 cm^3 divided by larger cylinder area of 5 cm^2. Thus it can be observed that for forces F_1 and F_2 acting on two cylinders undergoing displacements d_1 and d_2:

$$F_1 \times d_1 = F_2 \times d_2 \qquad (3.1)$$

Since the product of force and displacement is the work done, Equation 3.1 shows that work done by external force on the system is equal to the work done by the system.

3.4 Flow

Fluid flows from high pressure point to low pressure point. Fluid can be forced to flow from low pressure to high pressure by using a pump. In a hydraulic system, a pump is used to produce oil flow in the system. Flow can be measured in terms of velocity and flow rate.

3.5 Velocity

Velocity of a fluid is the mean speed with which fluid particles move past a given point in unit time. It is usually measured in metre per second (ms^{-1}). Flow velocity is of prime importance in design of hydraulic systems as the pipes and hoses are sized according to velocity requirement.

3.6 Flow Rate

Flow rate of a fluid is the volume of fluid moving past a given point in unit time. It is usually measured in litre per second (l/s) or cubic centimeter per second (cusec). Flow rate determines the speed at which a load moves and therefore it is an important factor for power calculations.

3.7 Relationship between Flow Rate and Velocity

Flow rate through a pipe is equal to product of flow velocity through the pipe and cross-sectional area of the pipe. The following example illustrates this relationship.

Example: Oil flows through a hydraulic pipe of 15 mm diameter at a flow rate of 12 litre per minute. Find the flow velocity.

Solution:

$$\text{Flow velocity}, \quad V = \frac{\text{Flow rate}, \quad Q}{\text{Area of pipe cross-section}, \quad A}$$

$$\text{Given} \quad Q = 12 \text{ litre/min} = \frac{12 \times 1000}{60} = 200 \ cm^3/s$$

$$\text{and} \quad A = \frac{\pi}{4}\left(\frac{15}{10}\right)^2 = 1.76 \ cm^2$$

$$\therefore \quad V = \frac{Q}{A} = \frac{200}{1.76} = 113 \ cm/s = 1.13 \ m/s$$

LESSON 4. PASCAL'S LAW, FLOW, ENERGY, WORK AND POWER

4.1 INTRODUCTION

Hydraulic devices are used to perform variety of tasks in industry, agriculture and many other fields. All these tasks require objects or substances to be lifted or moved from one location to another or a force to be applied to hold, shape or compress a product. Thus hydraulic devices perform work on objects in order to perform the desired task. A body is said to possess energy if it can do work and power is work done per unit time.

4.2 Energy

Energy is the capacity of a body to do work. Hydraulic devices are able to do work on objects because hydraulic oil possesses energy. The total hydraulic energy consists of three different types of energy:

(i) Kinetic energy – due to motion

(ii) Potential energy – due to position

(iii) Pressure energy – due to condition of the fluid

4.3 Kinetic Energy

By definition, kinetic energy is energy possessed by a body by virtue of its motion. Kinetic energy is proportional to mass of a body and square of its velocity. Hence greater the velocity, greater is the kinetic energy. For example, when water is released from a dam, it moves at a very high velocity which represents the energy of motion or kinetic energy. The kinetic energy possessed by a body of mass 'm' moving with a velocity 'v' is given by:

$$K.E.\; = \;\frac{1}{2}m{v^2} \qquad (4.1)$$

where, if 'm' is in kg and 'v' is in ms^{-1}, then unit of K.E. is N-m or Joule (J).

Since mass, m = volume of liquid 'V' × density 'r'

$$K.E.\; = \;\frac{1}{2}V\rho {v^2}\; = \;\frac{{V\rho {v^2}}}{2}$$

This is also called velocity pressure i.e. pressure caused by kinetic energy.

K.E. when expressed per unit weight is given by

$$\;\frac{{K.E.}}{{Weight}} = \;\frac{{\frac{1}{2}m{v^2}}}{{mg}}\; = \;\frac{{{v^2}}}{{2g}} \qquad (4.3)$$

In SI units, $v^2/2g$ is expressed in m.

4.4 Potential Energy

Potential energy is the energy of a body or a system due to the position of the body or the arrangement of the particles of the system. It is also called stored energy. An object has potential energy in proportion to its vertical distance above the ground surface. For example, water stored in a dam represents potential energy until it is released. When a mass is lifted up, the force of gravity will act so as to bring it back down. Lifting the mass requires energy to perform work on the mass. According to the law of conservation of energy, energy can neither be created nor destroyed; energy can only be changed from one form into another. Thus the energy that went into lifting up the mass is stored in its position in the gravitational field i.e. as potential energy. If the mass is dropped, this stored energy will be converted into kinetic energy. The potential energy in a hydraulic system is the equivalent of the height 'h' of the liquid column in the system.

Potential Energy = mass x gravitational acceleration x height

$$PE = mgh \tag{4.4}$$

Since the earth exerts a continuous gravitational pull on all objects of mass 'm', which we call weight 'W' = mg

$$PE = Wh \tag{4.5}$$

If 'm' is in kg, 'g' is in ms^{-2} and 'h' is in m, then unit of P.E. is N-m or Joule (J).

P.E. when expressed per unit weight is given by

$$\;\frac{{P.E.}}{{Weight}} = \;\frac{{mgh}}{{mg}}\; = \;h \tag{4.6}$$

Where 'h' is in m in SI units.

4.5 Pressure Energy

Pressure energy is the energy of a body by virtue of its condition. Pressure energy of a oil column of height 'h' is given by

$$\frac{P}{{\rho g}} \tag{4.7}$$

Where 'P' is the pressure of oil column and 'ρ' is the oil density.

4.6 Work

Work is a measure of energy expanded. By definition, work done by a force is equal to the product of the force and the displacement of its point of application in the direction of force.

For example, a force ‘F’ applied by a person on a cart using a rope moves it through a distance ‘s’, Figure 4.1.

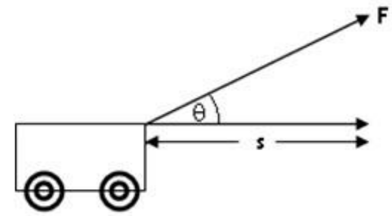


Fig. 4.1 : Cart pulled by force ‘F’ moves horizontally through displacement ‘s’

As the force ‘F’ has component $F\cos\theta$ in the direction of displacement ‘s’, work done is given by, $W = F\cos\theta \times s$

However if the force ‘F’ is applied along the displacement ‘s’, then $\theta = 0$ and consequently $\cos\theta = 1$, then

$$W = F \times s \tag{4.8}$$

In SI units, force is in Newton (N), displacement is in meter (m) and work done is measured in N-m or Joule (J).

4.7 Power

Power is the rate at which work is performed. It is defined as work done per unit time.

$$Power\; = \;\frac{{Work\;done}}{{Time\;Taken}} \tag{4.9}$$

SI unit of power is Watt (W) which is equal to Js^{-1}.

Horse-power (hp) is widely used unit of power and 1 hp = 746 W

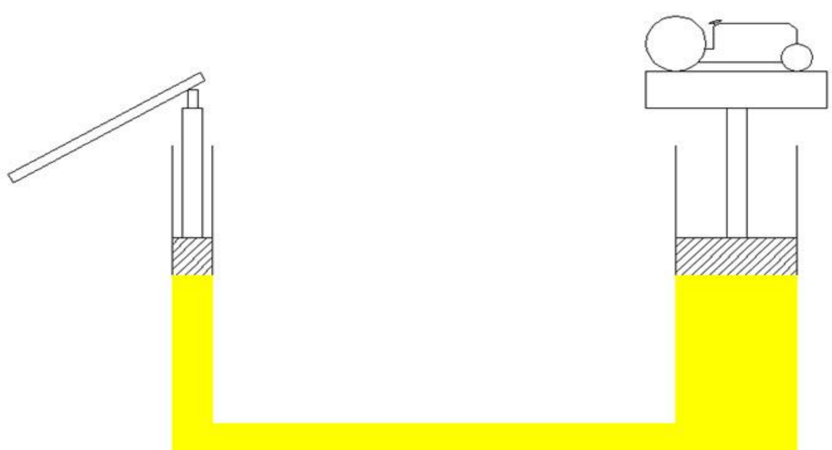


Fig. 4.2 : Power transmission through hydraulic fluid

4.8 Units of Work and Power

Work can be considered as time integral of power. As electrical power is measured in kilowatt (kW), kilowatt-hour (kWh) is also used a unit of work or energy.

Work (Energy)
1 J = 1 N-m = 0.102 kgf-m = 2.778×10^{-7} kWh = 10^{7} erg (cgs unit)
Power
1 kW = 1000 W = 102 kgf-m s^{-1} = 1.34 hp

LESSON 5. PASCAL'S LAW, FLOW, ENERGY, WORK AND POWER

5.1 INTRODUCTION

Hydraulic devices are concerned with flow of liquid in enclosed paths such as pipes, tubes, valves, actuators etc. Flow can be quantified in terms of volumetric flow rate and mass flow rates. Flow can be classified as steady flow and unsteady flow based upon state of conditions at a point with respect to time. Further flow may be classified as laminar flow and turbulent flow based upon flow pattern.

5.2 Volumetric Flow

Volumetric flow rate is the volume of fluid moving past a given point in unit time. It can be calculated as the product of average flow velocity and area of cross-section of the path. It is usually measured in litre per second (l/s) or cubic centimeter per second (cusec).

Volumetric flow rate, $V = v.A$, cm^3/s (5.1)

Where, 'v' is the velocity in cm/s and 'A' is area of pipe cross-section in cm^2.

Example: Calculate the volumetric flow rate of a liquid flowing with an average velocity of 15 cm/s in a pipe of diameter 5 cm.

Solution:

$$
\begin{aligned}
V &= vA \\
&= v\frac{\pi d^2}{4} \\
&= 15 \times \frac{\pi \times 5^2}{4} \\
&= 294.52\ cm^3/s
\end{aligned}
$$

5.3 Mass Flow

Mass flow rate can be defined as the measure of the mass of fluid passing through a point in the system per unit time. It is equal to the product of density of the fluid and its volumetric flow rate.

Mass flow rate, $M = rV$ gm^3/s (5.2)

Where, 'ρ' is the density in gm/cm^3 and 'V' is volumetric flow rate in cm^3/s.

Example: Calculate the mass flow rate of a liquid flowing with an average velocity of 15 cm/s in a pipe of diameter 5 cm. Density of the liquid is 60 gm/cc.

Solution: Volumetric flow rate,

$$
\begin{aligned}
V &= vA \\
&= v\frac{\pi d^2}{4} \\
&= 15 \times \frac{\pi \times 5^2}{4} \\
&= 294.52\ cm^3/s
\end{aligned}
$$

Mass flow rate = ρV

= 60 X 294.52 = 17,671.2 gm/cc.

5.4 Steady and Unsteady Flow

In steady flow, fluid properties like pressure, temperature and velocity at point in the system do not change with time. In the steady state flow rate there is no mass accumulation in the system or component.

Unsteady flow is a transient phenomenon which may become a steady flow or zero flow with time. For example, when a valve is opened suddenly, liquid flow into the pipe is unsteady which become steady with time. Similarly, when a valve is suddenly closed at the discharge end of a pipe, there will be fluctuations in both velocity and pressure in the pipe before the flow becomes zero in the pipe.

5.5 **Laminar and Turbulent Flow**

When a fluid is flowing through a pipe or pipe like structure ,there may be two types of flow that generally occur i.e. laminar flow or turbulent flow depending on the velocity of the fluid.

At low flow velocities, the flow pattern is smooth and linear. This is known as laminar or streamline flow. In this type of flow, velocity is minimum at the pipe walls and maximum at the centre of the pipe. As flow velocity increases, eddies start to form until at high flow velocities complete turbulence results. At this stage, flow velocty is virtually uniform across the pipe cross-section. Laminar flow and turbulent flow are depicted in Fig. 5.1

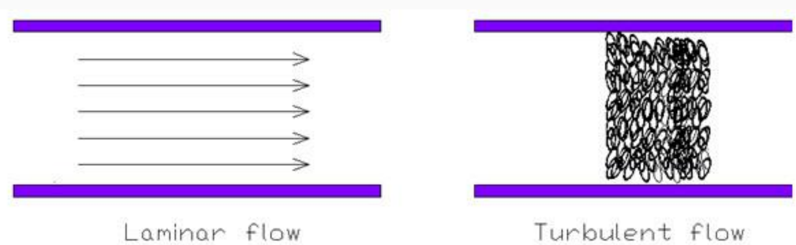


Fig. 5.1: Types of flow - laminar and turbulent

Laminar flow occurs in parallel layers, with no disruption between the layers. At low velocities the fluid tends to flow without lateral mixing, and adjacent layers move over one another. There are no cross currents perpendicular to the direction of flow. In laminar flow the motion of the particles of fluid is such that the particles are moving in straight lines parallel to the pipe walls.

In turbulent flow the fluid undergoes irregular fluctuations, or mixing. It is in contrast to laminar flow, in which the fluid moves in smooth paths or layers. In turbulent flow the velocity of the fluid at a point is continuously changing in both magnitude and direction. Common examples of turbulent flow are river flow, blood flow in arteries, oil transport in pipelines, ocean currents and flow through pumps and turbines.

5.6 Reynolds Number

The nature of the flow i.e. whether the flow is laminar or turbulent is determined by Reynolds Number, Re, given as:

$$\mathrm{Re} = \frac{vd\rho}{\eta} \qquad (5.3)$$

Where 'v' is flow velocity, 'd' is pipe diameter, 'ρ' is the fluid density and 'η' is the fluid viscosity. For a given liquid flowing in a pipe the fluid density, fluid viscosity and the pipe diameter are constant. Thus, the value of Reynolds Number depends upon flow velocity.

Reynolds Number is a ratio and hence dimensionless. For a fully developed flow in a pipe flow is laminar for $Re < 2000$ and flow is turbulent for $Re > 4000$.

5.7 Bernoulli's Principle

Recall that the total energy 'E' of a liquid flowing in a pipe is given by

E = Kinetic Energy + Potential Energy + Pressure Energy

And Kinetic Energy, $K.E.\; = \;\frac{1}{2}m{v^2}$

Potential Energy, PE = mgh

Pressure Energy = PV

Where 'm' is the mass, 'v' is the velocity, 'h' is the height, 'P' is the pressure and 'V' is the volume of liquid.

KE, PE and pressure energy when expressed as per unit weight of liquid are written as

$\;\frac{{{v^2}}}{{2g}}$, h and $\frac{P}{{\rho g}}$ respectively.

According to Bernoulli's principle, the total energy of a liquid is constant neglecting any losses

$$E = \;\frac{{{v^2}}}{{2g}}\; + \;h\; + \;\frac{P}{{\rho g}}\quad= \text{constant} \qquad (5.4)$$

Therefore, total energy of a flowing liquid at point 1 will be equal to total energy at point 2, i.e.

$$\frac{v_1^2}{2g} + h_1 + \frac{P_1}{\rho g} = \frac{v_2^2}{2g} + h_2 + \frac{P_2}{\rho g} \qquad (5.5)$$

$$mgz_1 + \tfrac{1}{2} mV_1^2 + p_1v_1 = mgz_2 + \tfrac{1}{2} mV_2^2 + p_2v_2 \qquad (5.6)$$

where,

m = mass

g = acceleration due to gravity

z_1 = head at 1

V_1 = velocity at 1

v_1 = volume at 1

p_1 = pressure at 1

z_2 = head at 2

V_2 = velocity at 2

v_2 = volume at 2

p_2 = pressure at 2

Therefore, Bernoulli's principle states that for a fluid flow, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluids potential energy. Bernoulli's principle can be applied to various types of fluid flow, and equation (5.4) is called Bernoulli's equation. Bernoulli’s equation is best applicable under the following assumptions:

- Fluid is under steady state flow, hence flow rate at all the positions in the pipe is not changing.
- Fluid is having streamline flow, hence flow at all the points is exhibiting streamline or laminar flow.
- Fluid is assumed to be of negligible viscosity, hence the fluid does not have tendency to stick on to the pipe.

LESSON 6. HYDRAULIC SYSTEMS

6.1 INTRODUCTION

Hydraulic systems are normally based on Pascal's law in which a liquid is moved in a closed system in such a way that it uses the laws governing liquids to transmit power and do work. This lesson describes some basic types of hydraulic circuits and the major components used there in. A sump or a tank is utilized for the purpose of oil storage. Filters,strainers and magnetic plugs condition the fluid by removing harmful impurities that could clog passages and damage parts. Accumulators are used to store energy. Heat exchangers or coolers are generally provided to keep the oil temperature within safe limits as this helps in maintaining the oil properties.

6.2 Features of Hydraulic Systems

Hydraulic systems offer many advantages and some disadvantages as compared with other methods of power transmission. Some of the major advantages are:

1. A hydraulic system is simple in design. In general a few standard hydraulic components replaces complicated mechanical linkages used in mechanical systems.
2. The hydraulic systems are smooth and quiet in operation.
3. The hydraulic components are connected with flexible pipes and hoses and therefore locating components in a setup is easier as compared to rigid mechanical elements.
4. In hydraulic systems, a wide range of speed and forces can be controlled easily.
5. It gives better efficiency with low friction loss which gives lower cost of power transmission.

A hydraulic system also has following disadvantages:

1. Oil leakage is a fire hazard and is unsightly.
2. Maintaining of the hydraulic system is costlier.

Care must be taken against rust, corrosion, dirt, oil deterioration etc.

6.3 Hydraulic Circuits

For the hydraulic fluid to do work, it must flow to the actuator, then return to a reservoir. The fluid is then filtered and re-pumped. The path taken by hydraulic fluid is called a hydraulic circuit of which there are several types. In this lesson two types of hydraulic circuits – closed centre type and open centre circuits are discussed. Closed centre circuits supply full pressure to the control valves, whether any valves are actuated or not. The pumps vary their flow rate, pumping very little hydraulic fluid until the operator actuates a valve. Open center circuits use pumps which supply a continuous flow.The flow is returned to tank through the control valve's open centre i.e. when the control valve is centred, it provides an open return path to tank and the fluid is not pumped to a high pressure.

6.4 Basic Hydraulic Closed Centre Circuit

In closed centre system circuit, the pump generally rests when the fluid is not required to operate an actuator or another device in the hydraulic circuit. This means that when the control valve is in the neutral position i.e. at the centre, the flow of the oil from the pump is altogether stopped or reduced to a minimum. The valve's spool therefore doesn't need an open centre return path to tank. A closed centre hydraulic system provides oil flow on demand, which enables simultaneous operation of many loads connected to one pump. A basic closed centre hydraulic circuit is shown in the Fig. 6.1.

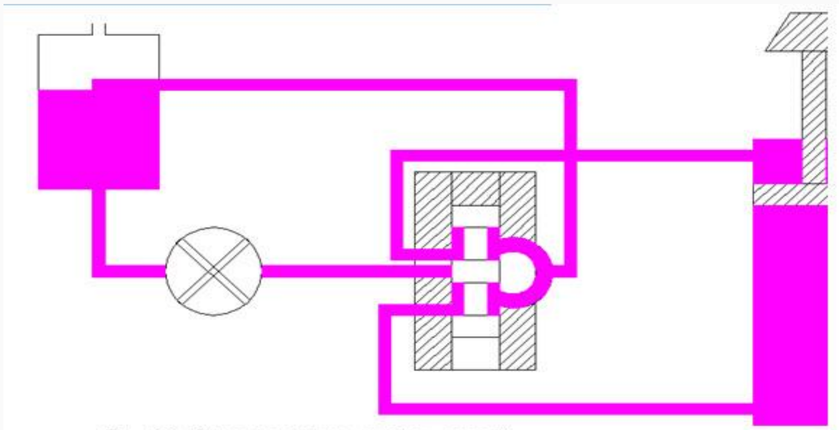


Fig. 6.1.: Closed centre system circuit

Closed centre hydraulic circuits almost always use variable flow pump. When a fixed displacement pump is used an accumulator is employed which is charged to required system pressure.

6.4.1 Fixed-Displacement Pump and Accumulator System

In fixed displacement pump and accumulator system, a pump of small but constant volume charges an accumulator. When the accumulator is charged to full pressure, an unloading valve diverts the pump flow back to a reservoir. A check valve traps the pressured oil in the circuit. On operating the control valve, an accumulator discharges its oil and actuation is caused into a cylinder. As pressure starts decreasing, an unloading valve directs the pump flow to an accumulator to recharge the flow. Since this system uses a small capacity pump, therefore, it is quite effective when operating oil is needed only for a short time. However, when there is a need of oil for longer periods, an accumulator system is not very effective unless provided with very large accumulator. A closed centre hydraulic circuit with fixed displacement pump and accumulator is shown in Fig. 6.2.

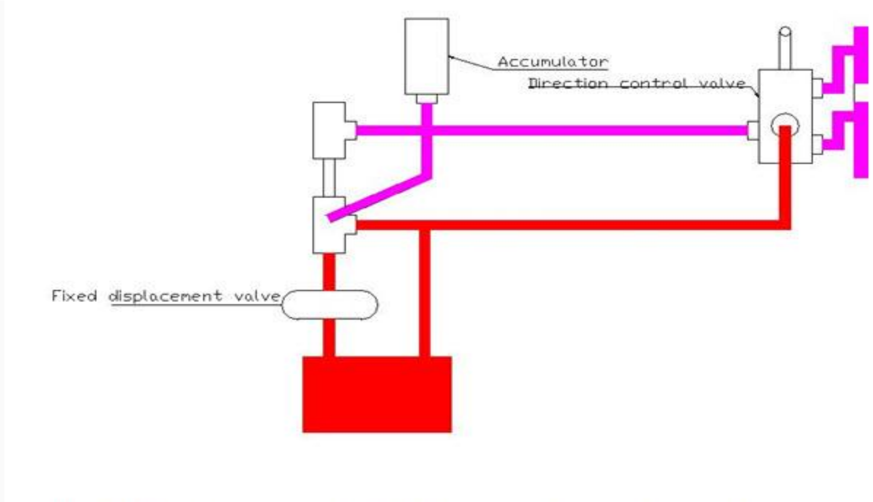


Fig. 6.2: Hydraulic Circuit with Fixed Displacement Pump with Accumulator

6.4.2 Variable Displacement Pump System

In this system, shown in Fig. 6.3,oil is pumped until the pressure rises to required system pressure when valve is at neutral position. A pressure-regulating valve allows the pump to stop and maintain this pressure to the valve. When the control valve is operating, oil is directed from the pump to the cylinder which raises the load. This causes the pressure to drop from maximum level and the pump is restarted. When the valve moves, the top of the piston connects to a return line and it allows the oil that was forced from the piston to return to the sump. When the valve is again positioned at neutral, the oil is trapped on both sides of the cylinder and the pressure in the passage between the pump and control valve begins to rise. When the pressure rises to required system pressure,the pump stops.

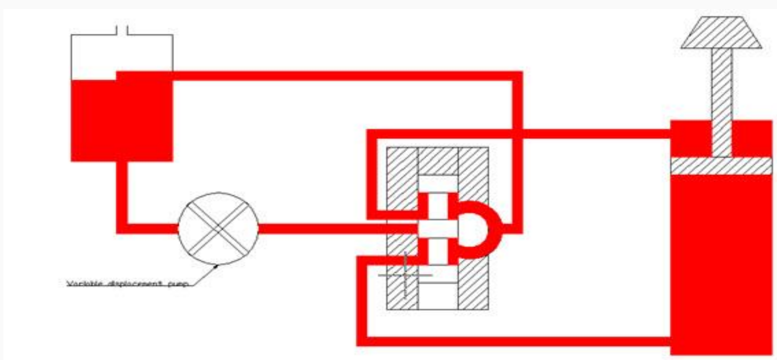


Fig. 6.3: Hydraulic Circuit with Variable Displacement Pump

6.5 Advantages of Closed Centre Circuit

Relief valve is not required as the pump stops by itself when standby pressure is reached.

The size of the flow lines, valves, and cylinders etc can be chosen as per the flow requirements in the hydraulic circuit.

Closed centre system is more efficient as compared to open centre system as the pump does not function continuously.

LESSON 7. HYDRAULIC SYSTEMS

7.1 Introduction

Hydraulic circuits are of different types. Two major types of hydraulic circuits are closed centre circuit and open centre circuit. The two types were introduced and the closed centre hydraulic circuit was discussed in the previous lecture. The open centre hydraulic circuit is discussed in this chapter.

7.2 Basic Open Centre Hydraulic Circuit

Open center system uses a pump which provides constant flow of oil continuously. The flow is returned to sump through the open centre of control valve at neutral position. When the control valve is actuated the oil is routed to or from an actuator based on the control valve position. The pressure of oil will get increased to meet any resistance, since the pump has a constant output. If the pressure becomes too high, the oil returns to sump through a relieve valve.

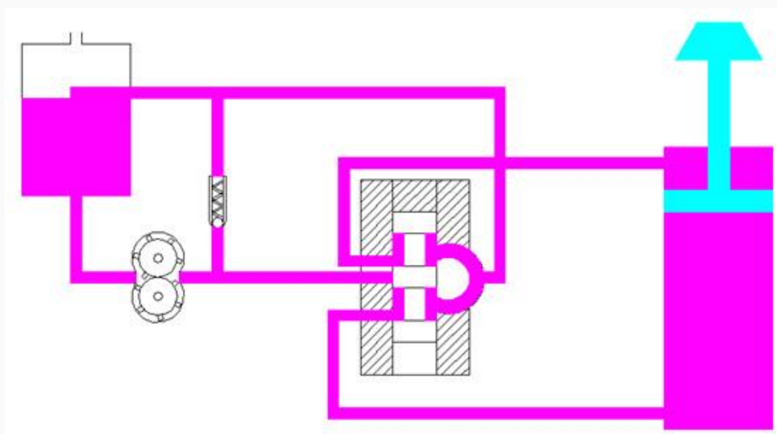


Fig. 7.1: Open Centre Hydraulic Circuit

An open centre hydraulic circuit is shown in Fig. 7.1. In this system, a control-valve (spool valve) is kept open at the center which allows the pump flow to pass through the valve and return to the sump. In order to operate several functions simultaneously, an open-center system must have the correct connections. An open-center system is normally efficient on single function but can also be utilized in multiple functions. Open center system may be in series, parallel or flow divider configuration.

7.2.1 Series Connection

Opencenter systems with series connection have the oil from a pump applied to more than one open centre control valves fitted in series. A series connection with three functions is shown in Fig. 7.2. The return from the first valve is directed to the inlet of the second, and so on. When all the control valves are kept at neutral, the oil moves through the valves in series and returns to the sump. When a control valve is operated, the incoming oil is diverted to the cylinder that the valve serves. Return oil from the cylinder is moved through the return line and on to the next valve. This system is performing satisfactorily when only one valve is operating at a time. This ensures the full output of the pump at full system pressure for that particular function.

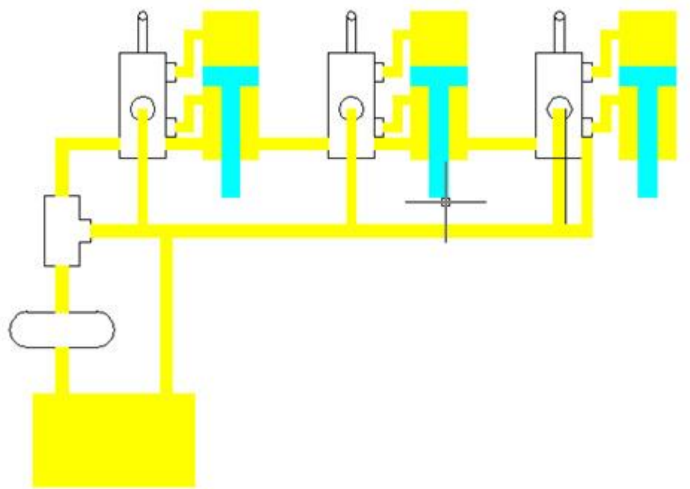


Fig. 7.2: Open Centre Hydraulic Circuit with Series Connection

7.2.2 Series Parallel Connection

In this system oil from the pump is directed through the control valves in series as well as in parallel. When the valve is kept at neutral, the oil moves through the valves in series. On operating any one of the valve, the return is closed and the oil is available to all the valves through the parallel connection. Whereas, on operating two or more valves, the cylinder that needs the least pressure will operate first, then the cylinder with the next least pressure requirement, and so on so forth. Therefore, the series parallel connection has an advantage over the series connection when operating two or more valves simultaneously.

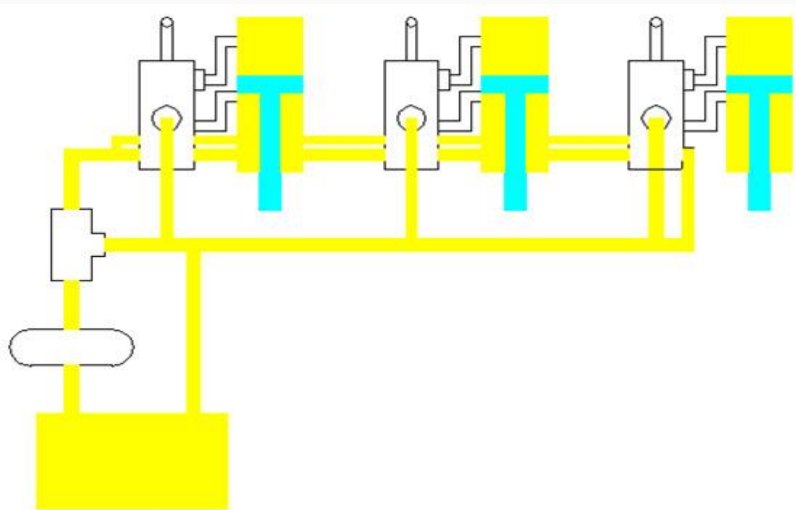


Fig. 7.3: Open Centre Hydraulic Circuit with Series-Parallel Connection

7.2.3 Flow Divider

A flow divider is a device which takes the volume of oil from a pump and divides it between two functions. An open Centre Hydraulic Circuit with Flow Divider is shown in Fig. 7.4. A flow divider used in open centre hydraulic circuit may be designed to open the left side first in case both control valves are actuated simultaneously. Or, it might divide the oil to both sides equally or in some other proportion. Hence the pump used in a flow divider circuit must be of larger capacity to operate all the functions in the hydraulic circuit simultaneously.

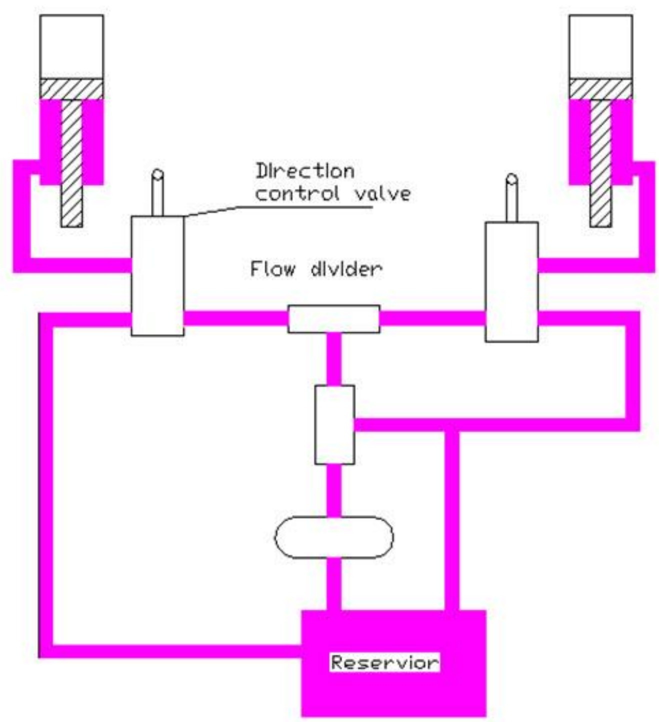


Fig. 7.4: Open Centre Hydraulic Circuit with Flow Divider

LESSON 8. Colour coding

8.1 Introduction

Hydraulics is the science of transmitting force or motion or both through the medium of confined fluid. Oil in a hydraulic system is in a state of rest or motion and the oil pressure is different in different sectors of the hydraulic circuit at any given time. The states of flow and pressure of the oil in a hydraulic system at a given time depends upon the stage of operation the system at that particular time. For example if a cylinder piston is extending towards the right, oil at high pressure is flowing from pump side into the left chamber of the cylinder and flowing out of the right chamber of the cylinder to the sump at low pressure. Similarly if a cylinder piston is fully extended towards right against a load, oil is at high pressure in the left chamber of the cylinder and oil flow is not taking place on both the sides of the piston. It is convenient to indicate the oilflow and pressure conditions in different parts of hydraulic circuits with industrial standardized colour codes.

8.2 Colour Coding

To understand or to depict the fluid states in hydraulic systems easily, Joint Industries Conference (JIC) and American National Standards Institute (ANSI) have established a standardized colour coding scheme for flow conditions or fluid paths as shown in Fig. 8.1.

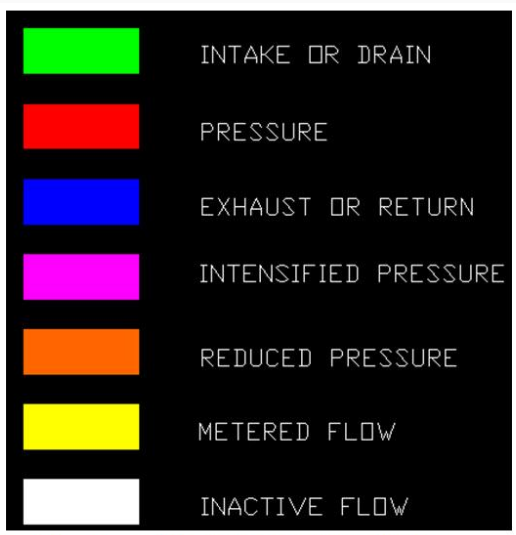


Fig. 8.1: Colour Codes for Fluid States in Hydraulic Circuits

The significance of different colours is as follows:

- **Green**colour signifies the intake fluid which is piped from oil reservoir to pump in the hydraulic circuit.
- The **red** colour generally signifies operating system pressure of the fluid. The oil from the pump flows through pressure relief valve to a directional control (DC) valve. The

DC valve either blocks the flow or directs the flow to a cylinder. The resistance to fluid flow due to a closed DC valve or a cylinder piston causes pressure to be created. The fluid under pressure is shown in red colour.

- The **blue** colour is used to indicate the fluid that is not restricted and having minimum oil pressure. It is generally used to show the oil exhausting from a cylinder or a valve to the sump.

A hydraulic system in which the fluid conditions are indicated with green, red and blue colours is shown in Fig. 8.2.

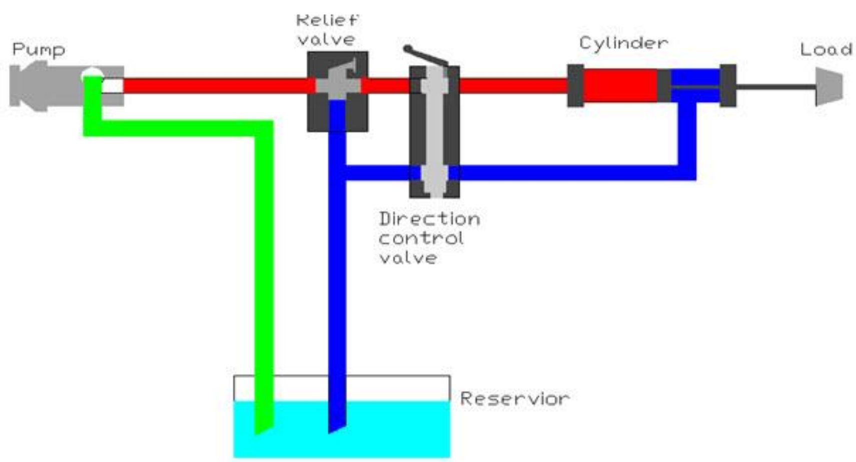


Fig. 8.2: Open Centre Hydraulic Circuit with Series-Parallel Connection

- **Yellow** indicates the controlled fluid flow or the oil which is metered through a restriction valve.

- **Orange** is generally for the oil flow that has been reduced from the system pressure like the oil at the output of a pressure regulating valve.

- **Violet** indicates the increased oil pressure due to the result of amplified system pressure, like oil with increased pressure at the output of intensifier

- .**White** is used to indicate the oil pressure in a part of the system which has no pressure. For example, oil at the output of a cylinder having fully extended piston is shown in whitecolour as fluid from the rod end of the cylinder to the sump is inactive as there is no movement.

LESSON 9. Reservoirs

9.1 Introduction

A hydraulic system usually consists of basic components like reservoir, pump, valves strainers, lines, etc. The hydraulic reservoir is a sort of fluid store house for the hydraulic system. It is having enough fluid to supply the normal operating requirements of the hydraulic system and an additional supply to replace fluid lost through minor leakages, if any. It also allows the settling of impurities like dust or dirt etc. The reservoirs may also be designed to do the separation of air from the fluid stored in it.

9.2 Reservoirs

A reservoir stores a liquid for transmitting the fluid energy. Hydraulic systems are generally operated by a liquid fluid being transmitted in the system components. The purpose of the hydraulic reservoir is to hold a volume of fluid, transfer heat from the system, allow solid contaminants to settle and facilitate the release of air and moisture from the fluid. A typical reservoir is shown in Fig. 9.1.

Fig. 9.1: Open Centre Hydraulic Circuit

(Courtesy: http://www.htetechnologies.com/vendors/view/Lube%20Devicesl)

Hydraulic systems, on the other hand, need a very large quantity of liquid fluid which is to be stored and reused continually as the circuit works. Therefore, part of any hydraulic circuit is a storage reservoir or tank. This tank may be part of the machine framework or a separate unit. In general reservoir design and its development is very important. The efficiency of a hydraulic circuit is greatly affected by tank design. Hence a hydraulic reservoir does much more than just provides a place to store fluid. A well-designed reservoir does the following functions.

- It should remove the gases if any.
- It should dissipate the heat. It should allow time for contamination to settle down at the surface.
- It should allow air bubbles to come to the surface and dissipate trapped air.

- It should give a positive pressure to the pump inlet.
- It may provide a convenient mounting place for the pump and motor, and valves.
- There are different types of reservoirs which may be installed in hydraulic circuit and are discussed as under.

9.2.1 Pump on Tank Top

It is the most commonly used layout of reservoir and pump. The flat top surface of a reservoir makes a perfect place to mount the pump and motor as shown in Fig. 9.2. Axial or in-line piston pump life may be affected by vacuum at its inlet when using this layout. The piping in this configuration is kept sealed. Also the piping should have least number of bends and it should be as short as possible.

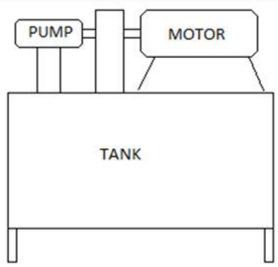


Fig. 9.2: Pump on Tank Top

9.2.2 Pump at side of tank

It is another type of design which is used satisfactorily for any type of pump. This arrangement is sometime called a flooded suction, because the pump inlet always is filled with fluid. Still, there may be some vacuum in the inlet line when the pump is running. This design is considered to be better than the pump on top arrangement. Pump on side of tank layout is shown in Fig. 9.3.

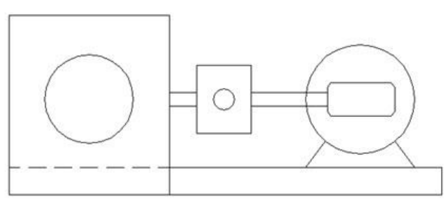


Fig. 9.3: Pump on Side of Tank

9.2.3 Pump under tank

It is one of the most useful pump and tank layout. In this design pump is kept below the reservoir to take advantage of static head pressure. Since the tank is above the pump, therefore the fluid is available at its inlet all the time. Pump under tank layout is shown in Fig. 9.4.

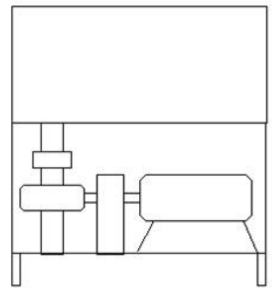


Fig. 9.4: Pump Under Tank

9.3 Shape of Reservoir

Shape of the reservoir should be such that it should have oil level as high as possible. For this high and narrow reservoirs are made rather than shallow and broad, which keeps the oil level high above the pump suction line. This prevents the vacuum at the line opening and thus prevents air from entering into the system. Aerated oil will not properly transmit power because air is compressible.

9.4 Size of Reservoir

While designing a reservoir the size is normally kept large enough so that it should have a reserve of oil with all the cylinders in a system fully extended. An oil reserve must be high enough to prevent a vortex (a whirling mass of fluid, especially one in which a force of suction operates, as a whirlpool) at the suction line opening. A reservoir must have sufficient space to hold all the oil when the cylinders are retracted, as well as allow space for expansion when the oil is hot. The size of reservoir in moving type of machine is generally kept in the range of 70 litre to 120 litre in a system requiring 350 LPM(Litre Per Minute) of oil flow rate. Whereas, for stationary equipment as a thumb rule, the size of reservoir is kept two to three times the pump output per minute. A large size tank is preferred for better cooling.

9.5 Location of Reservoir

In moving equipment reservoirs are normally located above the pumps, which create a flooded-pump-inlet condition. This condition reduces the possibility of pump cavitations (a condition where vapours are formed in low pressure region and when these vapours collapse on moving to high pressure region causing shocks and sometimes even erosion of metal parts).The location of a reservoir affects heat dissipation. Therefore while orienting the location of tank it should be kept in mind that tank walls should be exposed to the outside air.

9.6 Ventilation and Pressurization

Reservoirs are provided with vents to the atmosphere. A vent opening allows air to leave or enter the space above the oil as the level of the oil goes up or down. This maintains a constant atmospheric pressure above the surface of oil. A reservoir filter cap, with a filter element, is often used as a vent.

LESSON 10. Strainers and Filters

10.1 Introduction

The oils used in hydraulic systems contain foreign matter in solid and liquid forms, which is quite undesirable and need to be removed. Hence, strainers, filters, and magnetic plugs are used to remove dust particles or foreign matter from a hydraulic fluid and are effective as safeguards against contamination. It is very important to select a filter that will improve the reliability of a lubrication or hydraulic system by eliminating failure due to contamination of oil used in the system. Maintaining hydraulic fluid within the allowable limits is quite difficult to protect the equipment. Therefore it is necessary to prevent the contamination in the fluid and also remove the contaminants if present in the fluid. Hence filters are installed at suitable places in the hydraulic system.The filtration devices used in the system are commonly known as strainer and filters.

10.2 Strainers

To remove large particles of foreign matter from a hydraulic fluid a strainer is provided as the primary filtering system. Its screening action is not as good as that of a filter but a strainer offers less resistance to flow of the fluid. A strainer usually consists of a metal frame wrapped with a fine-mesh wire screen or a screening element made up of varying thicknesses of specially processed wire. Strainers are used in the pump inlet lines. There may be different possible arrangements of strainer for use in a pump inlet line. If one strainer causes excessive friction in the flow of fluid to the pump, two or more strainers can be used in parallel.

10.3 Filters

Filters are generally provided to remove the small foreign particles from a hydraulic fluid and are most effective in removing fine contaminants. Filters can be classified based upon (i) location and (ii) full/partial filtering action. Based upon location filters can be classified as inlet line filters, pressure line filters and return line filters. Based upon filtering action filters are classified as full-flow filters and proportional-flow filters.

10.3.1 Inlet Line Filters

Inlet filters for pipe-lines and systems are designed to stop dust and dirt particles from entering the pump and contaminating the oil. Replaceable elements are available as disposable, cleanable. Inlet line filters must cause low pressure drop or the pump will not be able to lift the oil from the tank. Therefore inlet line filters are coarse filters. Fig. 10.1 shows the location of inlet line filter.

Fig. 10.1: Inlet Line Filter Location Sketch

10.3.2 Pressure Line Filter

This type of filters is used to protect downstream components such as valves and actuators from contamination. Since these are sized for the output of the pump, pressure filters tend to be smaller than return line filters. In systems using accumulators, pressure filters must be sized according to the large effective flow rates.In some applications, pressure filters are used as isolation filters to protect specific components. These filters are non-bypass type of filters which are capable of withstanding full system differential pressure.

Fig. 10.2: Pressure Line Filter Location Sketch

10.3.3 Return Line Filters

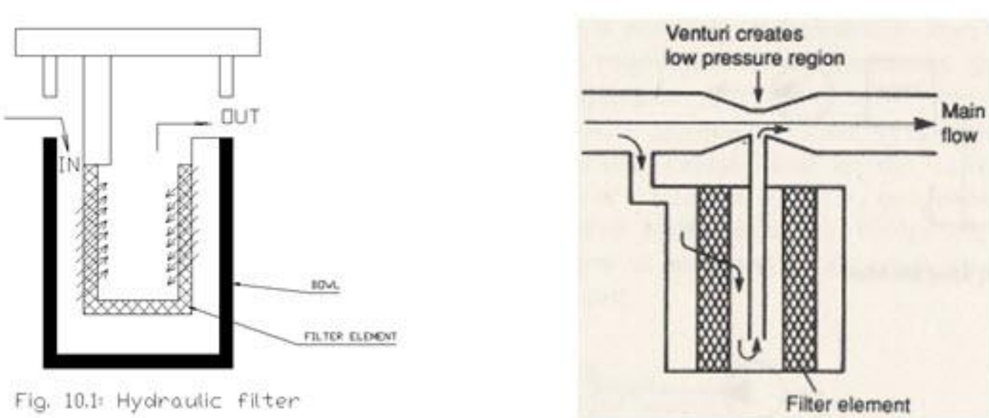
Return flow filters usually have cartridge elements in an in-line mounted housing within the reservoir itself which is also called as an in-tank filter. Return line filters are an integral part of an effective contamination control system. Return line filters are ideal for systems where the pump is the sensitive component. These are placed before the fluid enters the reservoir in order to prevent debris and particles from recirculation through the system.

Fig. 10.3: Return Line Filter Location Sketch

10.3.4 Full-flow Filter

A full flow filter is designed to filter the full output from pump. In this type of filter the fluid entering a unit passes through a filtering element. A full-flow type of filter provides a more positive filtering and offers greater resistance to flow, particularly when it becomes dirty. A hydraulic liquid enters a full-flow filter through an inlet port in the body and flows around an element inside a bowl.

Filtering occurs as a liquid passes through the element and into a hollow core, leaving the dirt and impurities on the outside of the element. A filtered liquid then flows from a hollow core to an outlet port and into the system.



(a) (b)

Fig. 10.4:(a) Full Flow Filter (b) Proportional Flow Filter

10.3.5 Proportional-flow Filter

In this type of filter there is a venturi tube. The throat of venturihas smaller diameter which increases the velocity of fluid moving through it . Flow through a venturi throat causes a pressure drop at the narrowest point. This pressure drop causes a sort of suctionthat draws a portion of a fluid down around a cartridge through a filter element and up into the venturi throat. This method has the advantage of low pressure drop.

10.4 Contamination Indicators

The effectiveness of the filter can be checked by a contamination indicator. The contamination of a filter is measured by the drop in pressure. As the contamination increases, the pressure ahead of the filter rises. This pressure acts on a spring-loaded piston. As the pressure increases, the piston is pushed against the spring and is displayed onto a display unit.

10.5 Contaminants

There may be following types contaminates which may be there in the hydraulic fluids-

- Biological materials like straw shreds, hair, flies, etc.
- Welding scales
- Bits of sealing materials
- Wear particles
- Rust particles
- Water
- Dirt from atmosphere
- New oil

LESSON 11. Filtering Elements

11.1 Introduction

Filtration is an important part of any hydraulic system or machinery which provides the safety of a system or machinery. It also maintains the right condition of fluid circulating in the circuit. Contamination of the fluid may result in wear in the moving parts, corrosion, reduced performance, and also clogging. Therefore filtration is needed to remove the solid contaminants from the circulating fluid. Usually filter work on the basis that it traps the particles in the small holes or pores. It allows the fluid to pass through it but the particles of certain size get trapped in the filters.

11.2 Types of Filter Elements

There are mainly two types of filter elements used in hydraulic systems – surface filters and depth filters.

11.2.1 Surface Filters Element

Surface filters are simple screens which are used to clean oil passing through their pores. These are normally made with thin sheets which are folded into many sections and then turned into a multi-pointed star shape as shown in Fig. 11.1. This increases the surface area for the fluid to be entered into it.By doing so the space required for the filter is reduced and this element is fitted into a bowl. The thin sheet is provided with number of pores of required size, which traps the solid contaminant when the oil is passed through it as shown in Fig. 11.2. Surface filters are usually made of woven steel wire, woven nylon fibre and cellular/paper.

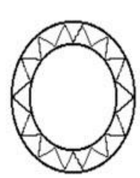


Fig. 11.1: Surface Filter Cross-section

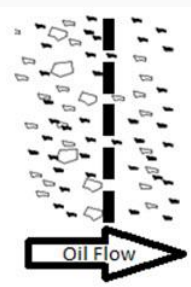


Fig. 11.2: Surface Filter Action

11.2.2 Depth Filter Element

Depth filters are thick walled filter elements through which oil is passed and undesirable foreign particles are trapped in the filter. Depth type filter elements consist of hollow cylinder and its walls are made up of thick layer of cellulose. These may also be made up of multi-layered fabric, compressed fabric, plastic, felt or metallic fibre. The fluid enters from the casing and flows through the element in the hollow space in the cylinder and then cleaned fluid is discharged. In this type of element coarse particles are separated at the inlet surface whereas, finer particles are separated within the material of element. These filters will have higher capacity of dirt retention for the same area cross-section.

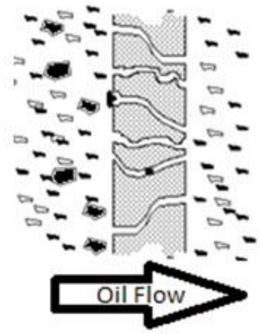


Fig. 11.3: Depth Filter Element

11.3 Comparison of Surface and Depth Filters

Depth-type filters capture particles and contaminant through the total thickness of the medium, while in surface filters particles are blocked on the surface of the filter. Surface filters are best for filtering sediment of similar-sized particles. If all particles are say five micron, a 5-micron surface filter works best because it has more surface area than depth filters. Compared with surface filters, depth filters have a limited surface area, but they have the advantage of depth.

LESSON 12. Filtering Materials

12.1 Introduction

Filtration may be defined as the removal of solid particles from a liquid or gaseous stream by means of a porous medium. There are numerous types of filtering material available for filtration. Filtering material may be mechanical or absorbent. Mechanical filters are relatively coarse and utilize fine wire mesh. Mechanical filters can usually be removed, cleaned and refitted for use. Absorbent filters are based on porous materials such as paper, cotton or cellulose. Filtration size in an absorbent filter can be very small as filtration is done by pores in the material.

12.2 Types of Filtering Material

There are different materials used for making filter elements are (i) Woven steel wire (ii) Woven nylon fibre and (iii) Cellulose or paper

12.2.1 Woven Steel Wire Type Material

This type of material consists of woven steel wire which may be stainless steel or epoxy based wire mesh available in different sizes which can filter from 150 µm to 40 µm of particle size. These type of materials are normally used for trapping large and harsh particulate.

Fig. 12.1: Stainless Steel Mesh

12.2.2 Woven Nylon Material

These are the nylon or synthetic fibres, which are smooth, rounded and provide less resistance to flow.Its uniform shape and size provide the smooth flow of fluid through the mat, which gives better filtration effectiveness in specific contaminants.

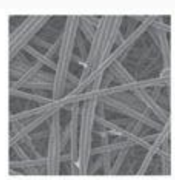


Fig. 12.2: Enlarged View of Woven Nylon Material

12.2.3 Cellulose typeMaterial

It is basically wood fibre having microscopic size. The fibres are held together by resin. These fibres are irregular in size and also in shape. It offers smaller pores in the material, which causes more resistance to the flow of fluid. But cellulose material provides greater effectiveness of filtration of hydraulic or other petroleum fluids

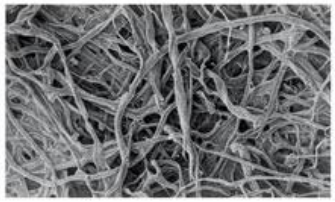


Fig. 12.3: Enlarged View of Cellulose Material

12.3 Filtration Test

Generally multi-pass test is carried out to evaluate the filter element performance.Fluid is circulated through the test circuit under controlled conditions, which indicates the following element performance characteristics:

- Dirt holding capacity
- Filtration efficiency as beta ratio

12.3.1 Beta Ratio (β)

It can be defined as the measure of filter element particle capturing efficiency. It is performance indicator of a filter element. Beta ratio is the ratio of particles larger than a given size counted upstream and downstreamof the test filter in a multi-pass test. Therefore it is a dimensionless number which gives degree of separation.

Example: In a multi-pass filter test 40,000 particles of 10 mm and larger size were counted upstream and 8,000 particles in the same range were counted downstream of the test filter. Find the beta ratio of the filter.

Solution: Given,

Threshold size of particles, x = 10 micron

Number of particles upstream, Nu = 40,000

Number of particles downstream, Nd = 8,000

Beta ratio of the filter is calculated as: $\beta_x = \frac{Nu}{Nd}$

Therefore,

$$\beta_{10} = \frac{40{,}000}{8{,}000}$$

$$= 5$$

Now, efficiency (η) of the filter is given by

$$\eta_{10} = \left(1 - \frac{1}{\beta}\right)$$

$$= \left(1 - \frac{1}{5}\right)$$

$$= 80\ \%$$

12.4 Element Indicator

The element indicator is the indicating device which gives the signals when the element is loaded to the point that it should be cleaned or replaced. The indicator may be connected mechanically to the bypass valve. But sometimesthere may be an independent differential-pressure sensing device type of an arrangement is there which gives visual or electrical signals or both.

LESSON 13. Hydraulic Accumulators

13.1 Introduction

Accumulators are the devices used in the hydraulic systems which store hydraulic energy in the form of fluid pressure and then provide this energy back to the system when it is required in the system. Accumulators store the energy when hydraulic system pressure exceeds a threshold value and provide hydraulic energy when the system pressure falls below the threshold value. In many respects it resembles the operation of a capacitor in an electronic power supply.

13.2 Accumulator Functions

An accumulator usually performs the following functions:

- It provides a reserve of power and supply oil for high transient flow demands
- It provides sufficient power to complete one or more cycles of operation of the equipment when pump does not work
- It helps to reduce pump ripple
- It acts as a hydraulic shock absorber
- It may be used as a primary power source for small hydraulic systems

Most hydraulic systems use an accumulator to dampen pressure transients in the system.The pressure transients result from pump ripple, opening/closing of valves, and so on. In some of the hydraulic systems accumulators are not being utilised, other design considerations are considered. The selection and design characteristics of accumulators will vary with the applications of accumulator in the system. A few of selection considerations are:

- The size and mass of unit
- Operating temperature range
- Operation to be performed by the unit
- Quantity of energy to be stored by the system

13.3 Types of Accumulators

Accumulators can be classified as dead-weight type,spring-loaded type and hydro-pneumatic type. The most commonly used accumulators in the industry are hydro-pneumatic type. They use a gas for storing oil under pressure. Dry nitrogen is used as the gas. Compressed air is not used to avoid air-oil vapour explosion. Following types of hydro-pneumatic accumulators are used in hydraulic circuits:

- Bladder type accumulator
- Diaphragm bladder type accumulator
- Piston type accumulator
- Metal bellows type accumulator

13.3.1 Bag or Bladder Type Accumulator

A bladder type accumulator consists of a metal shell,usually made of steel, attached to the fluid pipe or tube through a fluid port. The shell contains a elastomeric bladder in which gas can be filled through a valve located on the top of shell.A bladder type accumulator is shown in Fig. 13.1. The bladder is usually charged with nitrogen gas to a nominal pressure when the pumps are not operating. When the pressure in the pipe exceeds system pressure, oil flows into the accumulator against the gas pressure. When the bag is fully compressed, the nitrogen pressure and the hydraulic pressure are equal. As system pressure drops the bag expands, forcing fluid from the accumulator into the system. As the bag expands, pressure in the bag decreases. The bag will continue to expand until the bag pressure equals the hydraulic pressure. The maximum flow rate of the accumulator can be controlled by the opening area of the orifice and the pressure difference across the opening.The main advantages of this type of accumulator are fast response and low hysteresis. The bag type of accumulator is the best choice for pressure pulsation damping and is also reliable in service. Gas accumulators are generally larger than the other type of accumulators.

13.3.2 Diaphragm Accumulator

A diaphragm accumulator consists of a pressure vessel in two parts usually in the form of two hemispheres joined together. The two parts are separated by a flexible rubber diaphragm. A diaphragm type accumulator is shown in Fig. 13.2.This type of accumulator is similar to bag type of accumulator except the diaphragm which is used to separate the gas and oil in place of a bag or bladder to store the gas. This reduces the overall volume of the accumulator. The behaviour characteristics of a diaphragm accumulator are similar toa bag accumulator.

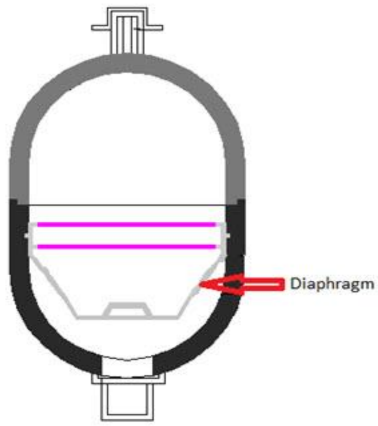


Fig. 13.2: Diaphragm Type Accumulator

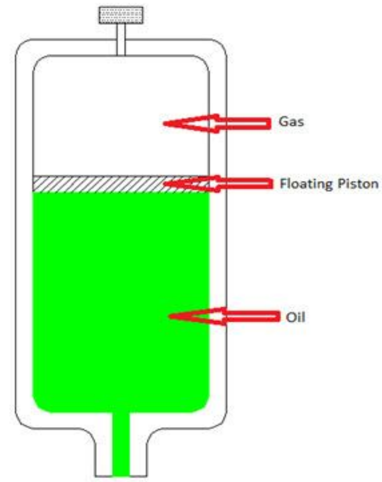


Fig. 13.3:Piston Type Accumulator

13.3.3 Piston Type Accumulator

Fluids are practically incompressible and hence cannot store pressure energy. The compressibility of nitrogen gas is utilized this type of accumulator. A gas piston accumulator consists of a cylinder body and a moveable piston. On one side of the piston is nitrogen gas and on the other side is the hydraulic fluid and connection to the hydraulic system. A piston type accumulator is shown in Fig. 13.3. The gas section is pre-charged with nitrogen and the fluid section is connected to the hydraulic circuit so that the piston accumulator draws in fluid when the pressure in the circuit increases. When the pressure decreases, the compressed gas expands pushing the piston and stored fluid is displaced into the hydraulic circuit. A gas piston accumulator will not respond as fast as a bladder accumulator. But a piston accumulator will have better damping. Piston accumulators will generally provide higher flow rates than gas accumulators for same accumulator volumes. This is because piston accumulators can accommodate higher pressure ratios (maximumsystem pressure to precharge pressure) in the range 10 to 1, as compared with bladderaccumulator ratios of 4 to 1. The disadvantages of piston accumulators are that they have a lower response time than bladderand will have hysteresis.

13.3.4 Metal Bellow Accumulator

A metal bellows accumulator consists of a pressure vessel with a metal bellows assembly separating fluid and nitrogen. Metal bellows are made up of Teflon and alloys which offer better dampening quality. Metal bellows are used where a fast response time is not critical. This type of accumulator is quite reliable for the hydraulic circuits. The accumulator is similar to a piston accumulator, except a metal bellows replaces piston and piston seals. Metal bellows accumulators are slow in responding to pressure changes due to increased mass of piston and bellows. Metal bellows accumulators are reliable, have long life components and have proven service history.

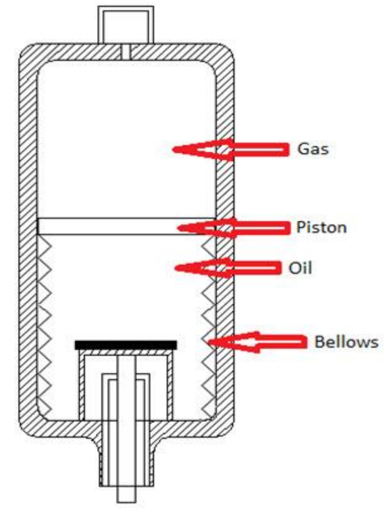


Fig. 13.4: Metal Bellows Accumulator

13.4 Gas Accumulator Precharging

The precharge may be expressed as the pressure of the gas in the accumulator without hydraulic fluid in the fluid side. A gas accumulator is pre-charged with nitrogen gas when there is no hydraulic fluid in the accumulator to the desired pressure. The gas accumulator pre-charge is a very important parameter for accumulator performance .

13.5 Accumulator Design Considerations

The design of an accumulator is based on the following factors:

- **Accumulator Type**: It includes various types of hydraulic accumulators like- bag or bladder type, diaphragm, piston, and metal bellows type. Each type has advantages and disadvantages and the specifications will also vary in each type of accumulator.
- **Accumulator Volume**: Another parameter is accumulator volume or the total volume of the accumulator which includes both gas and fluid volume.
- **Nominal Hydraulic System Pressure**: It is the hydraulic system pressure in the system, which will usually be the no-flow rating of the hydraulic pump
- **Minimum Hydraulic System Pressure**: This is the minimum pressure that the accumulator must maintain in the hydraulic system. This parameter helps in designing of size of the accumulator.
- **Precharge Pressure**: It is basically the pressure of the nitrogen in an accumulator without any hydraulic fluid in the accumulator. This pressure indicates the amount of fluid that an accumulator canhold at the system pressure and the desired minimum hydraulic system pressure.
- **Flow Rate**: The required flow rate is the basic requirement which determines the size of the accumulator. The accumulator volume for hydraulic flow is given bythe product of flow rate and time required for the flow.

Flow = Q * t

Where Q = flow rate

T = time required for the flow.

- **Output Volume**: It is the output volume capacity of the fluid volume of the accumulator that is capable of providing between the nominal hydraulic system pressure and the required minimum hydraulic pressure.
- **Response Time**: It is the time for the accumulator to make available the required fluid volume.
- **Recharge Time**: It is the time required to fully charge an accumulator from a fully drained condition.
- **Type of Fluid**: Accumulator seals and elastomeric bladder/diaphragm material must be compatible with the hydraulic fluid used in the system
- **Operating Temperature**: Accumulator performance should be evaluated over the expected temperature range of the nitrogen.

LESSON 14. Pressure Gauges

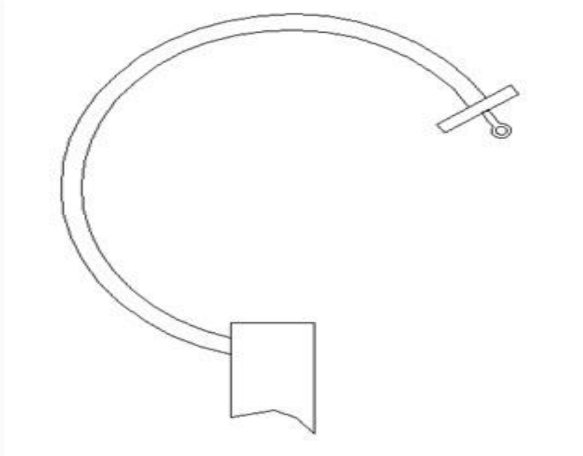
14.1 Introduction

The behaviour of a fluid can be gauged from measurements of pressure or flow. A flow transducer has to be fixed in the line in a way that it obstructs the flow of fluid, thereby changing the local behaviour of fluid. On the other hand, pressure transducers can be added non-intrusively to the pipe through which fluid is flowing.The pressure gauges are generally used to monitor the pressure in filter systems, pumps and pipeline systems in the hydraulic circuit. Pressure gauges are essential in liquid-powered systems to measure pressure to maintain efficient and safe operating levels. Pressure is generally measured in kg/cm^2, psi and bar. A typical pressure gauge for a hydraulic system is shown in Fig. 14.1

Fig. 14.1: A hydraulic System Pressure Gauge with Brass Connection

14.2 Pressure Gauges

Mostly dial type pressure gauges use a bourdon tube-sensing element generally made of a copper alloy (brass) or stainless steel for measuring pressures. Bourdon tube gauges are widely used in the hydraulic machines or systems to measure pressure and vacuum. Its construction is simple but is considered to be rugged and operation does not require any additional power source. The sensing element is usually a C-shaped tube having oval cross-section, fig 14.2 and 14.3. One end of the tube is exposed to the system pressure through suitable connection. The other end is sealed and free to move. This end is connected to the pointer through mechanical linkages. When pressure is applied to the tube it tends to attain a circular cross-section. This results in distortions which lead to a movement of the free end. The elements of a bourdon tube pressure gauge are shown in Fig. 14.2.



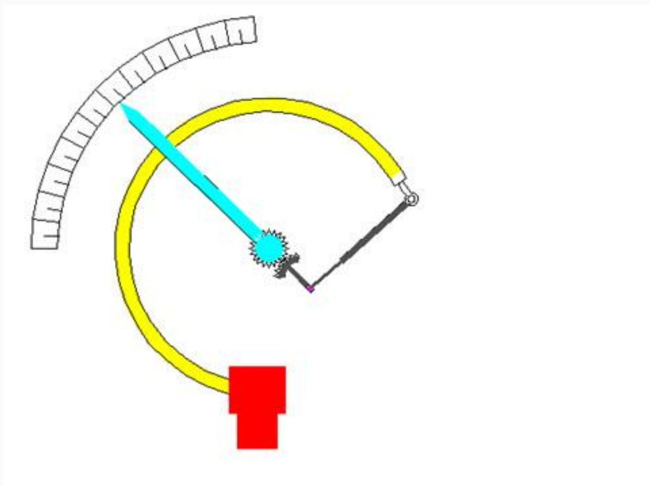


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Fig. 14.2: Elements of a Bourdon Pressure Gauge

The movement of the free end of the bourdon tube is converted to circular movement of a pointer using a sector and pinion arrangement. The restraining force is provided by a hair spring. As the external surface of the bourdon tube is exposed to atmospheric pressure, the pointer indicatesgauge pressure. These gauges are generally suitable for most of the fluids. A photograph of bourdon pressure gauge without the pointer is shown in Fig. 14.3. Note the almost flattened C-shaped bourdon tube made of copper alloy.

Fig. 14.3: An actual Bourdon Pressure Gauge

(Courtesy: http://www.indiamart.com/nationalinstruments/fluid-mechanics.html)

For low pressure ranges, a spiral tube is used to increase the sensitivity.Other configurations of bourdon tube used are helical and twisted type.

Digital gauges use an electronic pressure sensor to measure the pressure and then transmit it to digital display readout. Using this method information can be stored for processing.

LESSON 15. Volume Meters

15.1 Introduction

The working of hydraulic systems depends upon the flow rate and pressure of the oil in various sections of the circuit. Flow causes motion and increased rate of flow results in higher velocities of hydraulic cylinders or motors. Measurement of oil flow rate is important for controlling the speed of actuators in hydraulic systems. Further, higher flow rates may cause turbulent flow in the system leading to increased energy loss through friction and premature wear due to cavitation. Thus measurement of flow rate or velocity is of prime importance in hydraulic systems. In hydraulic systems, which use incompressible oil as the medium, volumetric flow is used to measure flow rate. A common type of inflow meter used for measuring volumetric flow rate is shown in Fig. 15.1.

Fig. 15.1: An Inline Flow Meter

(Courtesy: http://www.alibaba.com/showroom/diesel-oil-volume-meter.html)

Flow measurement may be expressed in units of rate of flow such as Litre Per Minute (LPM) or cubic meter per second (m^3/s) etc. It may also be expressed in terms of total quantity in litre or cubic meter.

15.2 Volume Meters

There are different types of flow meters depending upon the application. Choice of a flow meter depends upon the flow quantities, flow rates, and types of liquids involved. Flow meters must be used only for the purpose for which they were made. Some common methods used for measuring flow rate are discussed below.

15.2.1 Venturi / Orifice Meters

The traditional method of measuring flow is based upon Bernoulli's equation which was discussed in lesson 2. The flow velocity of the fluid in pipe is increased locally by introducing a restriction as shown in Fig. 15.2.

Add sktch

(a) (b)

Fig. 15.2: (a) Venturi Meter (b) Orifice Meter

The obstruction may be in the form of a venturi or an orifice plate. This increases flow velocity causing a pressure drop, the pressure being minimum where the cross section of the fluid stream is minimum. The differential pressure across points 1 and 2 is then a measure of the flow velocity or flow rate.

15.2.2 Variable Area Flowmeter

Variable area flowmeters, also known as rotameters, uses a float in a vertical tube of variable cross-sectional area as shown in Fig. 15.3

Fig. 15.3: Rotameter

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The obstruction in the path of fluid due to float causes increase in the fluid velocity which results in a differential pressure drop across the float. Due to this, an upward force acts on the float. The upward force is a function of the flow rate. The weight of the float acts downwards. If the upward force due to differential pressure drop is more than the weight, the float rises above, otherwise the float moves down. When the float moves up, the area around the float increases. This increase in area decreases pressure drop across the float and hence the upward force. The float therefore settles at a vertical position where the weight of the float balances the upward force due to differential pressure. The vertical position of the float thus gives the flow rate of the fluid.

15.2.3 Turbine Flowmeter

A turbine flowmeter uses a turbine mounted in a pipe to measure the flow rate of the fluid in the pipe as shown in Fig. 15.4.

Fig. 15.4: Turbine Flow Meter

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The flowing fluid makes the turbine propeller to rotate. The rotational speed of the propeller is proportional to the flow rate. Blade rotation can be counted by a proximity sensor which generates electric pulses. Thus turbine flow meter can be used for remote indication of flow rate.

MODULE 3.

LESSON 16. Hydraulic Circuits

16.1 Introduction

A hydraulic control system is used to control position / speed of a load and provide necessary force for doing work. This is achieved by designing and building appropriate hydraulic circuits required for operating some kind of a hydraulic machine or hydraulic power system. A hydraulic circuit includes various components like reservoir, pump, actuator, motor, pipes, hoses, clamps, accumulator, valves, intensifier etc. These components can be arranged in number of ways to get the desired output from the hydraulic circuit. There may be different types of hydraulic circuits as discussed in the following sections.

16.2 Speed Control Circuits

In hydraulic operated machine tools and other mechanical equipment, speed control is required to enhance the functional versatility of the machine. Speed control required during different strokes can be done by regulating oil flow to the cylinder. Speed control of a single load can be done using variable displacement pump. If the speeds of a number of loads are to controlled independently, the metering of the oil to individual cylinders is done by using flow control valves. Depending upon the location of flow control valve for metering the oil, speed control circuits can be classified as meter-in, meter-out and bleed-off circuits.

16.2.1 Meter-in Speed Control

This type of circuit consists of a pressure compensated flow control valve between the pump and cylinder. This flow-control valve is placed in pressure line that actuates the cylinder to work. Oilflowing into the work cylinder is metered through the flow-control valve. Since this metering action involves reducing flow from a pump to the cylinder, the pump must deliver more fluid than is required to actuate the cylinder at the desired speed. Excess fluid returns to the tank through a relief valve. To conserve power and avoid undue stress on the pump, the relief valve pressure is kept little higher than the working pressure. A meter-in circuit is considered to be better in applications where a load always offers a positive resistance to flow during a controlled stroke.These circuits are used where slow feed rates are required. A meter-in speed control is shown in Fig. 16.1.

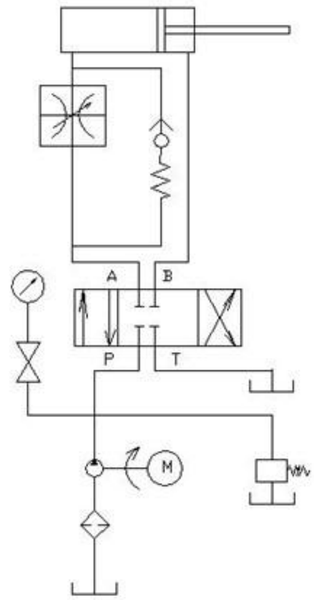

Fig. 16.1: Meter-in Speed Control Circuit

16.2.2 Meter-out Speed Control

In this type of circuit, a flow-control valve is installed on the return side of a cylinder so that it controls the cylinder actuation speed by metering its discharge flow. A relief valve is kept a little above the operating pressure which is required by the type of application. These types of circuit are best suited where work resistance is negative such as climb milling. These circuits may also be used for overhauling load applications in which a workload tends to pull an operating piston faster than pump delivery,like in drilling, reaming, boring, turning machines. A flow-control-and-check valve used in this circuit would allow reverse free flow. A meter out speed control circuit is shown in Fig. 16.2.

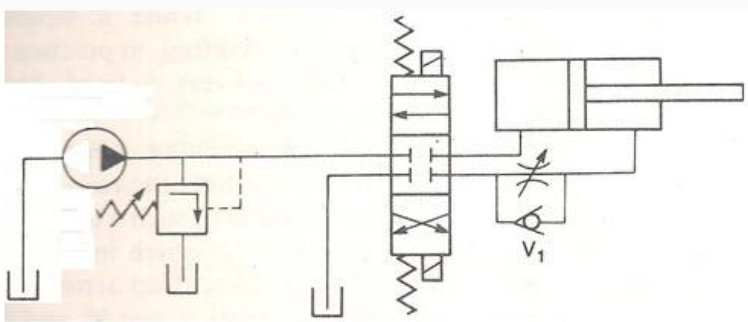

Fig. 16.2: Meter-out Speed Control Circuit

16.2.3 Bleed Off Speed Control

In this type of circuit flow control valve is not directly provided in the feed line but is connected to the pressure side as shown in Fig. 16.3. The flow control valve regulates flow to a cylinder by diverting a portion of a pump flow to the tank. This type of circuit usually involves less heat generation because pressure on a pump equals the work resistance during a feed operation. This type of circuit is used for constant load applications.

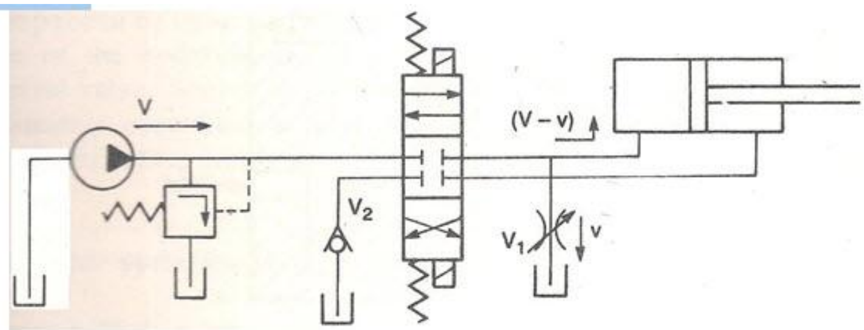

Fig. 16.3: Bleed Off Speed Control

16.3 Pressure Compensated Circuit

Flow rate through flow control valves can vary if either the fluid pressure or the temperature changes. In some cases where precise control of actuator speed is needed, a true flow control valve is required which delivers a fixed flow regardless of the line pressure or fluid temperature. For such cases, a compensated flow-control valve is used. This valve automatically changes the adjustment or pressure drop. A compensated flow-control valve is used mainly to meter fluid flowing into a circuit. A pressure compensated valve is shown in Fig. 16.4. A piston is subjected to pressure on the two sides of the orifice meant for flow control. The orifice setting is done with the help of adjustable screw. The net force on the piston balances the spring force set as per flow requirement. If the line pressure changes, the piston moves to the left or right thereby modulating the area of the variable orifice. This piston thus helps in maintaining a constant pressure drop across the flow control valve orifice, which implies a constant flow through the valve.

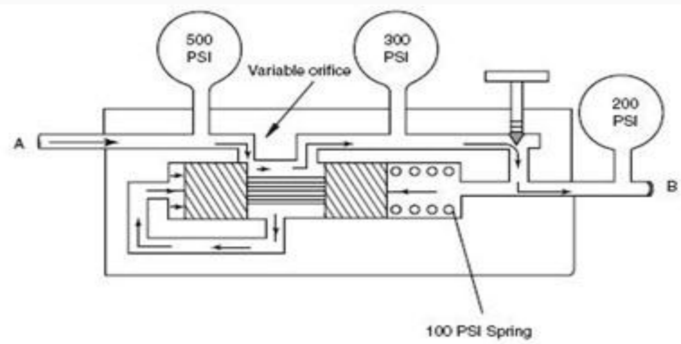

Fig. 16.4: A Pressure Compensated Valve

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16.4 Pressure Reducing Circuit

This type of circuit is normally utilized where two branches of a circuits are working at different pressures. In this one of the cylinder receives the pressure fluid from direction control valve in forward stroke where as other cylinder receives pump pressure through pressure reducing valve. The pressure of first cylinder will depend upon the relief valve setting. The pressure in the second cylinder can be adjusted by pressure reducing valve. A pressure reducing valve is shown in Fig. 16.5.

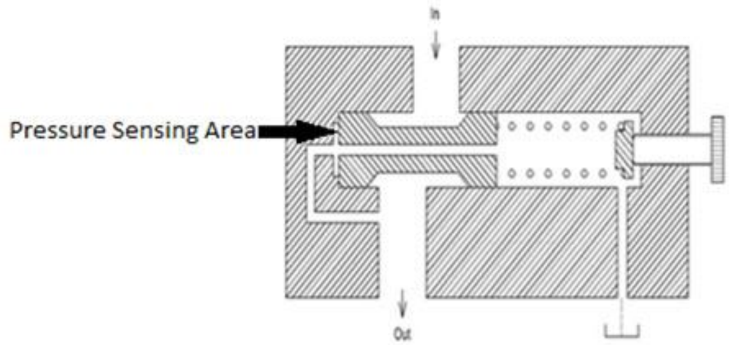

Fig. 16.5: A Pressure Reducing Valve

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A spring loaded spool senses the outlet pressure. If the force on the spool is more than the spring force, the spool moves towards right, thereby reducing the oil flow to the output side.Flow through the small bleed hole in the spool to the spring chamber and drain prevents the valve from closing completely.

16.5 Sequencing Circuit

Cylinders may be sequenced by restricting flow to one cylinder. This type of circuit is used where there are two cylinders and are to be operated in sequence. One method of restricting flow is with backpressure check valves. They prevent flow until a set pressure is reached. In this circuit, cylinder one extends and retracts ahead of cylinder two. This circuit is mainly comprised of a sequence valve which allows the flow into cylinder one (1) and then to the cylinder two (2) as shown in Fig. 16.6.

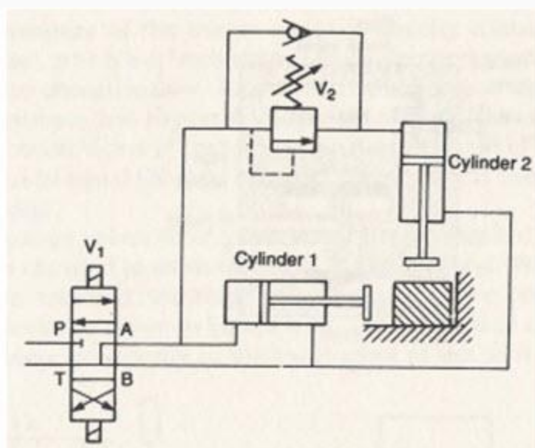


Fig. 16.6: A Sequencing Circuit

16.6 Intensifier

A hydraulic intensifier or booster is a device that converts low pressure from a large area of the intensifier into high pressure in a small area of the intensifier. An intensifier consists of two different-sized cylinders connected by a common piston.The force exerted on the smaller side is the same as that on larger side, but the pressure exerted on the smaller cylinder get intensified due to different sizes of pistons. An air-oil intensifier is shown in Fig. 16.7.

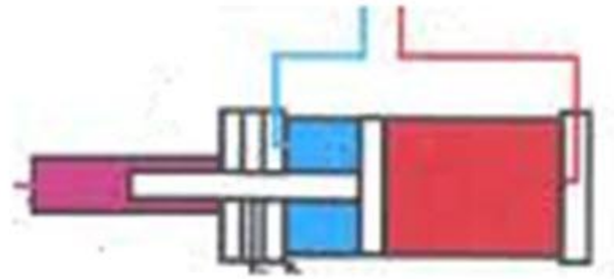


Fig. 16.6: Intensifier

The large-area air piston pushes a small-area hydraulic ram against trapped oil. The difference between the two areas gives high-pressure capability at the small ram. This capability is indicated by the area ratio. If the air piston has a 5-in. diameter and the oil piston has a 1-in. diameter, the area ratio is 25:1. With this area ratio, 80 psi acting on the air piston produces 2000 psi at the hydraulic piston.

16.7 Reciprocating Circuit

The back-and-forth extension and retraction of a hydraulic cylinder is called reciprocation of a piston in the cylinder. This type of circuit can be utilized in number of machines, like shaper machine, punch press etc. In the punch press there is a single hydraulic cylinder that extends and retracts and the required work is done with the help of single cycle cylinder reciprocation.

LESSON 17. Hydraulic Circuit Fittings and Connectors

17.1 Introduction

A hydraulic system includes various components like reservoir, pump, actuator, motor, accumulator, valves, intensifier etc. These components are connected with each other in different configurations to form different tasks. The connections are made with the help of fittings and connectors. Thus fittings and connectors are of great importance for the functioning of hydraulic system components. There are different types ofconnectors available, which dependon the type of circulatory system (pipe, tubing, or flexible hose), fluid medium, operating pressure of a system etc. Some of thecommonly used fittings and connectors arediscussed as under.

17.2 Threaded Connectors

Thesetype of connectors are generally used in low-pressure hydraulic systems. These are normally made of steel, copper, or brass, with varying designs. The connectors are made with standard female threading cut onthe inside surface. The end of the pipe is threaded with outside (male) threads for connecting.Standard pipe threads are tapered slightlyto ensure tight connections. A straight threaded connector is shown in Fig. 17.1. O-ring seal is provided for leak proof connection.

Fig. 17.1: A Threaded Connector

Add Sktch

17.3 Flared Connectors

Flared connectors provide safe, strong and dependable connections and this method does not require any thread, weld, or solder in the tubing. A connector consists of a fitting, a sleeve, and a nut. Fittings are made of steel, aluminum alloy, or bronze. The fittings should be of a material that is similar to that of a sleeve, nut, and tubing. Tubing used with flared connectors must be flared before being assembled. A tube with flared end is shown in Fig. 17.2 (a). A nut fits over a sleeve and, when tightened, draws the sleeve and tubing flare tightly against a male fitting to form a seal as shown in Fig. 17.2 (b). A male fitting has a cone-shaped surface with the same angle as theinside of a flare. The tubes are normally flared at 37° from the centreline. In some of the applications this angle may also be 45°.Thesetype of fittings are comparatively less expensive. Flared connectors will have leak if the flare is distorted, split and eccentric or if the sleeve is damaged.

(a) (b)

Fig. 17.2: (a) A Tube with Flared End (b) A Flared Joint

Add sktch

17.4 Flexible Hose Couplings

Flexible pipes are generally used to prevent vibration transmission or to allow relative movement between the ends. Hydraulic pumps are usually connected to the system with a flexible hose to prevent transmission of vibrations. The flexible tubes are made up of nylon or polyurethane but rubber tubes may also be utilized. Flexible hosing consists of several concentric layers. The material of the inner tubing is compatible with the hydraulic oil and its operating temperature. One or more braided reinforcing layers cover the inner tubing. The outer layer is provided to resist abrasion and protect inner layers from physical damage. Flexible hose coupling fittings are an integral part of hose assembly. A flexible hose with integral fittings is shown in Fig. 17.3.

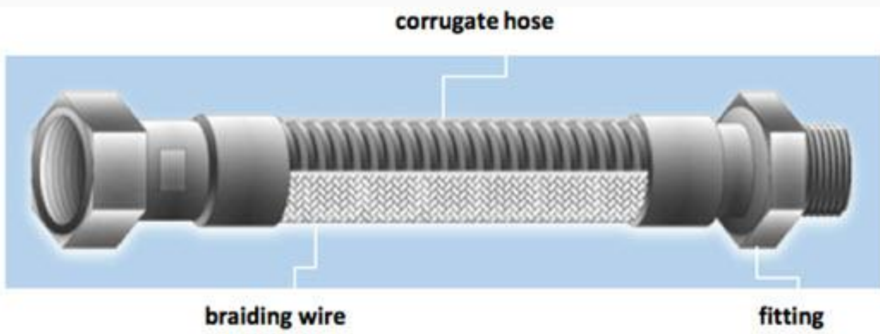


Fig. 17.3: Flexible Hose with Fittings

(Courtesy: http://majorflex.com/wp-content/uploads/2012/01/metalflex2.png)

17.5 Reusable Fittings

Reusable couplings are attached to a hose using a ferrule. A ferrule is a collar which is screwed on to the hose cover. The stem is wedged into the tube of the hose using threads on the ferrule. The compression of the hose between the stem and the ferrule holds the coupling on the hose. A reusable coupling with sectioned view of the ferrule is shown in Fig. 17.4.Permanent couplings are attached to the hose using a crimping tool. As the coupling is crimped inward, serrations on the ferrule pierce the hose cover.

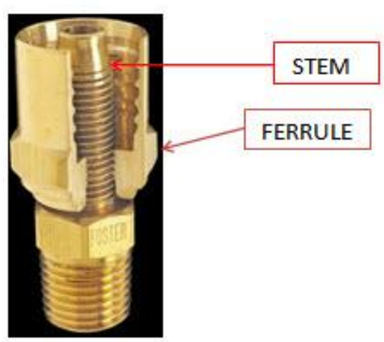


Fig. 17.4: Reusable Fitting

(Courtesy: http://kingflex.com/product-information/couplings-and-accessories/foster/)

17.6 Bite Ring Type Compression Fittings

Sometimes thickness of the tube is more and it becomes difficult to flare it. In such situations flare less fittings are used. Bite ring compression fittings consist of a bite ring or a ferrule having sharp leading edge which is pressed against the tube tightening the nut as shown in Fig. 17.5. The wedging action of the bite ring makes a seal between the tube and connector body.

Fig. 17.5: Bite Ring Compression Fitting

Add sktch

17.7 Leakage

Hydraulic system may havesome amount of leakage, which reducesefficiency of the system and results in power loss.Leakageis not always due to faults, sometimes leakage is introduced deliberately in a planned manner. The leakage may be internal, external, or both.

17.7.1 Internal Leakage

This type of leakage is generally provided or built-in into hydraulic componentsto lubricate various components likevalves, shafts, pistons, journals,pumping mechanisms, and similar other movingparts. Internal planned leakage is provided through small orifices or pathways that allow a fluid from a higher pressurized zone of a system to travel into a lower pressurized zone to lubricate, clean and cool a specific component or area. Hydraulic oilis not lost in internal leakages but it returns to a reservoir through return lines.

17.7.2 External Leakage

The most common cause of external leaks is faulty joints.Leakage from components is usually due to damaged seals and packings. External leakage can be harmful and expensive. Faultyinstallation and poor maintenance are the main reasonsof external leakage. Therefore, the components of the hydraulic system must be assembled and installedcorrectly so that there are fewer chances of leakages.

17.7.3 Prevention

External leaks are generally identified by oil spray from system or pool of oil under the system. Excessive internal leaks are detected by observing the temperature or by ultrasonic detection techniques. Oil leakages in hydraulic systems can be prevented by observing the following guidelines:

- Installation of pipes and tubing as per the recommendations of the manufacturer.
- Operating the hydraulic system at correct operating conditions.
- Regular preventive maintenance of the system.
- Never use additives without approval of the manufacturer.

17.8 Seals

Seals are packing materials used to prevent leaks in liquid-powered systems.Leakage is hydraulic systems is a common occurrence which must be prevented for efficient working of the system. Seals are used in both static and dynamic portions of hydraulic components to prevent leakage. A seal may be in the form of gasket, packing, seal ring, or other type designed specifically for sealing. Sealing ensures the hydraulic oil keep flowing in the lines or passages at desired pressure. Static seals are used when no relative movement occurs between the mating parts. Dynamic seals are used between the surfaces of hydraulic parts where movement occurs and they control both leakage and lubrication. Seals are usually classifies by the geometric shape or configuration as shown in Fig. 17.6.

Fig. 17.6: Common Seals

17.8.1 Seal Material

Both metallic and non-metallic materials are used for fabrication of seals used in hydraulic systems. Material hardness is an important characteristic for specific applications. Dynamic seals need to be softer as it helps in better sealing action through compression. Common seal materials are leather, elastomers, nitrile, silicone, neoprene.

LESSON 18. Pumps and pump classification

18.1 Introduction

Hydraulic pumps are the devices which converts the mechanical energy into hydraulic energy. Mechanical rotations are provided to the pump with the help of an electric motor , which creates a partial vacuum in the inlet of the pump and allows the fluid into the pump through inlet pipe . The entered fluid is being pushed by the pump into the various components of hydraulic system or machine.

There is a misconnect that a pump generates pressure, it only make the flow of fluid. Pressure occurs when the flow from the pump is subjected to a resistance. The mechanical action of the pump creates a vacuum at the inlet port, which allows atmospheric pressure to force liquid from the reservoir into the pump. The mechanical rotations of the pump then forces the liquid into the hydraulic system or hydraulic equipment.

18.2 Pump Classification

Classification

Pumps can be broadly classified into two categories-

- Positive Displacement Pumps
- Non Positive Displacement Pumps

18.2.1 Positive Displacement Pumps

Normally the hydraulic pumps used in the hydraulic systems are positive displacement pumps. A positive displacement pump has an extremely close fit between the pumping element and the pump housing, which results in very low or negligible slippage. A positive displacement pump causes a fluid to move by trapping a fixed amount of it and then forcing the trapped volume of fluid into the discharge pipe. This type of pumps work using an expanding cavity on the suction side and a decreasing cavity on the discharge side. Fluid flows into the pump as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity vanishes. In the positive displacement pump the flow enters and leaves the pump at same velocity and no change in the kinetic energy takes place.

Advantages

This type of pump will have the following advantages –

- It can produce high pressure
- These are having wide application in the hydraulic systems

- The volumetric efficiency is comparatively more
- This will have less change of efficiency through out the pressure range
- Size of pump is small

18.2.1.1 Positive displacement types

A positive displacement pump can be further classified depending upon the mechanism used -

- **Rotary pump**

Rotary type of pumps are most commonly utilized in the hydraulic systems when low to medium pressures are there. These may be of various types like - gear type, screw type, vane type etc. It works on the principle that a rotating gear, screw, or vane traps the liquid at bthe suction side of the pump and forces it to the discharge side of the pump. This type of pump is generally self type priming because it has the capability to remove the air from the suction side of pump. This type of pumps are having close clearance between the rotary element and the housing and hence rotated at low speeds to have reliable operation.

- **Reciprocating Pump**

This type of pumps are normally consisted of piston, cylinder, crank with connecting rod delivery and suction pipe, etc. Operation of reciprocating motion is done by the power source ytglike electric motor or an engine, etc.

18.2.2 Non positive displacement

Non-positive displacement pumps are those in which fluid is transferred with the help of inertia of fluid in motion . These pumps include centrifugal pump, propeller pump etc. These are normally used in low pressure and high volume systems. With this pump, the volume of liquid delivered for each cycle depends on the resistance offered to flow. This type of pump costs less as the it has fewer moving parts. It has the following advantages-

Advantages

- Its initial cost is low
- Simple in design
- Maintenance cost is low
- Reliability is more
- Operation is comparatively quiet

LESSON 19. Pumps working and Performance

19.1 Introduction

Mechanical energy is converted into hydraulic energy with the help of pumps. Rotations are provided to the pump with the help of an electric motor , which creates a partial vacuum in the inlet of the pump and allows the fluid into the pump through inlet pipe . The fluid so entered is being pushed by the pump into the various components of hydraulic system or machine. There is a misconnect that a pump generates pressure, it only make the flow of fluid. Pressure occurs when the flow from the pump is subjected to a resistance and it forces the liquid into the hydraulic system or hydraulic equipment.

19.2 Positive Displacement Pumps

Generally positive displacement pump has an extremely close fit between the pumping element and the pump housing, which results in very low or negligible slippage. In the positive displacement pump the flow enters and leaves the pump at same velocity and no change in the kinetic energy takes place. A positive displacement pump causes a fluid to move by trapping a fixed amount of it and then forcing the trapped volume of fluid into the discharge pipe.

19.2.1 Positive displacement types

A positive displacement pump can be further classified depending upon the mechanism used -

- **Rotary pump**

Rotary pump may be of various types like - gear type, screw type, vane type etc. It works on the principle that a rotating gear, screw, or vane traps the liquid at both suction side of the pump and forces it to the discharge side of the pump. In this type of pump generally priming is not required .This type of pumps are having close clearance between the rotary element and the housing and hence rotated at low speeds.

Gear Pump

The basic gear pump consists of two meshed gears , a housing to house the gears. One of the gear is connected to the drive shaft and other is driven as it is meshed with driver gear. .This type of pumps are capable of developing a very high pressure and it delivers a fixed quantity of fluid per revolution of pump shaft. These are simple in design and compact in size and used in moving equipment etc. There may be the following types of gear pumps-

- Spur gear pump
- Internal gear pump

- Screw pump
- Lobe pump

Spur Gear Pump

It consists of a driving gear and a driven gear enclosed in a closely fitted housing. Both the gears move in opposite directions and mesh at a point in the housing between the inlet and outlet ports. Both sets of teeth project outward from the center of the gears. As the teeth of the two gears separate, a partial vacuum forms and draws liquid through an inlet port into the housing is trapped between the teeth of the two gears and the fluid is discharged through the housing to the discharge side. The liquid then pushed through the outlet as the rotating gears develop sufficient pressure.

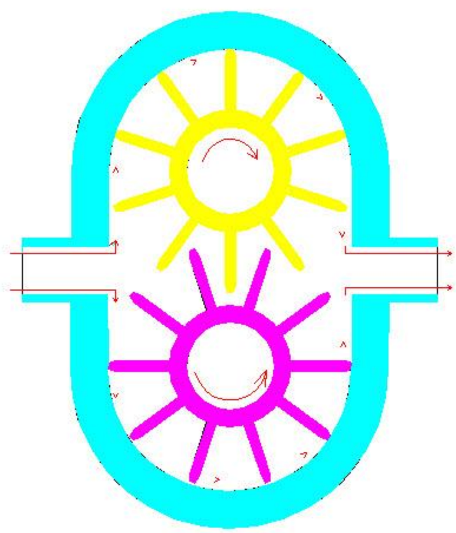
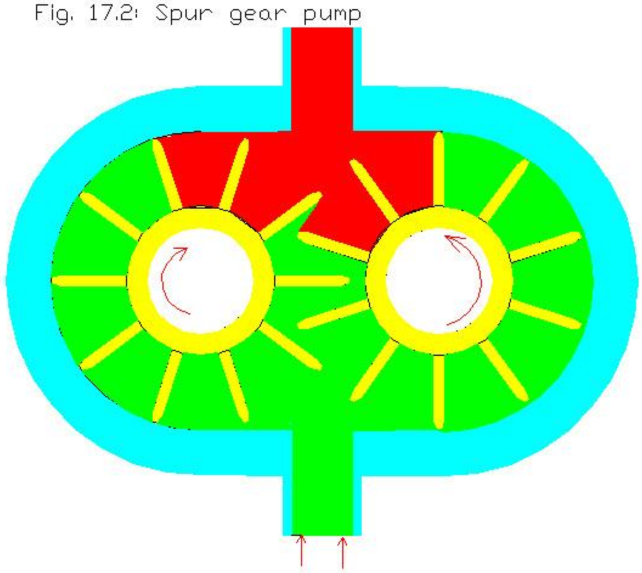


Fig. 17.1: External gear pump

Fig. 17.2: Spur gear pump



The velocity of fluid flowing through the pump can be given as-

$$v = \frac{Q}{A}$$

Where,

v = velocity

Q = Flow rate

A = Area

Volume of fluid can be calculated as-

Let V = volume of fluid

D1 = outer diameter of gear teeth

D2 = inner diameter of gear teeth

N = speed of pump (rpm)

w = gear teeth width

Therefore volume displaced in one revolution $V = \frac{\pi}{4}(D1^2 - D2^2)\text{x w}$

Discharge per sec $Q = \text{VxN}$

Efficiency $\eta = \frac{Qa}{Qt} x100$

Qa = actual discharge

Qt = theoretical discharge

Performance of Pump

Internal Gear Pump

Internal gear pumps used in hydraulic systems are versatile, efficient and produces less noise. It is consisted of internal gear, outside ring gear set offcenter. There is a stationary spacer between the two gears around which oil is carried. Liquid enters the suction port between the large exterior gear and the small interior gear teeth. Liquid travels through the pump between the teeth of the gear-within-a-gear principle. The spacer divides the liquid and acts as a seal between the suction and discharge ports. The large exterior gear and the small interior gear teeth mesh completely to form a sort of seal and forces the liquid out of the discharge port.

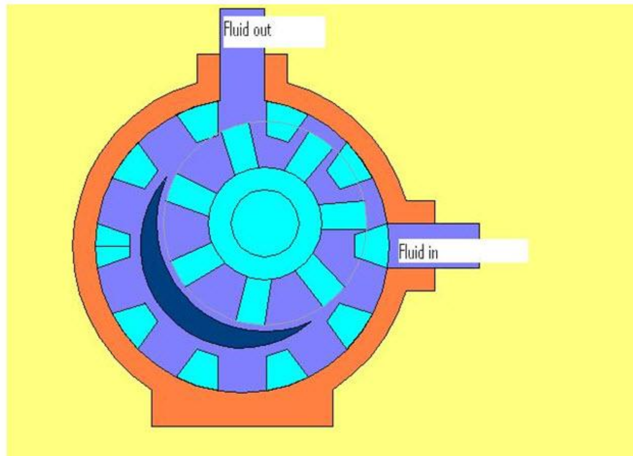


Fig. 17.3: Internal gear pump

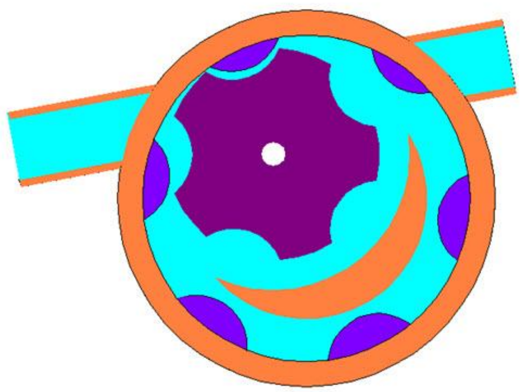


Fig. : 17.4 Internal gear pump

In the internal gear pump the internal gear is coupled with the drive shaft and the external gear is rotated or vise versa. It is a positive displacement pump and used for low pressure system to high pressure systems.

Screw Pump

This type of pumps are a little complicated type of rotary pumps as compared to other types. It is having two or three screws with opposing thread and in this type one screw turns clockwise, and the other anticlockwise. The screws are each mounted on shafts which moves parallel to each other. These shafts also have gears on them that mesh with each other in order to turn the shafts together and keep everything in place. The rotation of the screws, and subsequently the shafts to which they are mounted, draws the fluid through the pump. The clearance between moving parts and the pump housing is kept quite less.

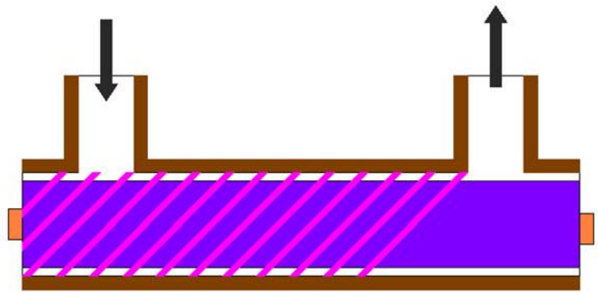


Fig. : 17.4 Screw type pump

Lobe Pump

Lobe pumps are rotary type of pumps which are positive displacement pump. A positive displacement pump operates by trapping a fixed amount of fluid from tank or inlet pipe and then forced the trapped volume into a delivery pipe. In this two lobes are used to rotate one against the other, creating two chambers between the lobes and the of pump housing. One of the lobe is driven by the power source where as other is rotated by the timing gear. As the lobes un-mesh on the intake side, they create a cavity with an expanding volume. And hence , the fluid is trapped between the lobes and the housing of pump and moved from suction side to the delivery side. The capacity of material being pumped can be changed by varying speed of the pump.

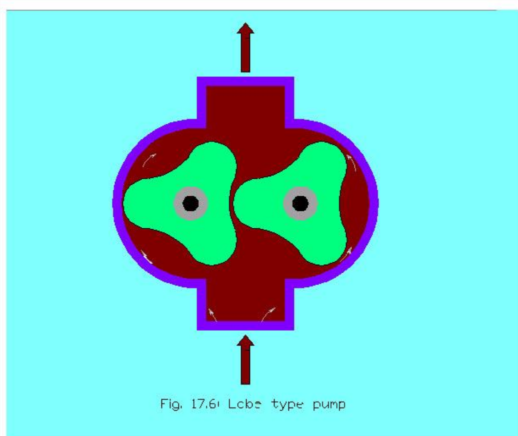


Fig. 17.6: Lobe type pump

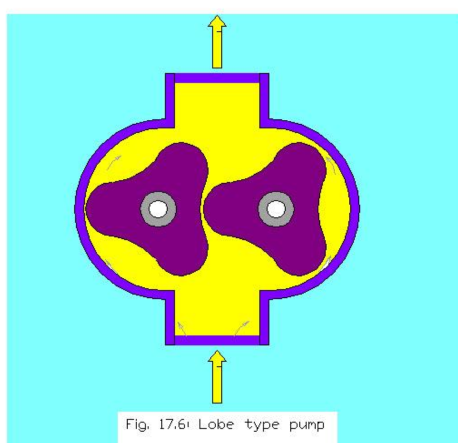


Fig. 17.6: Lobe type pump

Vane pump

The rotary vane pump is consisted of rotor and stator**.** The stator is the stationary enclosure in which the rotor rotates. The rotor is mounted with eccentric and therefore the rotor makes contact with the stator at the top of the stator between the inlet and the outlet. This point is called the contact point and is actually in close contact separated only by a thin film of oil. The sliding vanes move in and out of the rotor, making contact with the stator surface. The vanes can be spring-loaded or slide by centrifugal force. These are high volume pumps which can pump at higher pressures .When the rotor rotates within the stator , at the inlet of the pump one of the vanes and the contact point create a large volume which is initially void of molecules. This allows the fluid to to enter the pump. As it enters inside the pump, the fluid is trapped between the rotor vanes and the stator during rotation, it is pushed out through the outlet of the pump..

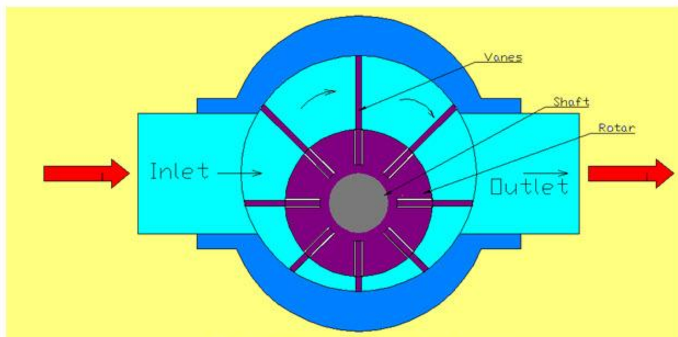


Fig. 17.7: Vane type pump

Reciprocating Pump

This type of pumps are normally consisted of piston, cylinder, crank with connecting rod delivery and suction pipe, etc. Operation of reciprocating motion is done by the power source ytglike electric motor or an engine, etc. Power source gives rotations to the crank through the connecting rod which is subsequently converted into reciprocating motion of piston in the cylinder. When crank moves from inner dead centre to outer dead centre vacuum will create in the cylinder. When piston moves outer dead centre to inner dead centre and piston force the fluid at outlet or delivery value. The reciprocating type pump may be of axial piston pump or radial piston type pump.

Axial Piston pump

An axial piston pump is that type of pump, which uses the contact between the a swash plate and rotating piston to convert rotary motion of shaft to linear motion of pistons. Axial piston pumps may be an in-line or angle type. Efficiency of this pumps is high, and pumps generally have better durability. In an in-line piston pump , a drive shaft and cylinder block are on the same centerline. Reciprocation of the pistons is accomplished by a swash plate . In the axial piston pump the pistons reciprocate parallel to the drive shaft. Generally the pistons are fitted around a cylinder block which turns also. Displacement in this type of piston pump is found by the size and number of pistons as well as the length of stroke. This variabledisplacement piston pump changes the length of the stroke continuously to match the changing flow requirements of the hydraulic system. Each piston is fitted with a ball joint shoe and each shoe has a flange. As the swash plate is rotated, the pistons will be forced into and out of the their respective bores as the cylinder block rotates. When the swash plate is not rotated, the pistons remain stationary in their bores as the cylinder block is turned and no oil is pumped.

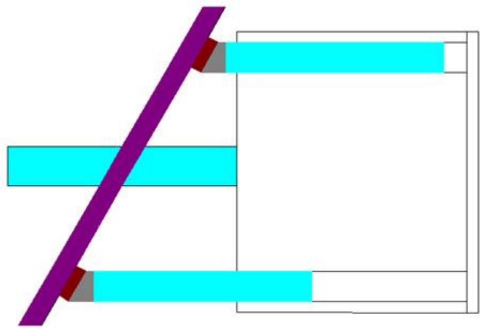


Fig.17.8: Axial plunger pump

Radial Piston Pump

Radial piston pumps are compact and reliable. These are capable of builting high pressure, high volume and high speed. It is having a number of closely fitted parts and therefore wear is also considered to be more. In this type of pump , the pistons are arranged like wheel

spokes in a short cylindrical block. There are many types of designs of radial piston pump . In this type of pump the pistons are arranged radially around an eccentric cam . The cam is a part of the main shaft. As the shaft rotates the pistons are reciprocated in the cylinders which are oriented radially . As the piston moves inwards the suction is caused and the space in the cylinder is filled with the fluid . When the piston moves outwards the fluid filled inside the cylinder forced outside the cylinder to the delivery side.

fig.

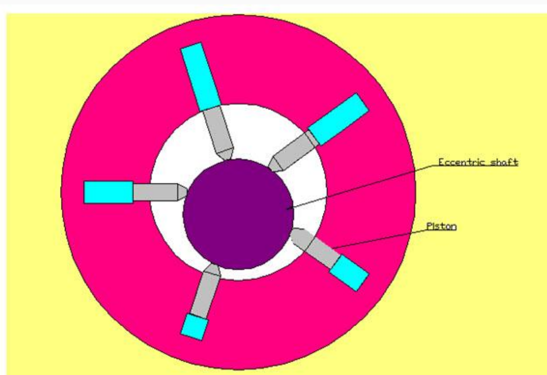


Fig.17.9: Radial piston pump

LESSON 20. Design of Gear Pump

20.1 Introduction

Most of the hydraulic systems are generally provided with positive displacement pumps. In these pumps there is hardly any slippage and the quantity of fluid pumped is nearly same for each rotation of shaft. Specially piston pumps exhibit this quality. The piston sucks and pushes the same quantity (volume) of fluid every rotation of shaft.

20.2 Design of Gear Pump

Therefore,

$$Q = V \times N$$

Where, Q = Flow rate

V = Displacement

N = speed

In actual practice there may be some leakages because of mating components are not perfect fits and therefore, the leakage occur in valves or pistons. The leakage will be more with the increase in pressure , as in fig . .

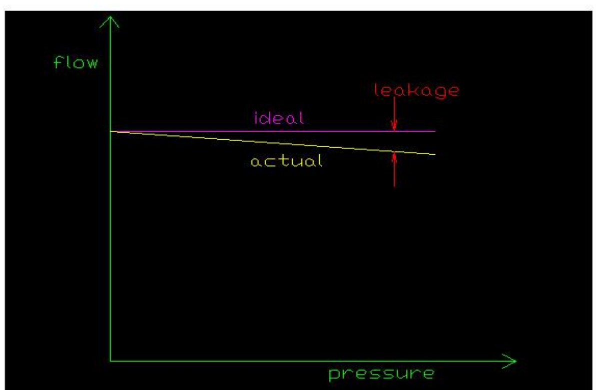


Fig. 18.1: Leakage of pump

20.3 Volumetric Efficiency

The volumetric efficiency may be defined as the ratio of actual flow rate to the theoretical flow rate

Let

Qa = actual flow rate

Qt = theoretical flow rate

η_{vol} = volumetric efficiency

$$\eta_{vol} = \frac{Qa}{Qt} \times 100$$

The piston pump is the most suitable example of positive displacement pump but other pumps like gear pump, lobe pump, screw pump and vane pump also come under the same category and calculations can be made accordingly.

20.4 Power of the Pump Shaft

It can be defined as the mechanical power transmitted to the pump shaft by the shaft of power source. It is basically product of torque and speed of the shaft. Hence it can be given as –

$$P_s = \omega \times t$$

Ps = shaft power

ω = angular speed

t = torque

The angular speed of the shaft isfined as the in radians per second and torque transmitted is in Nm. Now if the torque is transmitted in Nm and speed in revolution per second (rpm) the the equation can be deduced as below-

$$P_s = \frac{2 \pi N \tau}{60}$$

N = speed (rpm)

20.5 Fluid Power Calculations

It can be defined as the energy per second by the fluid in the form of pressure and the quantity of fluid. It is product of fluid quantity (flow rate) and the differential pressure. Hence

$$P_f = Q \times Dp$$

Where P_f = Fluid power

Q = flow rate , m^3/s

Δp = differential pressure, N/m^2

20.6 Overall Efficiency

It can be defined as the ratio of fluid power to the shft power or in other words ratio of output power to the input power. The input power is greater than the ouput power due to leakages in the sysem and friction between the moving parts. Hence overall efficiency can be given as-

$$\eta_{ova} = \frac{Pf}{Ps} x100$$

Where

η_{ova} = overall efficiency

$$\eta_{ova} = \frac{fluid\ power}{shaft\ power} x100$$

Example 1

A pump delivers $10x10^{-3}$ m^3 /min with a pressure rise of 680 N/m^2 .The shaft speed of 1400rpm and the nominal displacement is 8.2 cm^3/rev. The applied torque is 12 Nm. Determine the followings-

a) Shaft power

b) Volumetric efficiency

c) Overall efficiency

Soln.

Shaft power	Ps	=	$\frac{2\pi N \tau}{60}$
		=	$\frac{2\pi x 1400 x 12}{60}$
		=	1759.3Nm
Theoretical flow rate	Qt	=	Nominal displacement x speed
		=	8.2 x 1400
		=	11480 cm^3/min
		=	$11480x10^{-6}m^3/min$
Actual flow rate	Qa	=	$10x10^{-3}$ m^3/min
Volumetric efficiency	η_{vol}	=	$\frac{Qa}{Qt}$ x 100
		=	$\frac{10x10-3}{11480x10-6}$ x 100
		=	87.1%
Now fluid power	P_f	=	Qa x Δp
	Qa	=	$10x10^{-3}$ m^3/min
		=	$\frac{10x10-3}{60}$ m^3/s
		=	$16.67x10^{-6}$ m^3/s
	Δp	=	680 N/m^2
		=	$680x10^5N/m^2$
	P_f	=	$16.67x10^{-6}x680$ $x10^5$ watts
		=	1133.5 watts

Overall efficiency	η_{ova}	=	$\frac{Pf}{Ps}x100$
		=	$\frac{16.67x10-6x680\,x105}{1759.3}x100$
		=	64.4%

Example 2

The pump is operating at a speed of 410 rpm and the pressure difference over the hydraulic pump is 82 bar. The nominal displacement is 5.2 cm^3/rev. The overall efficiency is 83% and the volumetric efficiency

Is 91% calculate the followings-

a) Theoretical flow rate

b) Actual flow rate

c) Fluid power

d) Shaft power

e) Torque transmitted

Soln.

Given

$N = 410$ rpm

$= 410/60$ rps

$= 6.83$ rps

Theoretical flow rate Qt = Nominal displacement x speed

$= 5.2 \times 6.83$

$= 35.51\ cm^3/s$

$= 35.51 \times 10^{-6} m^3/s$

Volumetric efficiency $\eta_{vol} = \frac{\text{Qa}}{\text{Qt}} \times 100$

$Qa = Qt \times \eta_{vol} / 100$

$= 35.51 \times 10^{-6} \times 91/100$

$= 32.3 \times 10^{-6}\ m^3/s$

Now fluid power $P_f = Qa \times \Delta p$

$Qa = 32.3 \times 10^{-6}\ m^3/s$

$\Delta p = 82\ N/m^2$

$= 82 \times 10^5 N/m^2$

$P_f = 32.3 \times 10^{-6} \times 82 \times 10^5$ watts

$= 264.86$ watts

Shaft power $Ps = \frac{2\pi N}{60}$

Overall efficiency $\eta_{ova} = \frac{\text{Pf}}{\text{Ps}} x100$

$Ps = Pf \times 100/h_{ova}$

$= 264.86 \times 100/83$

$= 319.1$ watts

$Ps = \frac{2\pi x410x}{60}$

$t = 319.1 \times 60/ 2\pi x410$ Nm

$= 7.43$ Nm

LESSON 21. Design of Reciprocating type of Pump

21.1 Introduction

Hydraulic systems are generally provided with positive displacement pumps. The piston sucks and pushes the same quantity (volume) of fluid every rotation of shaft .In these pumps there is hardly any slippage and the quantity of fluid pumped is nearly same for each rotation of shaft. Specially piston pumps exhibit this quality..

21.2 Design of Reciprocating type of Pump

In the reciprocating pump as the crank rotates the reciprocating motion transmit a liquid from a pump inlet to its outlet. When a piston moves to the, a partial vacuum is created which draws a liquid through an inlet valve into a cylinder. When a piston moves other way an inlet valve is closed and the fluid is forced out of a cylinder through an outlet valve.

Let us consider single acting reciprocating pump

Let D = diameter of cylinder

A = crosectional area

L = length of stroke

R = radius of crank

N = speed of crank

Qth = theoretical discharge

Qth = Ax LxN discharge per min

= Ax LxN/ 60 discharge per second

The ratio of actual discharge (Qac) to the theoretical discharge (Qth)is called discharge coefficient (c_d). But when discharge coefficient is expressed in percentage it is called as volumetric efficiency.

c_d = \[\frac{{{\text{Qac}}}}{{{\text{Qth}}}}\]

Slip

It can be defined as the difference between the theoretical discharge and the actual discharge. If S' is the slip,

then

$$S' = (Qth - Qac)$$

Percentage slip can be given as-

S = [1 - \[\frac{{{\text{Qac}}}}{{{\text{Qth}}}}\]] x 100

Work done and Power Requirement of Reciprocating Pump

It can be defined as the product of of weight fluid lifted and the total height through which it has been lifted .

Let W = work done / s

w = weight of fluid lifted

H = Total height of fluid lifted

Q = discharge of pump

$$W = w \times Q \times H$$

$$H = (hs + hd)$$

hs = suction head

hd = delivery head

Example

A reciprocating pump is having diameter of piston 260 mm with stroke length of 510 mm operating at a speed of 32 rpm delivers 0.0125 m^3/ s of fluid.Calculate the followings-

a) Theoretical discharge of pump

b) Coefficient of discharge

c) Slip

d) Percentage slip

Soln

Given

diameter of piston D = 260 mm = 0.26 m

stroke length of L = 510 mm =0.51 m

actual discharge Q_{ac} = 0.0125 m^3/s

Speed of pump N = 32 rpm

$Qth = A \times L \times N / 60$

$A = \frac{\pi D^2}{4}$

$= \frac{\pi (0.26)^2}{4}$

$= 0.053\ m^2$

Now $Qth = 0.053 \times 0.51 \times 32 / 60$

= 0.0144 m^3/s

Coefficient of discharge $c_d = \frac{\text{Qac}}{\text{Qth}}$

$= \frac{0.0125}{0.0144}$

= 0.868

= 86.8%

Slip S' = (Qth - Qac)

= (().0144 – 0.0125)

= 0.0019 m^3/s

Slip % $S = [\ 1 - \frac{\text{Qac}}{\text{Qth}}\ ] \times 100$

$= [\ 1 - \frac{0.0125}{0.0144}\ ] \times 100$

= 13.1 %

LESSON 22. Design of Vane Pump

22.1 Introduction

Vane pumps are the rotary type of pump which are fitted in the hydraulic systems. In these pumps there is hardly any slippage and the quantity of fluid pumped is nearly same for each rotation of shaft. These are generally positive displacement pumps

22.2 Design of Gear Pump

Gear pump consists of a driving gear and a driven gear enclosed in a closely fitted housing. The gears rotate in opposite directions . Both sets of teeth project outward from the center of the gears. As the teeth of the two gears separate, a partial vacuum forms and draws liquid through an inlet port . Liquid is trapped between the teeth of the two gears and the housing so that it is carried and a force is developed which drives a liquid through an outlet port. Volume of fluid can be calculated as-

Volume of fluid

Let V = volume of fluid

D_1 = outer diameter of gear teeth

D_2 = inner diameter of gear teeth

N = speed of pump (rpm)

w = gear teeth width

Therefore volume displaced in one revolution $V = \frac{\pi}{4}(D_1^2 - D_2^2) \times w$

Discharge of pump

Discharge per sec . $Q = V \times N$

Efficiency

Efficiency $\eta = \frac{Qa}{Qt} \times 100$

Qa = actual discharge

Qt = theoretical discharge

22.3 Vane Pump Design Calculations

The rotary vane pump is consisted of rotor and stator**.** The stator is the stationary enclosure in which the rotor rotates. The rotor is mounted with eccentric and therefore the rotor makes contact with the stator at the top of the stator between the inlet and the outlet. This point is called the contact point and is actually in close contact separated only by a thin film of oil. The sliding vanes move in and out of the rotor, making contact with the stator surface. The vanes can be spring-loaded or slide by centrifugal force. These are high volume pumps which can pump at higher pressures .When the rotor rotates within the stator , at the inlet of the pump one of the ffallows the fluid to to enter the pump. As it enters inside the pump, the fluid is trapped between the rotor vanes and the stator during rotation, it is pushed out through the outlet of the pump.

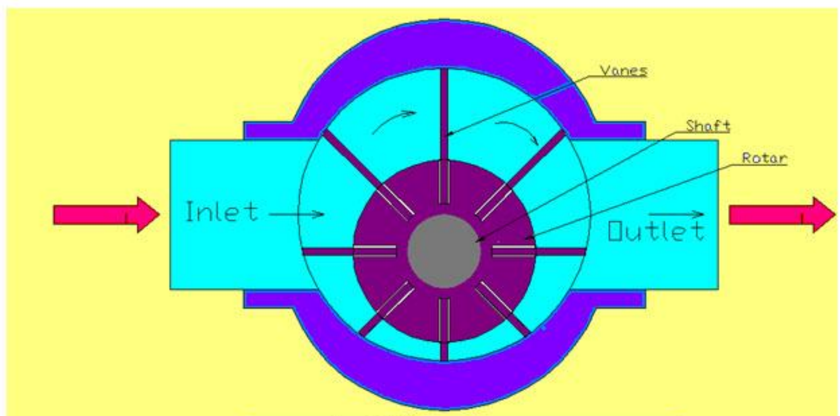


Fig. 20.1: Vane type pump

22.4 Volumetric Displacement

It can be defined as the product of area and width of rotar. It can be given as-

Let Dc = diameter of cam ring/stator

Dr = diameter of rotor

e = eccentricity

N = speed (rpm)

w = width of rotor

Maximum eccentricity can be given as

$e_{max} = \frac{Dc - Dr}{2}$

Now volumetric displacement will be- $A = \pi r^2$

$Vd = \frac{\pi}{4}(Dc^2 - Dr^2) \times w$

$= \frac{\pi}{4}(Dc - Dr)(Dc + Dr) \times w$

$$= \frac{\pi }{4}(Dc + D{r^2}) \text{ x } 2e_{max} \text{ x } w$$

$$= \frac{\pi }{4}(Dc + D{r^2}) \text{ x } e_{max} \text{ x } w$$

22.5 Cavitation

Pump cavitation is the formation and subsequent collapse of vapor bubbles in a pump. It occurs when the absolute pressure on the liquid falls below the liquid vapor pressure. When the vapor bubbles collapse with high frequency, it sounds like marbles are moving through the pump. It causes wear and tear and damage to the pump.

22.6 Aeration

Aeration is the presence of air in the hydraulic fluid . It causes the fluid to appear milky and components are to operating erratically. It is because of the compressibility of trapped air in the fluid.

MODULE 4.

LESSON 23. Hydraulic actuators and cylinders

Introduction

Hydraulic actuator are the devices which receives pressure energy and converts it to mechanical output in the form of force and motion. An actuator can be linear or rotary. A linear actuator gives force and motion outputs in a straight line. It is commonly known as a cylinder but is also referred to as a ram or linear motor. A rotary actuator produces torque and rotating motion. It is called a hydraulic motor or simply motor.

In the hydraulic systems pump is utilized to make the flow of the fluid and valves are utilized to the flow of fluid , pressure in the circuit or direction of flow. Whereas, the actual purpose is achieved with the help of actuators. The actuators are converting the hydraulic fluid energy into useful work or mechanical output. There are two basic types of hydraulic cylinders-

- single-acting cylinder and
- double-acting cylinder

Single Acting cylinder

This type of cylinder is consists of a tube, sealed at both the ends and a piston along with piston rod which moves in the cylinder linearly in the tube. The fluid leakjage if any out of the cylinder is controlled by seals. When oil is pumped into the cylinder, it pushes the piston and the extend of piston takes place. To return or retract a cylinder, oil must be braught back to the reservoir.

In the single acting cylinder a piston returns either because of the weight of a load or from some mechanical force like a spring.

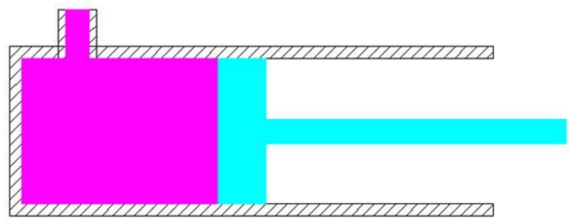


Fig.21.1: Single acting cylinder

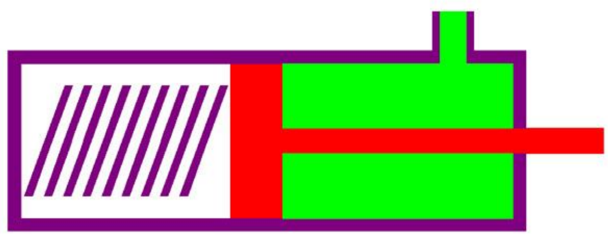


Fig.21.1: Single acting cylinder with spring

Double Acting Cylinder

The double acting cylinder can hydraulically actuated or moved in both the directions with the help of fluid which is not in the single cylinder cylinders. As the oil is pumped into the head end of the piston it moves the piston to extend. The oil in the rod end is pushed out and returned to the reservoir. To retract a rod, flow is reversed. Hence oil from a pump goes into a rod end, and the oil from head end is connected to allow return flow.

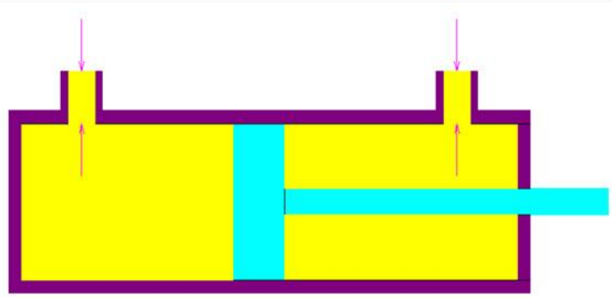


Fig.21.3: Double acting cylinder

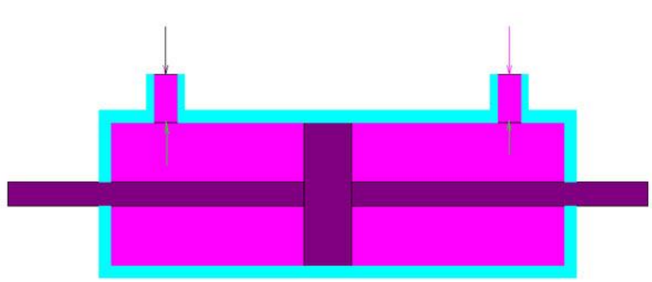


Fig.21.4: Double acting cylinder with two rods

Baics of cylinder actuator

Force

The hydraulic fluid pushes the piston and applies a force over it which can be given as

$$F = p \times A$$

Where F = force, N

p = pressure, N/m^2

A = correctional area, m^2

It is assumed here that other side of piston is having negligible pressure.If pressure is acting on the rod side then it can be given as-

$$F = p \times (A - a)$$

a = rod area

Piston Speed

Piston speed is commonly based on the flow rate of fluid, hence at piston side

$Q = A \times v \quad m^3/s$

Q = flow rate, m^3/s

A = crossectional area, m^2

v = velocity m/s

Flow rate at rod end $Q = (A - a) \times v \quad m^3/s$

Piston power

It can be defined as the product of force and velocity, which can be given as-

$P = F \times v$ watts

Where F = force, N

v = velocity, m / s

Example :

A single acting cylinder has piston diameter of 70 mm and is having a fluid flow rate of

$0.2 \times 10^{-3} m^3/s$, with applied pressure of $1.5 \times 10^6\ N/m^2$calculate the followings

a) thrust force

b) velocity

c) power

Soln:

Given D = 70 mm

Q = $0.2 \times 10^{-3} m^3/s$

p = $1.5 \times 10^6 N/m^2$

0.07

A = $\frac{\pi D^2}{4}$

= $\frac{\pi (0.07)^2}{4}$

= $0.0038 m^2$

F = p x A

= $1.5 \times 10^6 \times 0.0038$

= 5772.6 N

= **5.77 kN**

Q = A x v m^3/s

0.20×10^{-3} = $0.0038 \times v$

v = $\frac{0.20 \text{x} 10^{-3}}{0.0038}$

= **0.0526 m/s**

P = F x v

= 5772.6 x 0.0526

= **303.8 watts**

Example 2 :

In a double acting hydraulic cylinder the push force produced is 12.1 kN with available flow rate at both the directions of $0.2 \times 10^{-3} m^3/s$. The bore of the cylinder is 98 mm with stroke of 125 mm. and the rod diameter is 40 mm. Calculate the followings-

a) pressure of the system

b) force required to pull

c) speed in outward stroke

d) Speed in inward stroke

e) power in inward stroke

Soln. :

Given $F = 12.1$ kN

$= 12100$ N

$Q = 0.2 \times 10^{-3}$ m^3/s

D **=** 98 mm

$= 0.098$m

$A = \frac{{\pi {D^2}}}{4}$

$= \frac{{\pi {{\left({0.098} \right)}^2}}}{4}$

$= 0.0075$ m^2

$L = 125$ mm

$d = 40$mm

$= 0.04$ m

$a = \frac{{\pi {D^2}}}{4}$

$= \frac{{\pi {{\left({0.04} \right)}^2}}}{4}$

$= 0.0012$ m^2

Pressure $p = F/A$

$= \frac{{12100}}{{0.0075}}$

$= 1.61 \times 10^6$ N/m^2

Pulling force $F = p\ (A - a)$

$= 1.61 \times 10^6\ (0.0075 - 0.0012)$

$= 10164$ N

speed in outward stroke = Q/A

= $$\frac{{0.2x10 - 3}}{{0.0075}}$$

= 0.0266 m/s

speed in outward stroke = Q/ (A – a)

= $$\frac{{0.2x10 - 3}}{{\left({0.0075 - 0.0012} \right)}}$$

= 0.031 m/s

Power P = pxQ

= $1.61x10^{6}x0.2x10^{-3}$

= 322 N

LESSON 24. Construction Application Maintenance of Linear Actuators

Introduction

Linear actuator are the devices which receives pressure energy and converts it to mechanical output in the form of force and motion. A linear actuator gives force and motion outputs in a straight line. It is commonly known as a cylinder but is also referred to as a ram or linear motor. In the hydraulic systems, pump is utilized to make the flow of the fluid and valves are utilized to the flow of fluid , pressure in the circuit or direction of flow. Whereas, the actual purpose is achieved with the help of actuators. The actuators are converting the hydraulic fluid energy into useful work or mechanical output. This may be single-acting cylinder or double-acting cylinder.

Construction

The cylinder are generally constructed of cold drawn steel barrel or tube. The piston and rod are chrome plated and polished. Two end caps, and suitable oil seals are used to prevent leakages. A barrel is usually seamless steel tubing,or cast, and the interior is kept highly finished and very smooth. A steel piston rod is highly polished and usually hard chrome-plated to resist scoring. .

The end caps are screwed on to the tube, welded, attached by tie bolts or bolted flanges. If the cylinder barrel is cast, the head-end cap may be integral with it. Seals are provided in the rod end cap to keep the rod clean and to prevent

Application

Hydraulic systems have many requirements and therefore actuating cylinders are available in different shapes and sizes. A cylinder type actuator is versatile and may be the most trouble-free component of a hydraulic systems. A cylinder and a mechanical member of a unit to be actuated is required to be aligned properly. Any misalignment will cause excessive wear of a piston, a piston rod, and the seals etc.

- Single-acting cylinders are used wherever hydraulic power is required for only one direction of motion. For example lifting, clamping and lowering work piece, in hydraulic lifts, lifting platforms and lowering and raising of implement in hydraulic lift of a tractor.

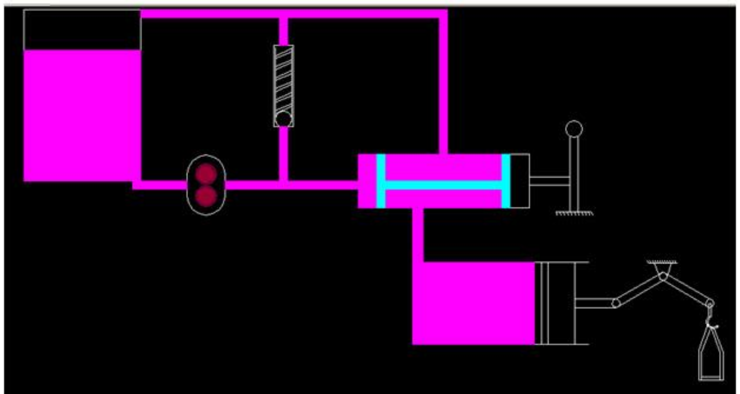


Fig.22.1: Hydraulic lift with single acting cylinder

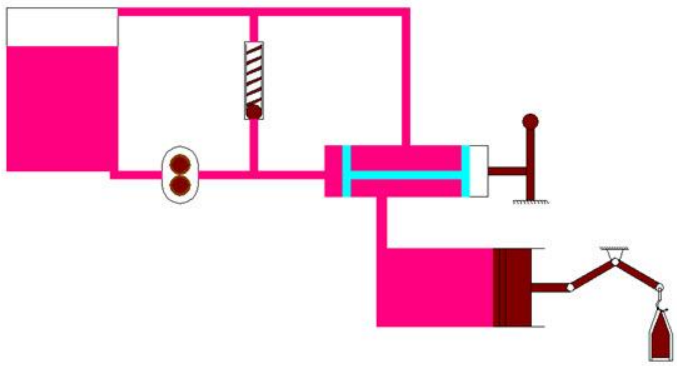


Fig.22.1: Hydraulic lift with single acting cylinder

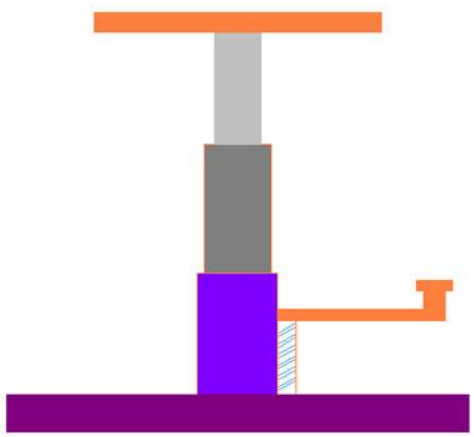
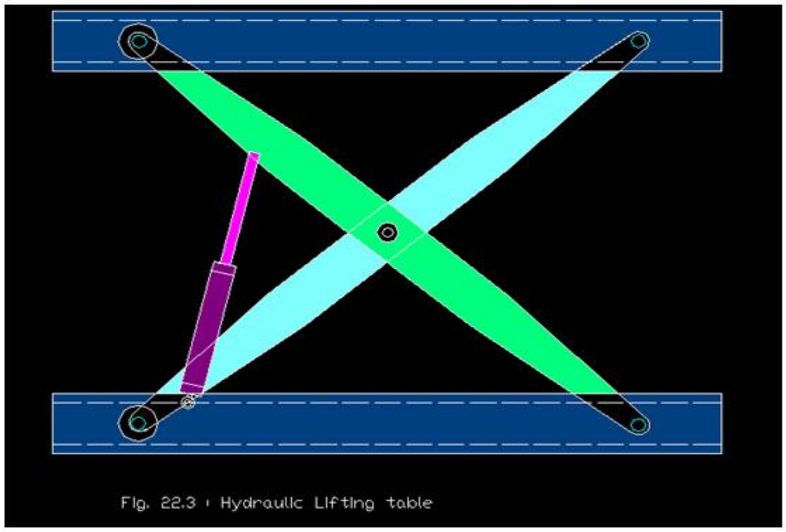


Fig.22.2: Hydraulic work peice lift

Mounting of cylinder

vertical mounting

when the return movement of the piston is brought with the help of external forces like lifting table



Lifting table

horizontal mounting

It is done in single-acting cylinders with spring-return. Like in hydraulic presses

Double Acting Cylinder

The movements generated by hydraulic cylinders are used for the followings-

Machine tools

- Feed movements for tools or work piece
- Clamping devices
- Movements on presses
- Movements on printing and injection moulding machines, etc.

Handling devices

- Lifting and lowering in fork-lift etc.

Moving equipment

- Excavators
- Loaders
- Tractors
- Tipper trucks

Maintenance of Linear Actuators

The linear actuators are the hydraulic cylinders, which are compact and simple in design. The seals and pivots are important to be considered. The following points are required to be viewed in maintaining cylinders-

External Leakage :

If a cylinder's end caps are leaking, tighten them. If the leaks still do not stop, replace the gasket. If a cylinder leaks around a piston rod, replace the packing.

Internal Leakage :

If the leakage ocure after the piston seals inside a cylinder can cause sluggish movement . Piston leakage can be caused by worn piston seals or rings. Therefore replace all the seals and packings.

Creeping Cylinder :

If a cylinder creeps when stopped in midstroke, check for internal leakage

Sluggish Operation :

Some times air comes in a cylinder and cause the sluggish operation. Internal leakage in a cylinder is another cause. If sluggish operation there, check for oil of too high a viscosity or check for other, etc.

Loose Mounting :

If pivot points and mounts are loose, the bolts or pins are needed to be tightened.

Periodically check all the cylinders for loose mountings.

Misalignment :

Piston rods are required to work in line . If it is not so, the piston rods may be bent or get damaged. Hence go for proper alignment

Rotary actuators

Hydraulic actuators are the muscles of many machines. They are produced in varying sizes from miniature units to massive actuators. A rotary actuator is a device that produces a rotary motion or torque. The motion developed by an actuator may be either continuous rotation or an angular rotation..It basically transforms the hydraulic energy into rotary energy in the form of mechanical rotations which can be applied to the an object with the help of a shaft. These are also called hydraulic motors.

MODULE 5.

LESSON 25. Hydraulic motors

Introduction

Hydraulic motors are the devices which receives pressure energy and converts it to mechanical output in the form of motion or rotation. These are rotary actuators. A rotary actuator produces torque and rotating motion is called a hydraulic motor or simply motor. Hydraulic actuators are the muscles of many machines. They are produced in varying sizes from miniature units to massive actuators. A rotary actuator is a device that produces a rotary motion or torque. The motion developed by an actuator may be either continuous rotation or an angular rotation..It basically transforms the hydraulic energy into rotary energy in the form of mechanical rotations which can be applied to an object with the help of a shaft.

Hydraulic Motors

A hydraulic motor is a device which converts the flow of a liquid under pressure into rotational motion. It is similar in construction to a hydraulic pump. Instead of mechanical parts are moved and fluid is pushed , high-pressure fluid pushes the mechanical parts, causing them to move. The rotary motors are provided in the hydraulic systems to convert the fluid power into shaft power by forcing the shaft to rotate .When fluid pushed is at faster speed , the shaft speed is more and vise versa. Basically there are three types of hydraulic motors, like- gear, vane and piston.

Gear Motor

The gear motor is consist of two meshed gears in a housing, with inlet and outlet pipes on opposite sides. Both gears are driven gears, but only one is connected to the output shaft. Its working is reverse of a gear pump. Fluid at high pressure is injected into the housing, where it flows , between the gear teeth and the housing wall. Similar to the gear pump gears in gear motor are closely fitted into the housing. This forces the gears to rotate. The meshing teeth of gears prevent the fluid from flowing back, and results in continuous rotations. This rotary motion is then available in the form of rotary work at the output shaft. The direction of motion can be reversed by changing the direction of fluid through the motor.

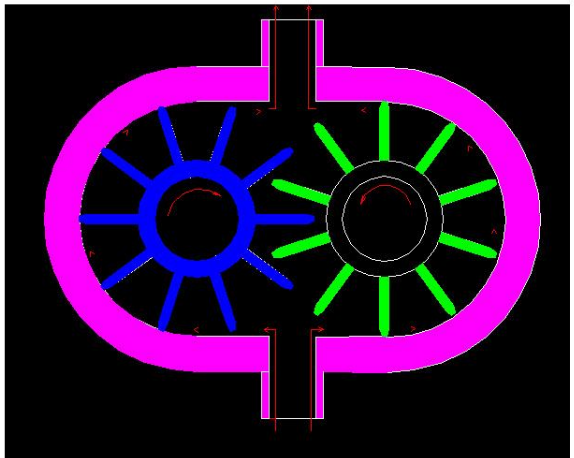


Fig. 23.1: Gear type motor

Vane Type motor

This type of motor is a positive displacement motor. Vane motors is having a single rotor with vanes sticking at the housing wall of motor. The inlet and outlet pipes are located on opposite sides of the motor. The fluid flow from the pump enters the inlet of the motor and forces the rotor and vanes to rotate, and passes out through the outlet pipe. As motor rotate it causes the output shaft to rotate . As the vane is near to inlet pipe, it get rotated due to fluid and a tight seal is created .The seal is loosening and letting the fluid flow from the outlet pipe of the housing of the motor. Since the fluid is always pushing against the vanes tangentially, the rotor is rotated by the fluid pressure.

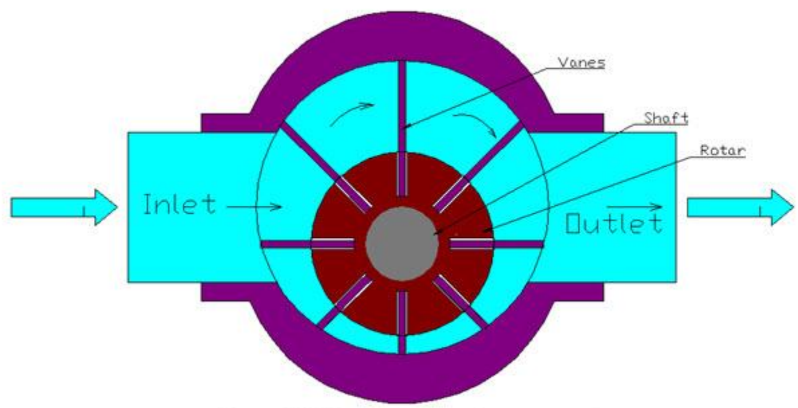


Fig. 23.2: Vane type motor

Piston Motors

This type of motor is a positive displacement motor which can develop torque at shaft with the help of pressure of the fluid. It may be of following three types

- In line piston
- Axial piston
- Radial piston

Axial piston

This type of motor consists of a cylinder fitted with a number of pistons. As the fluid is forced into the cylinder barrel with pressure, the pistons forced outward against an angled plate. By pushing on the plate at an angle, the pistons rotate the plate and generate torque. Y In this manner fluid energy is converted into rotary output .

Radial piston

Radial piston motors are best suited for low speed high torque applications, like in winches. Radial piston motors are designed in in varying capacities ranging from 20 to 10,000 cm^3/rev at higher pressures like $450x10^5 N/m^2$ or so. In radial piston motor the pistons are connected to a shaft with the help of crank . The pump flow into the cylinder forces the piston to reciprocate and rotate the shaft. In this way a high power and torque is produced.

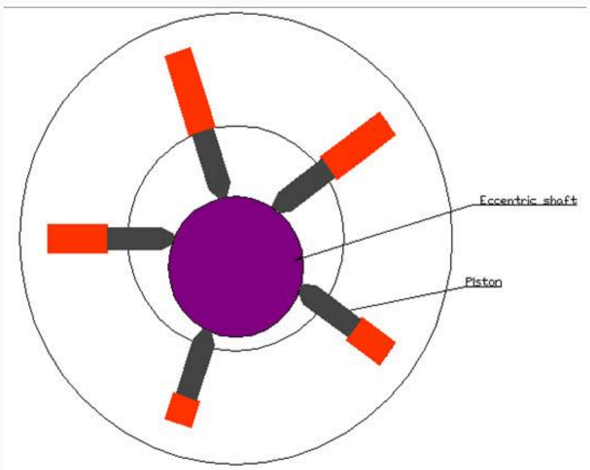


Fig.23.3: Radial piston motor

Points to be considered while choosing a hydraulic motor

- Torque needed
- Working pressure of the hydraulic system
- Speed required
- Size of fly wheel required
- Heat generated if any

Calculations in Motor

Motor Power

It is the output power of motor shaft which can be defined as the product of shaft torque and speed .

$$P_s = \frac{2\pi N}{60}$$

where N = speed (rpm)

τ = torque

Fluid Power Calculations

It can be defined as the energy per second by the fluid in the form of pressure and the quantity of fluid. It is product of fluid quantity (flow rate) and the differential pressure. Hence

$$P_f = Q \times \Delta p$$

Where P_f = Fluid power

Q = flow rate , m^3/s

Dp = differential pressure, N/m^2

Overall Efficiency

It can be defined as the ratio of output power to the input power or shaft power to the fluid power, which can be given as-

$$\eta_{ova} = \frac{\text{output power}}{\text{input power}} x100$$

$$\eta_{ova} = \frac{\text{Shaftpower}}{\text{Fluidpower}} x100$$

$$\eta_{ova} = \frac{\text{Ps}}{\text{Pf}} x100$$

Where

η_{ova} = overall efficiency

P_f = Fluid power

P_s = Shaft power

Speed and Flow Rate

The flow rate and speed can be given as-

Flow rate Q = K_q x speed

Where K_q = Nominal displacement of motor, cm^3/rev

Torque and Pressure

Let motor be 100% efficient, then the shaft power will be equals to fluid power.

Therefore,

Shaft power = Fluid power

$P_s = P_f$

$\frac{2\pi N}{60} = Q \times Dp$

$\tau = \frac{Q \times p \times 60}{2\pi N}$

Volumetric Efficiency

It can be defined as the ratio of theoretical flow rate to the actual flow rate of fluid.

Let

Q_a = actual flow rate

Q_t = theoretical flow rate

η_{vol} = volumetric efficiency

$\eta_{vol} = \frac{Q_t}{Q_a} \times 100$

Example

A hydraulic motor is running at a speed of 395 rpm with the differential pressure of 8.2×10^6 N/m^2. The nominal displacement is 5 cm^3/rev and the overall efficiency and volumetric efficiency of 86 and 89% respectively. Calculate the followings-

a) Theoretical flow rate

b) Actual flow rate

c) Fluid power

d) Shaft power

e) Torque of shaft

Soln.

Given N = 395 rpm

Δp = 8.2×10^6 N/m^2

η_{ova} = 86%

η_v = 89%

K_q = 5cm^3/rev

$= 5 \times 10^{-6} m^3/rev$

Theoretical flow rate $Q_t = K_q \times N$

$= 5 \times 10^{-6} \times 395/60$

$= \mathbf{3.29 \times 10^{-5}\ m^3/s}$

$$\eta_{vol} = \frac{Q_t}{Q_a} \times 100$$

$$Q_a = \frac{Q_t}{\eta_{vol}} \times 100$$

$$= \frac{3.29 \times 10^{-5}}{89} \times 100$$

$= \mathbf{3.69 \times 10^{-5}\ m^3/s}$

Fluid power $P_f = Q \times \Delta p$

$= 3.69 \times 10^{-5} \times 8.2 \times 10^{6}$

$= 303.27\ Nm/s$

$= \mathbf{303.27\ watt}$

Shaft Power $\eta_{ova} = \frac{P_s}{P_f} \times 100$

$P_s = 86 \times 303.27/100$

$= 260.8$ watt

Shaft Torque

$$P_s = \frac{2\pi N}{60}$$

$$\tau = \frac{P_s \times 60}{2\pi N}$$

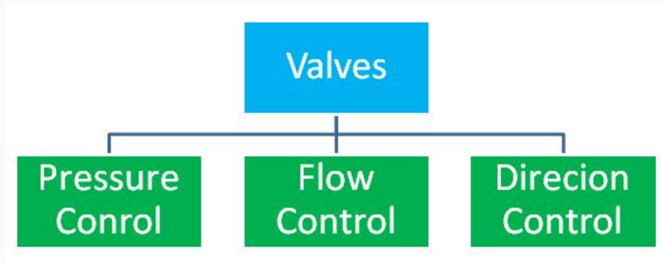
$$= \frac{260.8 \times 60}{2 \times \pi \times 395}$$

$= \mathbf{6.3\ Nm}$

LESSON 26. Valves pressure control valves, Direction control valves, Flow control valves

Introduction

In the hydraulic systems valves play an important role. These are necessary to control the pressure, flow rate and the direction of flow in the circuit. These are generally made with high standards, strong materials and with precision. These valves can be operated manually, hydraulically, pneumatically or electrically. It can be classified as-



Pressure Control valves

This type of valves are used to control the pressure of hydraulic system or circuit and called pressure control valves. It includes pressure reducing valve, pressure relief vale etc.

Pressure relief valve

This type of valves are utilized to limit the maximum operating pressure in the circuit. These are also called safety valves and protects the pump and other components from overloading, etc. Pressure relief valve is provided in the circuit such that one port is connected to the pressure line and the other port is connected to the the reservoir. There is a ball which is held on its seat with the spring force. The spring force can be changed by rotating the adjusting screw. When the circuit pressure at the valve inlet is less than the spring pressure , the ball remains on its seat and the valve is closed and no flow takes place through it. As the pressure in the circuit exceeds the adjusted spring force, the ball is forced off its seat and the valve is opened. Now the liquid flows from the pressure line through the valve to the reservoir. This diversion of flow continue till the. pressure decreases below the valve setting and hence the spring reseats the ball and the valve is again closed. In this way it prevents circuit and provide the safety.

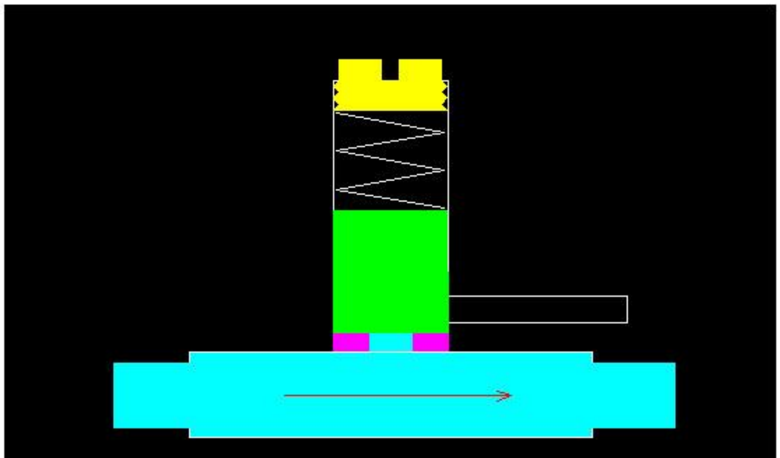


Fig. 24.1 : Pressure relief valve

Pressure reducing valve

Pressure reducing valves are used to reduce the output pressure which is part of circuit from rest of circuit . It generally limits the pressure in a branch circuit at lesser value than the required in the main circuit. If in a hydraulic system, a branch circuit is required to be limited to a pressure of 200 N/cm^2, but the main circuit is to be operated at a pressure of 600 N/cm^2. Therefore, a relief valve in a main circuit will be kept at a pressure setting above 600 N/cm^2 to meet the main circuit requirements. Therefore, in the branch circuit a pressure reducing valve will be provided to keep the pressure at 200 N/cm^2 It is normally a open valve rather than closed as in relief valve. As the liquid from the main circuit enters the valve at the inlet port it flows and enters the branch circuit through the outlet port .The fluid bleeds to the tank through the valve drain passage, pressure will start reducing . This result in a reduced pressure equal to the setting of the valve.

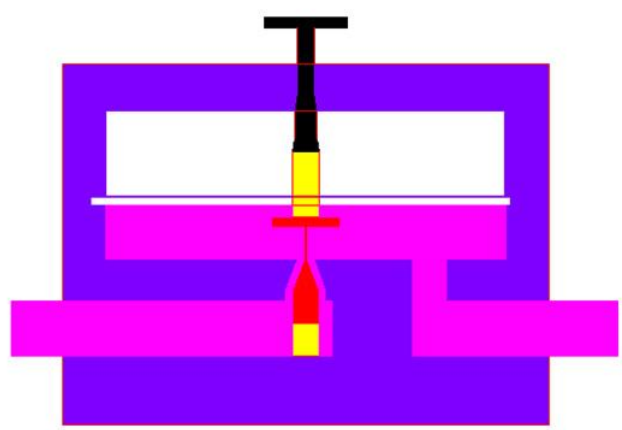


Fig. 24.2 : Pressure reducing valve

Flow Control valves

Flow control valves are those which are used to control the flow rate of the fluid in the circuit and also called volume control valves, like needle valve, globe valve, gate valve, etc. Flow-control valves are generally used to control the speed of hydraulic motors or actuators in work spindles and the travel rates of tool heads, etc. Flow control valves keeps uniform flow rate in the circuit with the help of pressure compensator. A non pressure, compensated flow control, like in needle valve etc., there may be changes in the flow rate.

Needle valve

Needle valves are generally designated as non-compensated flow control or throttling valves. They are good metering devices when the pressure differential across the valve remains constant. This type of valve is used in the hydraulic system where there is no need of precise speed control because the flow may vary with pressure difference. A needle valve and globe valve are similar in design and operation . In this type of valve there is a long, tapered point at the end of a valve stem which can be raised or lowered to control the flow through it. A long taper allows a needle valve to open or close gradually. A needle valve is used to control flow at points where a small flow rate is desired or at other points where precise flow is required.

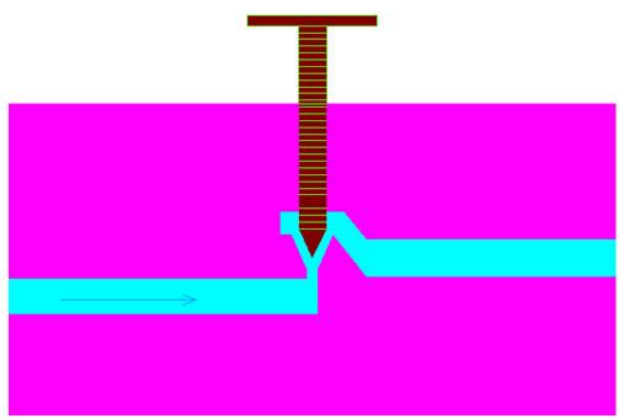


Fig. 24.3 : Needle valve

Globe Valve

In the globe valve there is a disc, which is attached to the end of the stem which controls flow of fluid through the valve. The valve is closed by lowering a disc into a valve seat and opened by raising it off the seat. Since fluid flows equally on all sides when a valve is open, there is no unbalanced pressure on a disc to cause uneven wear.

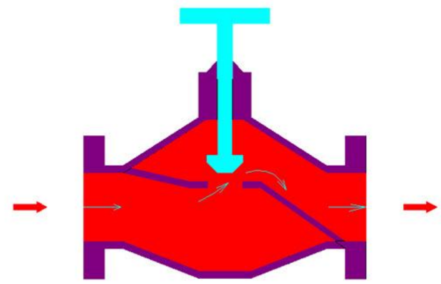


Fig. 24.4 : Globe valve

Gate Valve

This type of valves are normally used to allow or prevent the flow of liquids and also used for regulating the flow of fluid. In this type of valve there is a wedge or sort of gate which controls the flow. Opening and closing of a passage is done with the help of a hand wheel, which moves a wedge or gate up and down across a flow line. The gate valve is provided with good sealing surfaces between the gate and seats. As the valve is opened, the gate moves up within the bonnet and as it is closed, the gate blocks the flow by coming across the line where it rests firmly against the seats. The gate valve permits the flow and offers small or no resistance to the fluid flow when the valve is fully open. But if it is in the partially open it restrict the flow rate through the circuit.

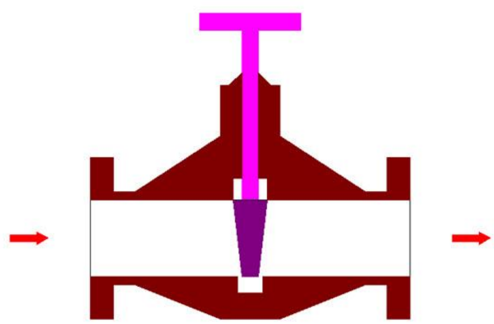


Fig. 24.5 : Gate valve

Direction Control valves

Those valves which are use to give a particular direction to the fluid in the circuit are called direction Control valves, like spool valve.

Spool valve

Spool valve is a valve which controls the direction of hydraulic fluid flow. It consists of cylindrical spools which can block and open the channels in the hydraulic system. A spool valve can change the direction of flow of hydraulic fluid from a hydraulic pump to an actuator by blocking off the route of the fluid through which it takes place.

Spool valve is consists of a spool which can move in the body of the valve and may have four or five ports. As in the figure below, a three way spool valve connected to an actuator of cylinder type. The fluid is applied to the port P of the valve and C of the cylinder, whereas, port T of the valve is connected to drain or return to the tank. Port A of the valve is connected to the B of the cylinder. Now if the spool is moved to right side with the help of lever, the high pressure fluid flows from port A and B. The moves to right due to pressre of fluid and displacing the fluid through port C and P.Now if the spool is moved to left, high pressure fluid comes into the cylinder through port C, and the piston moves to left causing the fluid into the tank via port B and A and T.

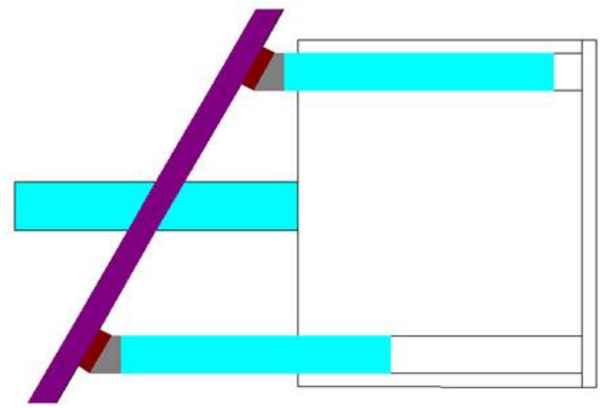


Fig.17.8: Axial plunger pump

Sequence valve

It is also a sort of direction control valve which gives the sequence of operation in the hydraulic circuit. It gives entire fluid to one of the circuit until pump delivery exceeds the requirement

of that particular circuit and then extra fluid is made available to other circuits. This type of valve is very much of use in the machine tool operation. One of the outlet port is open and the and is utilized for clamping of work piece. After completing this operation fluid pressure builts up and forces the spool to move against the spring force and allowing the fluid to flow through port 2 to actuate main actuator for tooling of work piece.

LESSON 27. Hydraulic Valve installation, Valve failures and remedies, valve assembly, Troubleshooting

Introduction

Hydraulic valves are necessarily required to control the pressure, flow rate and the direction of flow in the circuit. These are generally made with high standards, strong materials and with precision. In the hydraulic systems valves play an important role. These valves can be operated manually, hydraulically, pneumatically or electrically.

Valve installation

Hydraulic valve is a device in a hydraulic system or equipment which gives better control of the fluid flowing through the lines and pumps. There are various types of hydraulic valves like flow control, pressure control and directional control valves. A flow-control valve meters the flow in one direction only, and hence the inlet and outlet ports are required to be connected correctly. The drain connection of valve should be connected to tank to avoid pressure surges if any. The location of a flow-control valve with respect to workload should be proper. The basic types of flow-control valve installations are

- Meter-in circuit - In this type of circuit flow control valve is installed in pressure line.
- Meter-out circuit – In a meter-out circuit, a flow-control valve is installed on the return side of a cylinder to control cylinder actuation by metering its discharge.
- Bleed off circuit – In general bleed-off circuit is not installed directly in a feed line.

Valve failures, remedies and troubleshooting

Hydraulic valves are manufactured with precision and are required to be as accurate as possible to control pressure of fluid , direction, and flow in the hydraulic system. Valve failures are normally due to contamination in the hydraulic fluid . Small amounts of dust, dirt, rust, or sludge may cause improper functioning of valve parts and may lead in leakages in the valve.

Possible causes their remedies in the valve

Source of trouble	Causes	Remedies
Excessive noise	a) Valve chatter due to dust or dirt b) Flow noises during operation c) Wrong design	Clean the valve Check for noise Redesign

Inadequate power	a) Operating pressure set too low b) Internal leakages c) damaged valve seat	Reset pressure Remove leakages Correct the valve seat
Excessive temperature	a) constant flow is low b) pressure setting too high	Make more constant flow Make proper pressure setting
Jerky motor or cylinder movement	a) Valve chatter due to dust or dirt b) Non suitable remote control valve	Clean the valve Have suitable valve

valve assembly

The following points are to be considered while assembling of the valves-

- Wash the parts of valve in kerosene
- Blow the air to dry them and then dip in hydraulic oil with rust inhibitor to prevent rusting.
- Make sure that valve mating surfaces are free of burrs and paint.
- Replace all the seals and gaskets when repairing a valve assembly.
- Soak the new seals and gaskets in clean hydraulic oil before assembling.
- Make sure to assemble a valve sections in their correct order.
- Check for distortion if any while mounting valves.
- Make sure that spool of valve is working properly

MODULE 6.

Lesson 28 Hydraulic circuit diagrams and troubleshooting

Introduction

Hydraulic systems is consisted of a number of components which work closely together to get desired performance which may be pressure control, flow control direction control or miscellaneous functions. A family of graphic symbols has been developed to represent fluid power components and systems on schematic drawings. Hydraulic-circuit diagrams are complete drawings of a hydraulic circuit. It includes the description, a sequence of operations, notes, and a components list. Such diagrams are essentially required by the designers, the machine makers and mechanics to repair it.

Hydraulic Circuit Diagrams

The circuit diagrams are used in hydraulics to show the components along with their interaction. It a useful tool for the manufacturers and assemblers so that they can come to know how the components are to be connected. Mechanics or technicians will be helped with it, that how the system works, what each component does and what is the flow of the fluid . It helps them in repairing and also in maintenance of the system. There are various types of hydraulic circuit diagrams which are as follows-

Block Diagram

This type of diagram indicates the various components and the lines between the blocks, which indicate connections and/or interactions.

Cutaway Diagram

This type of diagram indicates the internal construction of the components along with the flow paths. This diagram uses colors, shades, or various patterns in the lines thus it can depict the flow and pressure conditions.

Pictorial Diagram

This type of diagram indicates a circuit piping arrangement. The components are usually having similarity of their actual shapes and sizes.

Graphical Diagram

This type of diagram indicates is usually preferred for design and troubleshooting. It uses simple geometric symbols for various components and their controls and connections.

Troubleshooting in hydraulic system

Troubleshooting procedure is required to be performed in a proper manner so that no component is being changed illogically. Hence systematic approach for correcting a hydraulic problem is a must in the hydraulic circuits. Before starting any troubleshooting operations get informed about the problem. Make out the possible causes and their suitable remedies of different hydraulic problems occurred during hydraulic system operation. Take care to check that the proper drawings and diagrams are always available of the system or circuit .A convenient table is given for probable cause and suitable remedies-

Fault	Probable causes	Remedies
Noisy Pump	Hydraulic pump may have cavitations and taking air into the system.	Remove cavitations
	Low fluidl level	Fill fluid
	To heavy of flud	Use light fluid
	Cold fluid	Raise temperature
	Suction filter clogged	Clean it
Fluid does not come	Fluid level in the reservoir is low.	Add the recommended fluid
	Fluid inlet hose or inlet filter is clogged	Clean the filter
	Air leak in the inlet line prevents priming	Repair the leaks
	The viscosity of fluid is too high	Use a lighter oil viscosity
	Pump has dirt in it	Clean the pump
Overheating of fluid	Contaminants present in relief valve	
	Viscosity is low	
	fan not running	
	Dirty oil	
	Low fluid level	
	Excessive pump wear	
Low pressure in the	Air in the fluid e	Fill the tank nearly full or

system		recommended level
	Pressure relief valve set too low	Reset valve
	Defective or worn out pump /actuator	Repair or replace pump / actuator
	Pressure relief valve not properly seated	Rectified, adjust the relief valve.
	Leak in the hydraulic line	Tighten leaky connections.
Foaming of fluid or air in the fluid	Air leak in hydraulic pump suction side	Tighten leaky connection
	fluid level low	Fill fluid
	Wrong fluid put in tank	Use proper fluid
	Pump shaft seals or access plates could be drawing air into the system	Check for leakage
Excessive Wear	Viscosity of fluid is too low .	Use appropriate recommended fluid
	High pressure occurs above the maximum pump rating	Check the relief
	Misaligned in the drive or belt drive is tight	Check the parts and rectify the problem.
	Air recirculation is causing a chatter in the system	Remove the air from the system
	Abrasive matter in the hydraulic oil is being circulated	Put a proper filter to check dust particles
Control valve sticky or working hard	Misalignment in control valve	Align it
	Valve is broken	Repair or replace it

Lesson 29 United States of American Standards institute (USASI) Graphical symbols

Introduction

Schematic symbols are used to identify and graphically depict the function of fluid power components. Recognizing and understanding schematic symbols will enable us to know about the circuit functioning. The United States of American Standards Institute (USASI), the old American Standards Association (ASA), and the Joint Industry Conference (JIC) are three systems of symbols used in circuit diagrams.

Reservoir

It is represented by a rectangle in which horizontal side is kept longer than the other side. A reservoir if vented to the atmosphere, the top of the symbol is open and a reservoir if pressurized, the top is closed. Lines which connect to a reservoir usually drawn from the top. But the line terminates below the fluid level, it is drawn to the bottom of the symbol.

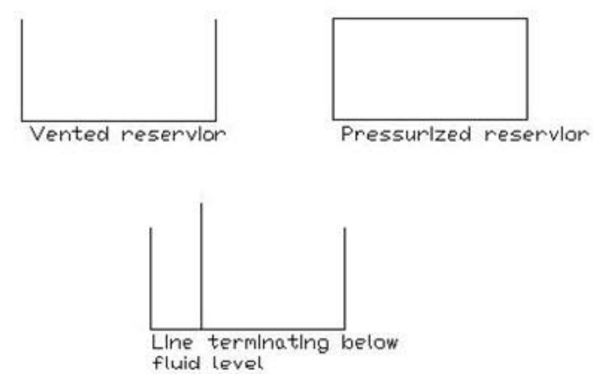


Fig. 27.1 : Reservior symbol

Lines

Working line

It is made as solid line which indicates a hydraulic pipe, tube, hose, or other conductor carrying the fluid between the components.

Pilot line

It is given by long dashes which indicates control lines.

Drain line

It is given by short dashes which indicates drain lines.

Flexible line

It is made a solid, arced line which is drawn between two dots which represents a flexible line in the system.

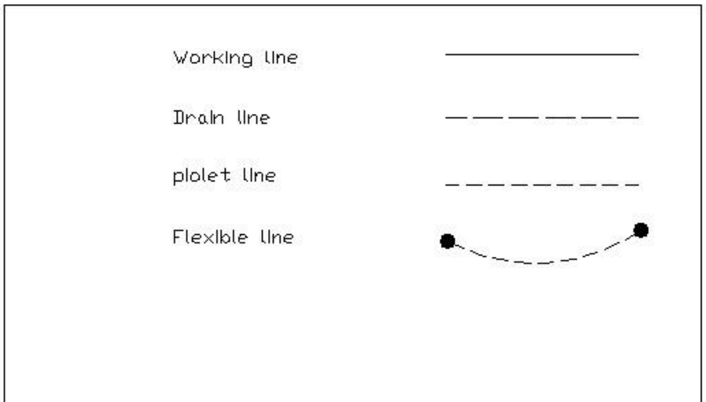


Fig. 27.2 : Hydraulic line symbols

Pump

The hydraulic pump is a usually given by a symbol of circle with a black triangle in the circle pointing outward. The triangle indicates the flow direction The pressure line from the pump is drawn from the tip of the triangle, whereas, the suction line is drawn opposite it.. If a pump is reversible, it will have two triangles.

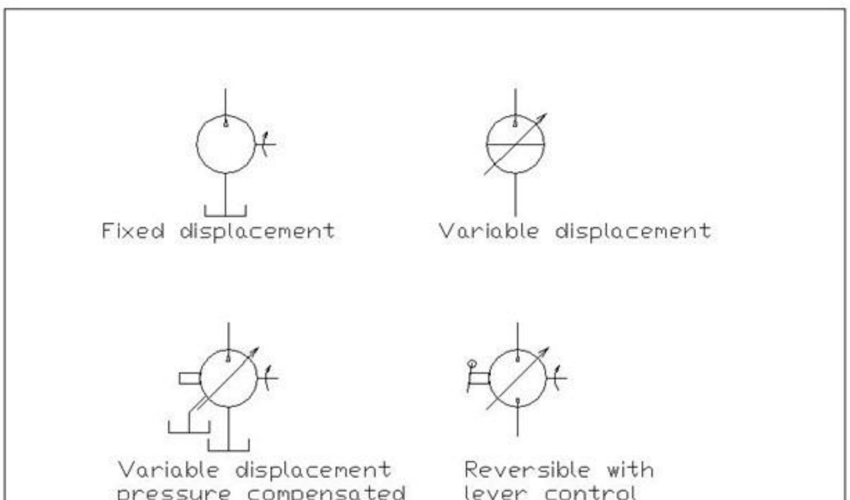


Fig. 27.3 : Hydraulic pump symbols

Motor

In the hydraulic system motor is also symbolized as circle like in pump but the black triangles pointing inward, which is a indication of receiving of pressure energy. One triangle indicates a nonreversible motor; two triangles indicate a reversible motor.

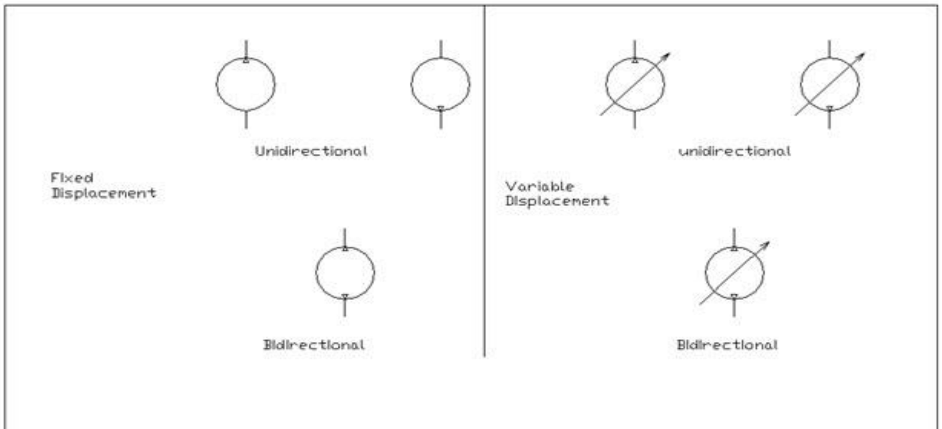


Fig. 27.4 : Hydraulic motors

Cylinder

A simple rectangle is the symbol for cylinder but it is different for different types of cylinders and is as below-

Single acting cylinder

One of the cylinder is open in the cylinder symbol

Double acting cylinder

Both ends of the cylinder are closed in the cylinder symbol

Double end rod cylinder

A rod line extends from each end of the basic cylinder symbol.

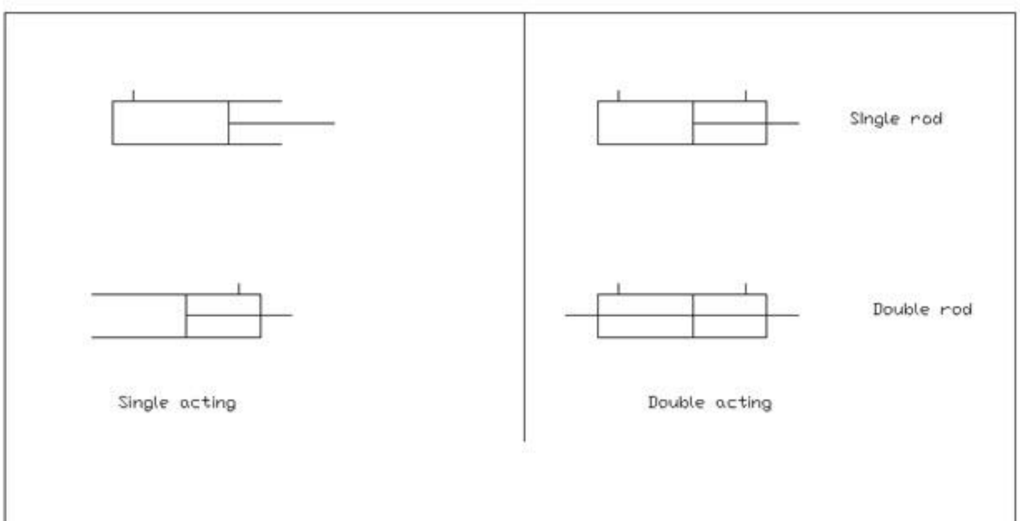


Fig. 27.5 : Hydraulic cylinders

Pressure-Control Valves

The pressure control valve is given the symbol as a square with external port connections. An arrow inside shows the direction of flow of fluid.

Relief Valve

The relief valve's symbol goes between the pressure line and the tank. The flow-direction arrow points away from the pressure-line port and toward the tank port. When pressure in the system overcomes the valve spring, flow is from the pressure port to the tank port

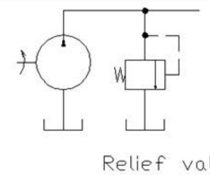


Fig. 27.6 : Relief valve symbol

Pressure Reducing Valve

It is a unit which gives nearly constant output pressure provided that the inlet pressure remains higher than the required outlet pressure. The symbol indicates the outlet pressure opposite the spring

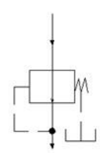


Fig. 27.7 : Pressure Reducing valve symbol

Flow Control Valve

This type of valve may be with fixed output in which variations in inlet pressure do not affect rate of flow will have the different symbols for the basic flow control valve, adjustable and nonadjustable valves.

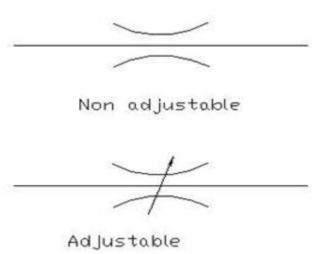
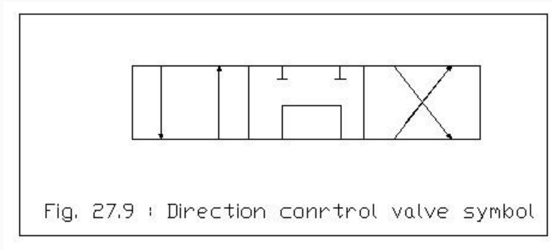


Fig. 27.8 : Flow conrtrol valve symbols

Directional Control Valves

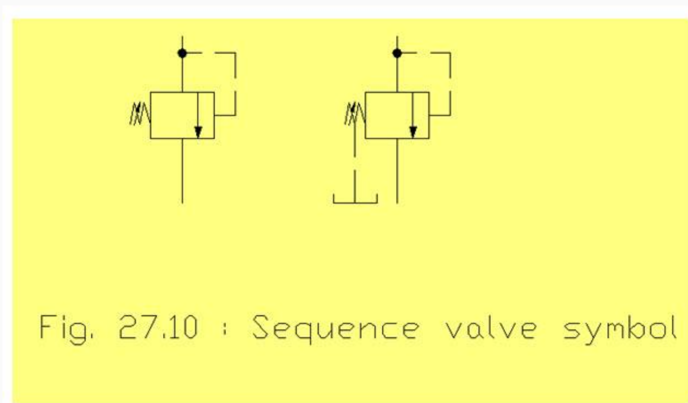
These are the valves which provide full or restricted flow by opening or closing of one or more paths .A directional control valve symbol uses a multiple envelope system. It has separate rectangle for each position. All the port connections are made to the envelope, which shows the neutral condition of the valve. It is also having the arrows in each envelope which indicates the flow paths when the valve is moved to that position.

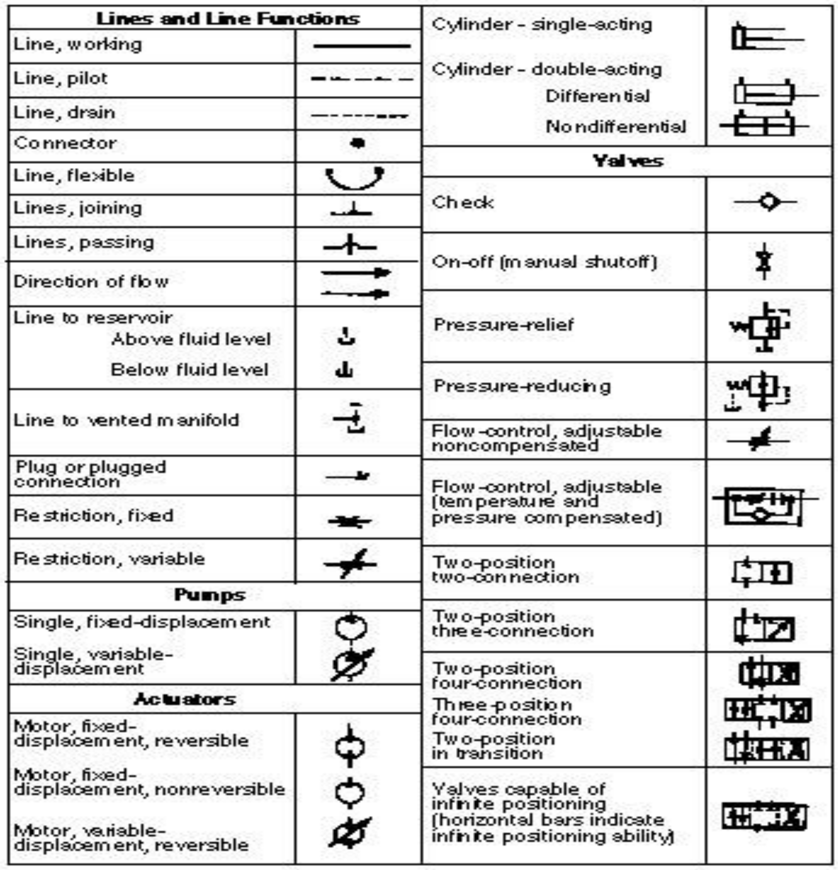


Direction control valve

Sequence valve

In a sequence valve the inlet port is connected to a primary cylinder and the outlet port is connected to the secondary cylinder. This valve is drained externally and therefore drain connection is added to the symbol.

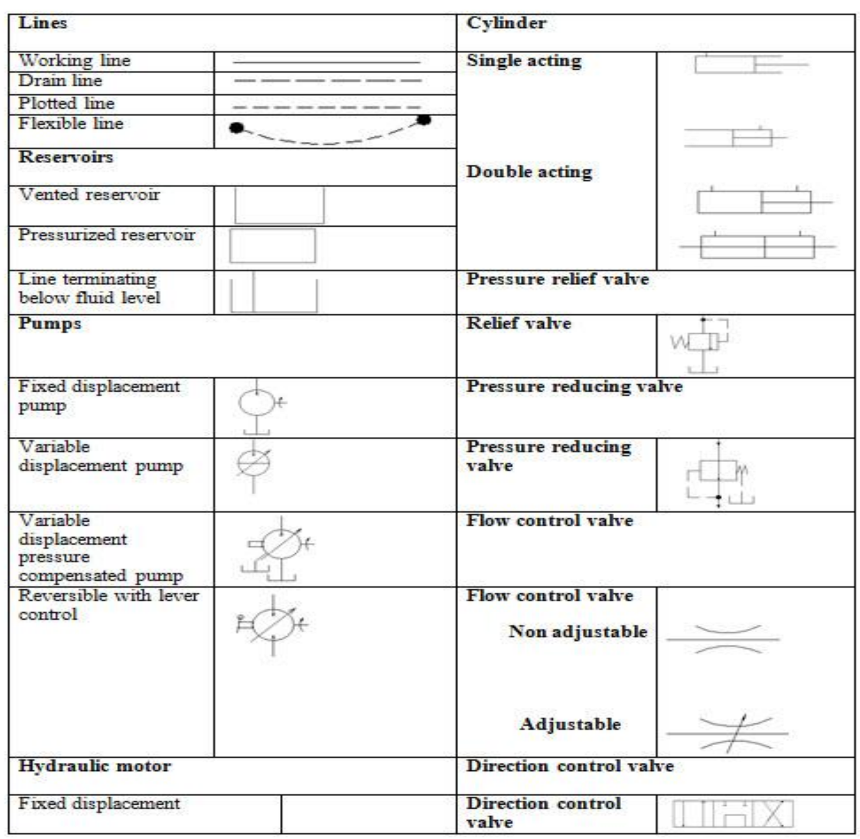




Lines and Line Functions	
Line, working	
Line, pilot	
Line, drain	
Connector	
Line, flexible	
Lines, joining	
Lines, passing	
Direction of flow	
Line to reservoir Above fluid level Below fluid level	
Line to vented manifold	
Plug or plugged connection	
Restriction, fixed	
Restriction, variable	
Pumps	
Single, fixed-displacement Single, variable-displacement	
Actuators	
Motor, fixed-displacement, reversible Motor, fixed-displacement, nonreversible Motor, variable-displacement, reversible	

Cylinder - single-acting Cylinder - double-acting Differential Nondifferential	
Valves	
Check	
On-off (manual shutoff)	
Pressure-relief	
Pressure-reducing	
Flow-control, adjustable noncompensated	
Flow-control, adjustable (temperature and pressure compensated)	
Two-position two-connection	
Two-position three-connection	
Two-position four-connection Three-position four-connection Two-position in transition	
Valves capable of infinite positioning (horizontal bars indicate infinite positioning ability)	

Figure 6-2. USASI graphical symbols



Lines	
Working line	
Drain line	
Plotted line	
Flexible line	
Reservoirs	
Vented reservoir	
Pressurized reservoir	
Line terminating below fluid level	
Pumps	
Fixed displacement pump	
Variable displacement pump	
Variable displacement pressure compensated pump	
Reversible with lever control	
Hydraulic motor	
Fixed displacement	

Cylinder	
Single acting	
Double acting	
Pressure relief valve	
Relief valve	
Pressure reducing valve	
Pressure reducing valve	
Flow control valve	
Flow control valve Non adjustable Adjustable	
Direction control valve	
Direction control valve	

Unidirectional Bidirectional Variable displacement Unidirectional Bidirectional		Sequence valve	
		Sequence valve	

Fig 27.11 : USASI graphical symbols

MODULE 7.

Lesson 30 Tractor hydraulics and nudging system

Introduction

It is desired by a tractor to have more useful work performed at the field which led to the application of hydraulic system to accomplish various field tasks like tilling, harrowing, plowing, interculture, sowing etc. quickly. The most basic description of hydraulics is that it is the science of transmitting force or motion through a fluid. The hydraulic engineering through which we are well concerned with it is called hydrostatics, and deals with the ability to transmit force or motion through a fluid which is confined. Since the fluids are considered practically to be incompressible, hence these are preferred over gasses can be compressed. Flexibility of fluid make it the most advantageous in its use to transmit power. It can change shape, divide into parts, reunite as a whole, and fit exactly into the container of any shape. The liquid usually used in hydrostatics is hydraulic oil which gives the lubricating qualities also required by the moving components of the hydraulic system.

Components of a hydraulic system

Normally a hydraulic system is consisted of various components like sump, pump, safety valve, actuator, direction control valve, lines hoses, clamps etc. these are discussed here below-

Hydraulic pump

One type of fluid power transmission device is provided in the system which could be piston pump or gear pump or vane pump, etc. Reciprocating pumps are most efficient in hydraulic systems but rotary pumps are convenient to put in the system

Spur Gear pump

At present so many tractors are fitted with rotary pump like spur gear pump. The spur gear type pump is having a driving gear and a driven gear enclosed in a closely fitted housing. The rotary motion from crank shaft of tractor engine is transferred to the driving gear of the pump. Both the gears move in opposite directions and mesh at a point in the housing between the inlet and outlet ports. Both sets of teeth project outward from the center of the gears. As the teeth of the two gears separate, a partial vacuum forms and draws liquid through an inlet port into the housing and is trapped between the teeth of the two gears and the fluid is discharged through the housing to the discharge side. The liquid then pushed through the outlet as the rotating gears develop sufficient pressure. In this way the pressurize fluid flows through lines to a hydraulic ram or actuator.

Radial Piston Pump

Some of the Indian tractors are fitted with radial piston pump. Radial piston pumps are compact and reliable. These are capable of building high pressure, high volume and high speed. It is having a number of closely fitted parts and therefore wear is also considered to be more. In this type of pump , the pistons are arranged like wheel spokes in a short cylindrical block. There are many types of designs of radial piston pump . In this type of pump the pistons are arranged radially around an eccentric cam . The cam is a part of the main shaft. As the shaft rotates the pistons are reciprocated in the cylinders which are oriented radially . As the piston moves inwards the suction is caused and the space in the cylinder is filled with the fluid . When the piston moves outwards the fluid filled inside the cylinder forced outside the cylinder to the delivery side.

Lubrication

It is desired to have lubrication in the components of pump and actuator for smooth operation of the hydrostatic system. The pressure and flow of the fluid to the actuator which is ram cylinder begins when the pump moves the fluid away from its centered position by the tractors control apparatus. Lubrication of the various component increases as the system pressures rise by providing more fluid flow. Fluid which is utilized for lubrication should be an additional quantity so as not to affect the functioning of the system.

Pressure Control Valve (Relief Valve)

It is needed in the hydraulic system to have resistance in the flow of fluid which produces pressure and is necessary for the system to function. If the amount of resistance could not be controlled, it could become so high that the weakest component may burst. Therefore, the hydraulic circuit requires a relief valve to protect against excessive pressure cuased if any. The relief valve allows the fluid to be returned to the reservoir. The relief valves are utilized to limit the maximum operating pressure in the circuit. These are also called safety valves and protects the pump and other components from overloading, etc. Pressure relief valve is provided in the circuit such that one port is connected to the pressure line and the other port is connected to the the reservoir. There is a ball which is held on its seat with the spring force. The spring force can be changed by rotating the adjusting screw. When the circuit pressure at the valve inlet is less than the spring pressure , the ball remains on its seat and the valve is closed and no flow takes place through it. As the pressure in the circuit exceeds the adjusted spring force, the ball is forced off its seat and the valve is opened. Now the liquid flows from the pressure line through the valve to the reservoir. This diversion of flow continue till the. pressure decreases below the valve setting and hence the spring reseats the ball and the valve is again closed. In this way it prevents circuit and provide the safety.

Direction Control Valve

Valves which are used to control cylinder type actuators are known as the directional control valves. These may be check valve, rotary valve or spool valve, etc. Most of Indian tractors are fitted with spool type of valve. It may be open centre type or closed centre type depending upon type of circuit. Spool valve is a valve which controls the direction of hydraulic fluid flow. It consists of cylindrical spools which can block and open the channels in the hydraulic system. A spool valve can change the direction of flow of hydraulic fluid from a hydraulic pump to an actuator by blocking off the route of the fluid through which it takes place. Spool valve is consists of a spool which can move in the body of the valve and may have four or five ports. As in the figure below, a three way spool valve connected to an actuator of cylinder type. The fluid is applied to the port P of the valve and C of the cylinder, whereas, port T of the valve is connected to drain or return to the tank. Port A of the valve is connected to the B of the cylinder. Now if the spool is moved to right side with the help of lever, the high pressure fluid flows from port A and B. The moves to right due to pressure of fluid and displacing the fluid through port C and P. Now if the spool is moved to left, high pressure fluid comes into the cylinder through port C, and the piston moves to left causing the fluid into the tank via port B and A and T. Spool valve are generally manually operated in the tractors and are located at the right hand side of the operator.

Cylinder Type Actuator

A hydraulic system of tractor may have single or double acting cylinder . Most of our tractors are fitted with single acting cylinders . In this type of actuator the fluid is pumped into the cylinder forcing the piston outward. As the direction control valve is kept to neutral, the fluid get trapped and the load remained lifted. As the lever of this valve is moved to the left or right the trapped fluid gets away to sump. In single acting cylinder the piston braught back due to weight on the piston. But in the double acting cylinder the fluid can move both the sides of piton and applies the pressure to extend and retract the piston in the cylinder.

Sump

There is a rectangular shaped sump which store the fluid in it to move the piston for lifting the load. Hydraulic systems are generally operated by a liquid fluid being transmitted in the system components. A receiver tank, which stores energy for future use is basically a pressure vessel .It need a very large quantity of liquid fluid which is to be be stored and reused continuously as the circuit works. This tank is generally part of the tractor framework . In general reservoir design and its development is very important. The efficiency of a hydraulic circuit is greatly affected by tank design. Hence a hydraulic reservoir does much more than just provide a place to put fluid.

Lines and connectors

Tractor fluid lines are generally made up of metal tubing or flexible hose. Metal tubings are used where there are long runs are there. It is used to connect components like control valve and actuator or pump and safety valve etc. hoses are preferred where moving parts are there or where vibrations occurred. Metallic tubes are made up of steel ,or titanium etc. Various types of connectors may be used to connect the lines to the components.

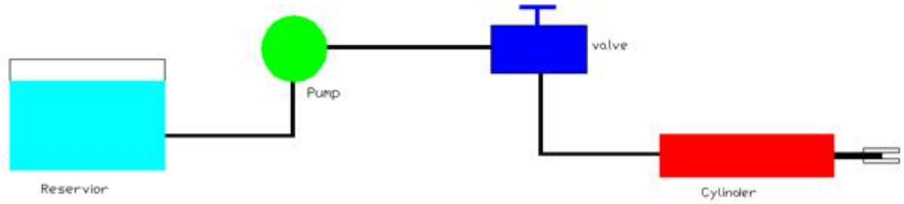


Fig. 28.1: Simple hydraulic system of a tractor

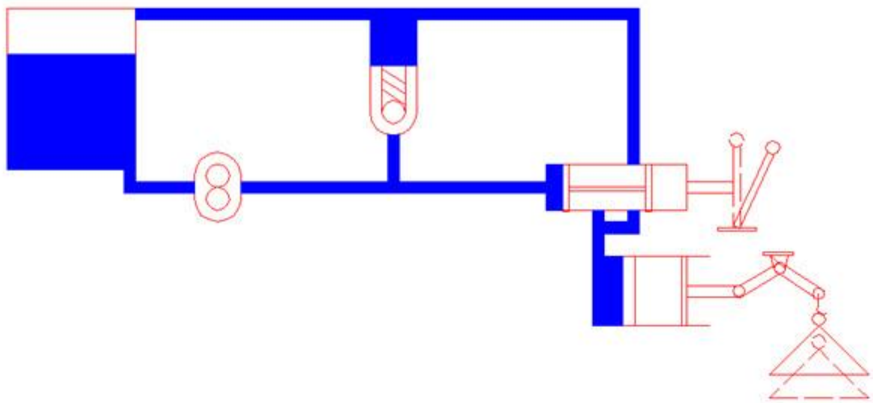


Fig. 28.2: Hydraulic system of actual tractor (lifting)

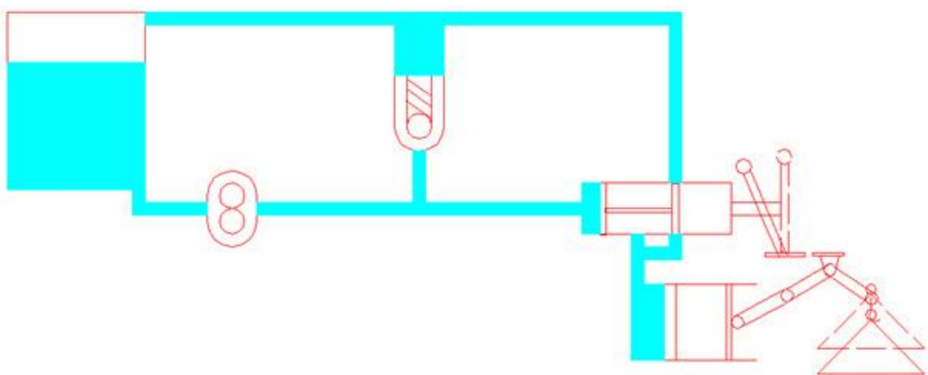


Fig. 28.3: Hydraulic system of actual tractor (lowering)

Automatic Draft and Depth Control (ADDC)

In some of the tractors a mechanism is provided so that required depth of field operation is maintained quite closely and simultaneously draft control is also allowed to work to have better traction. This is known as automatic draft and depth control.

MODULE 8.

Lesson No 31 Fail safe and safety systems in hydraulic and pneumatics

Introduction

The components of hydraulic and pneumatic circuits are normally designed with simplicity, ease of maintenance and adaptability point of view. It is having a number of considerations which improves the reliability and field performance of the system. A fail safe device is that which even get failed but responds in such a manner that it will cause no harm or least harm to other devices of the system or sub system.

Fail safe devices

Fail safe devices are those which even get failed but responds in such a manner that it will cause no harm or least harm to other devices or the system / sub system etc. These may be actuator, valves, etc.

Safety in Hydraulics

Consider the following points while observing the safety of a hydraulic circuit-

- Do not crack a hydraulic connector for finding the pressure, flow, etc. in a hydraulic system.
- Do not leave or test a hydraulic system or component to atmosphere, partially or fully open a transmission line to atmosphere.
- Do not have the air bleeding in a hydraulic component or system to atmosphere
- Provide safe-T bleed in the hydraulic systems which is a safety device.
- Skilled and trained workers are to be put on and around hydraulic systems from safety point of view.
- Park the hydraulic machines beyond the reach of children.
- Lower the machines to the ground before leaving the machines.
- Do not service the hydraulic system when motor or engine is running.
- Do not remove the cylinder until the working units are resting on the ground.
- Relieve the hydraulic pressure and discharge the accumulator before disconnecting oil lines
- Ensure there is no leakage and all the lines connections are tight.

- Make use of hoist or jacks to remove the heavy components of hydraulic system.

Safety in Pneumatics

Consider the following points while observing the safety of a pneumatic circuit-

- Operate the pneumatic system within operating range of pressure
- While under pressure do not disconnect the lines.
- Do not activate the compressed air until all the line connections are complete.
- Take precautions while switching on the compressed air
- Make use of shortest lines possible.
- Make use of safety glasses
- Switch off the compressed air before repairing or dismantling the circuit.

Lesson No 32 Robotics , Hydraulic and Pneumatics and Programmable Logic Control

Introduction

Robots are making a considerable impact on the many aspects of modern life, from industrial field to transportation, and in agricultural fields. It is basically a machine which is skilled and having intelligence (computer).. Production, assembly and packaging fields are are specifically automated. The development of automation pushed forward for development of robots . Hydraulic and pneumatic drive are widely used to give linear or rotary outputs in the robos. Therefore, these systems use devices such as linear pistons and rotary vane actuators to accomplish the motion of the joint. Pneumatic drive is normally used for smaller robots used in simple material transfer applications. Electric drive and hydraulic drives are used on sophisticated industrial robots. Control engineering and automation has evolved long back. Earlier to which human beings were the main source controlling systems. The development of low cost computer has revolutionized the in the field of programmable logic controller (PLC). These are gaining popularity in many applications, specifically in manufacturing controls, etc.

Robotics

Robotics may be defined as the technology which deals with the design, manufacturing operation and application of robots along with computer systems for the control, sensory feedback, and information processing. Robots are normally consisted of several systems working together as a whole. Generally these are comprised of following systems-

- Controller
- Body
- Mobility
- Power
- Sensors
- Tools

Control System

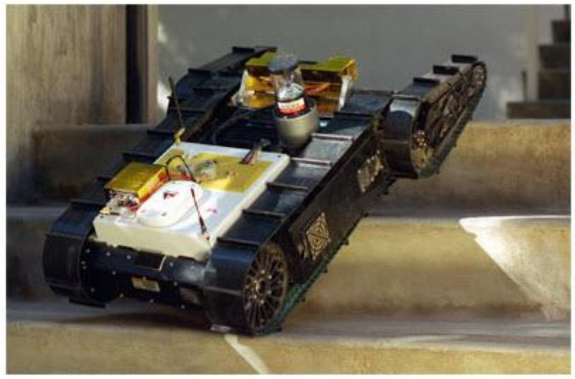
The controller controls the movements of the robot which is also called brain or intelligence of the robot. It generally uses a computer which stores the information about the robot and the work environment and it also execute programs which operate the robot. The control system contains programs, data algorithms, logic analysis and various other processing activities which enable the robot to perform. Depending upon the task to be performed by robots its control system may be of simple type or sophisticated type. It is having a Central processing Unit (CPU) and Power Unit which enable it for power generation, power conditioning, power distribution and control, analog and digital input output (I/O) control and processing, computing , and data storage in memory, etc.

Body

The body of the robot may be of any shape or size depending upon type of task to be performed by it. Industrial robots are generally of the shape of a body less arm as it is suitable to the job to be performed by it . Space robots have many different body shapes such as a sphere, a platform with wheels or legs depending upon task to be performed . Some planetary rovers have solar platforms driven by wheels. Aerobat bodies are balloons that will float through the atmosphere of other worlds collecting data.

Mobility

Mobility of robot is basically movement of it viz how do robots moves. It depends on the task to be performed under a particular environment. http://web.mit.edu/afs/athena/org/t/towtank/www/tuna/pictures.html U nmanned submersible robots are used ocean studies or industry for which automated underwater vehicles use propellers and rudders to control their direction of travel. Their shape may also be similar to fish for easy mobility. Similarly land based robots or rovers may move on legs or tracks or wheels. If the surface uneven the robots can move easily with the track type of arrangement.



Power

Robots can be powered with electric, pneumatic or hydraulic source. Electric motors are efficient, require little maintenance, and are less noisy. Pneumatic robots use compressed air and come in a wide variety of http://jewel.morgan.edu/~salimian/courses/IEGR470/223_lab.htmlsizes. It requires another source of energy like electricity or gasoline to provide the compressed air. Hydraulic robots use oil under pressure and generally perform heavy duty tasks. This is larger and heavier than the other power sources. A hydraulic robot also needs another source of energy to move the fluids through its components. Pneumatic and hydraulic robots require maintenance of various components like tubes, fittings and hoses which connect the various components.

Sensors

Sensors in the robot are the devices which collect the useful information as a engineering parameter about the internal state of robots. These are used to communicate with outer world. These also measure physical quantities like contact, distance, light, sound, strain, rotation, magnetism, smell, temperature, inclination, pressure , etc. Sensors generate the signals which subsequently processed with the help of computer brain of robot to provide meaningful information. Robots are equipped with sensors and hence they can have an understanding of their surrounding environment and make changes in their response on the basis of collected information. Robot can also be fitted with acoustic sensor to detect sound, motion or location, infrared sensors to detect heat sources, contact sensors, tactile sensors to give a sense of touch.

Tools

Robots are fitted with tools called end effectors so as to interact with the environment and to carry out assigned tasks. These tools will have the variation according to the tasks to be performed for which it has been designed. A robot in the manufacturing unit will be fitted with interchangeable tools such as paint sprayers or welding torches. Many robots carry their tools at the end of a manipulator. The manipulator contains a series of segments for moving objects. The manipulator includes the arm, wrist and end effectors. An end effector is a tool or gripping mechanism attached to the end of a robot arm to accomplish some task like a gripping device, a paint gun, a drill, an arc welding device, etc. There are specific tools to do a particular

Programmable Logic Controller (PLC)

A programmable logical controller (PLC) is a digital computer which is used in automation for processes, such as control of machinery in a factory assembly line, production, pneumatic , hydraulic ,etc.. PLCs are used in many industries and variety of machines. PLC basically used to monitor inputs, and depending upon their state make decisions by using its program or logic, to control its outputs to automate a machine or a process. The PLC may be designed for multiple inputs and output arrangements. Programmable Logic Controllers (PLCs) are microprocessor-based devices used to control industrial processes or machines. They provide advanced functions, including analog monitoring, control and high speed motion control as well as share data over communication networks.

Advantages

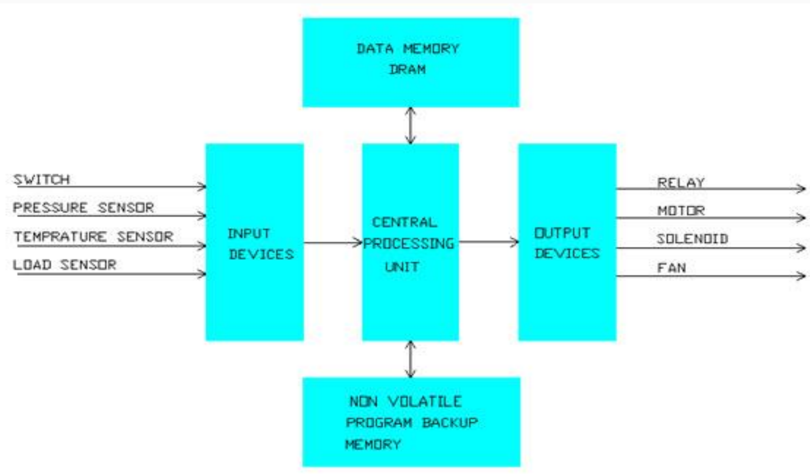
- It is rugged in design
- It can withstand vibrations, temperature, humidity, and noise.
- It is provided with interfacing for inputs and outputs
- It can be easily programmed
- The language used for programming is simple
- Cheap and reliable
- Low cost

Disadvantages

- Connecting wires is difficult
- It is difficulty to make changes or replacements.
- It is difficulty to find errors

Configuration of PLC

PLC is basically an industrial microcontroller system or microprocessor based system which is having hardware and software as per the requirement or use. Block diagram below give the details of various components of it.



Fif. 31.1 : Block diagram of configuration of PLC

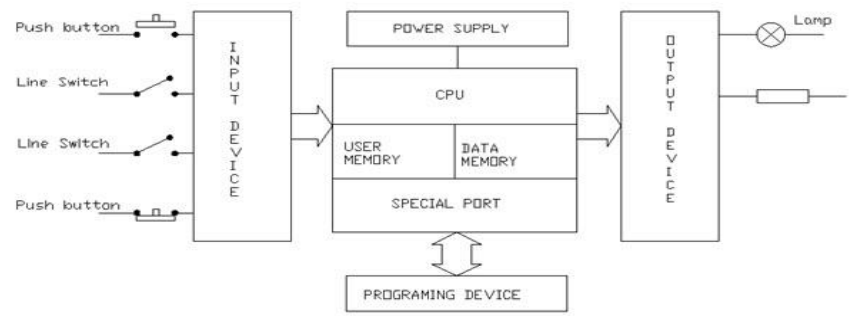


Fig. 31.2 : Block diagram of working of PLC

Central Processing Unit (CPU)

Central Processing Unit is the brain of a PLC controller. CPU itself is usually one of the microcontrollers. These are normally 16 and 32 bit microcontrollers. The CPU consists of a microprocessor, memory chip and other integrated circuits to control logic, monitoring and communications. It can operate in different operating modes. In *programming mode* it accepts the downloaded logic and then in *run mode* it can execute the program and operate the process.

CPU also takes care of communication, interconnecting of other parts of PLC controller, program execution, memory operation, overseeing input and setting up of an output.

Input Output System

The input output (I/O) system provides the physical connection between the equipment and the PLC. A PLC input device is anything which gives an input to the PLC. These can consist of digital, analog, switches, sensors, intelligent devices etc. A digital input card in an input device handles discrete devices which give a signal like on or off such as a pushbutton, limit switch, sensors or selector switches. An analog input card converts a voltage or current into a digital form which is an equivalent number easily accepted by the CPU. Force transducer, pressure transducer, thermocouples, torque sensors etc are give the analog signals which are converted into digital form and processed by microprocessors. Similarly output device is also consist of digital or analog types. A digital output card gives the signal out to put a device on or off like as lights, LEDs, small motors, and relays, etc. An analog output card will convert a digital number sent by the CPU to real world voltage or current which are used to drive mass flow controllers, pressure regulators and position controls or some other device.

Programming PLC

The software part is the heart of a PLC and is written by a programmer. The programming is so done that the PLC can control or monitor the devices. These softwares are executed by the processor in the CPU module or controller module. There are various types of PLC software design packages which are in use. The logic can be written in Ladder Logic, Instruction List, Sequential Function Charts, or any of the IEC (international electrotechnical commission) languages.

Power Supply

In PLCs electrical power supply is used to operate the central processing unit. Most PLC controllers work on DC voltage. Therefore it is necessary to convert the 230 V AC voltage to required DC voltage needed for logic circuit of processor and also for I/O system of controller. The power supply may be a separate module in the PLC or some times integral part of the CPU. . Depending upon the design of PLC current rating will be by the power supply to the I/O module . Different types of modules use different amounts of electrical current. This electrical supply is usually not used to start external inputs or outputs. Separate supplies are provided in starting PLC controller inputs or outputs. By doing so pure supply is applied to the CPU which is not affected by industrial environment.

Working of PLC

A PLC interfaces various types of external electrical and electronic signals. These signals can be AC or DC currents or voltages from various sensors or devices. It ranges 4 to 20 milli-amperes (mA) or 0 to 120 VAC and 0 to 48 VDC. These signals are called as I/O points.The I/O (input/output) system is physically connected to the field devices which are used in the control of a process. These field devices may be discrete or analog I/O devices, like load cells, pressure transducers, push buttons, motor starters, solenoids, limit switches, etc. The I/O interfaces provide the connection between the CPU and the information providers (inputs) and controllable devices (outputs). The CPU completes three processes viz. it reads, the input data from the field devices via the input interfaces, then it executes, the control program stored in the memory system, and thirdly it writes, or updates, the output devices though the output interfaces. This process of sequentially reading the inputs, executing the program in memory, and updating the outputs is known as scanning.

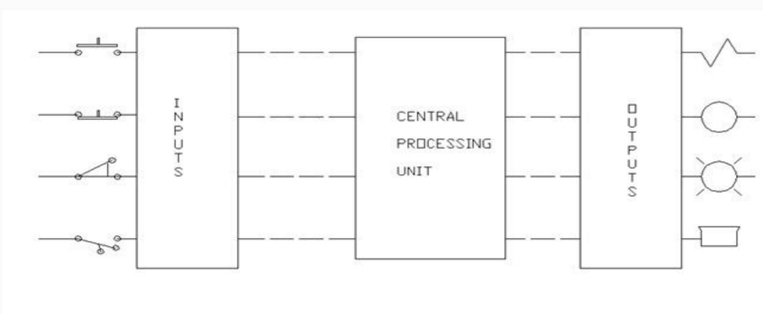


Fig. 31.3 : Programable Controller Block Diagram

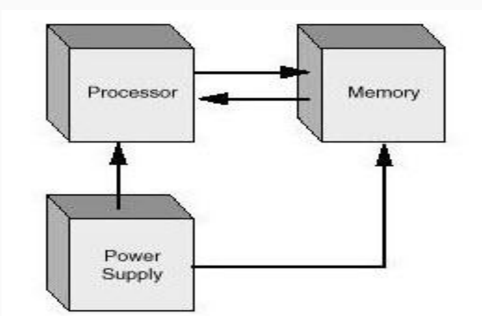


Figure 1-6. Block diagram of major CPU components