Fluid Power Systems

7th SEMESTER

Sub code:17ME72

DEPARTMENT OF MECHANICAL ENGG

BGSIT, BG NAGARA

MODULE 1: INTRODUCTION TO FLUID POWER SYSTEMS

Fluid power system: components, advantages and applications. Transmission of power at static and dynamic states. Pascal's law and its applications.
Fluids for hydraulic system: types, properties, and selection. Additives, effect of temperature and pressure on hydraulic fluid. Seals, sealing materials, compatibility of seal with fluids. Types of pipes, hoses, and quick acting couplings. Pressure drop in hoses/pipes. Fluid conditioning through filters, strainers, sources of contamination and contamination control, heat exchangers.

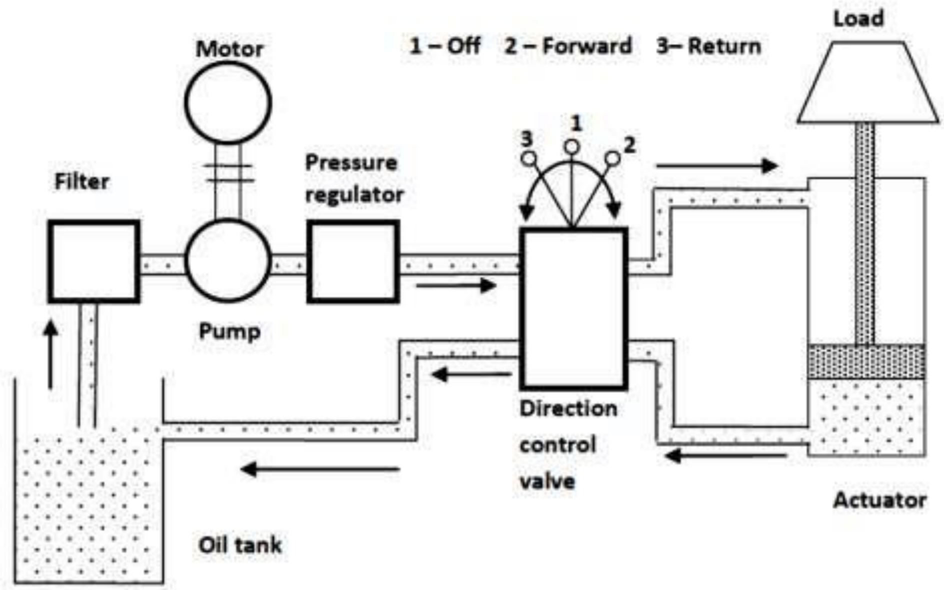
FLUID POWER SYSTEM

Fluid Power is the technology that deals with the generation, control, and transmission of power, using pressurized fluids. Fluid power is called ***hydraulics*** when the fluid is a liquid and is called ***pneumatics*** when the fluid is a gas.

Hydraulic systems use liquids such as petroleum oils, synthetic oils, and water. Pneumatic systems use air as the gas medium because air is very abundant and can be readily exhausted into the atmosphere after completing its assigned task.

COMPONENTS OF A FLUID POWER SYSTEM:

Hydraulic System:



There are six basic components required in a hydraulic system:

1) A tank (reservoir) to hold the hydraulic oil.

2) A pump to force the oil through the system.

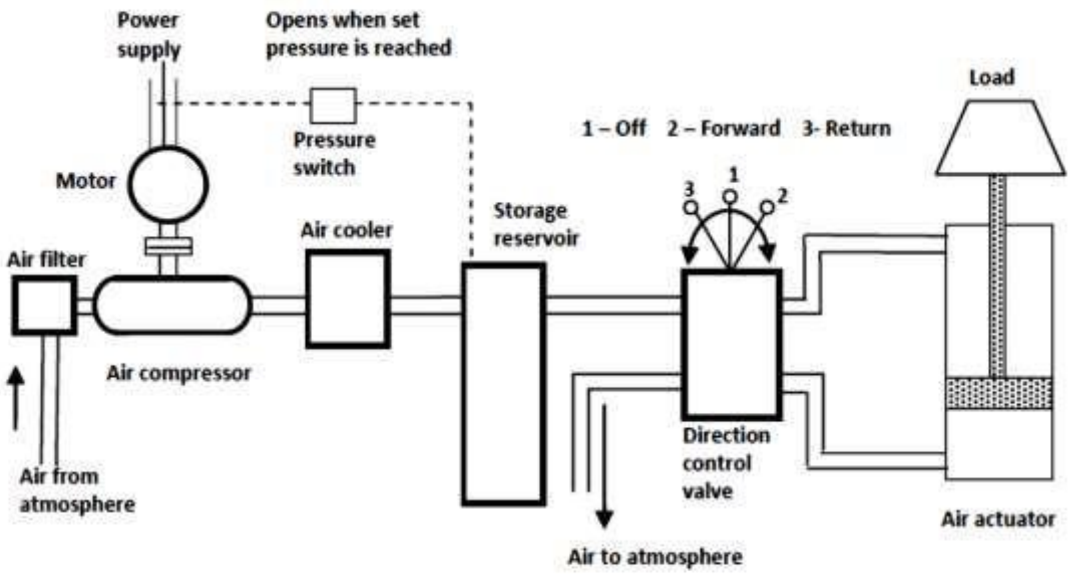
3) An electric motor or other power source to drive the pump.

4) Valves to control oil direction, pressure, and flowrate.

5) An actuator to convert the pressure of the oil into mechanical force to do the useful work.

6) Piping to carry the oil from one location to the other.

Pneumatic System:



Pneumatic systems have components that are similar to those used in hydraulic systems.

1) An air tank to store a given volume of compressed air.

2) A compressor to compress the air that comes directly from the atmosphere.

3) An electric motor or other prime mover to drive the compressor.

4) Valves to control air direction, pressure and flowrate.

5) Actuators, which are similar in operation to hydraulic actuators.

6) Piping to carry the pressurized air from one location to another.

ADVANTAGES OF FLUID POWER SYSTEM:

The advantages of a fluid power system are as follows:

1) Fluid power systems are simple, easy to operate and can be controlled accurately: Fluid power gives flexibility to equipment without requiring a complex mechanism. Using fluid power, we can start, stop, accelerate, decelerate, reverse or position large forces/components with great accuracy using simple levers and push buttons.

2) ***Multiplication and variation of forces:*** Linear or rotary force can be multiplied by a fraction of a kilogram to several hundreds of tons.

3) ***Multifunction control:*** A single hydraulic pump or air compressor can provide power and control for numerous machines using valve manifolds and distribution systems.

4) ***Low-speed torque:*** Unlike electric motors, air or hydraulic motors can produce a large amount of torque while operating at low speeds.

5) ***Constant force or torque:*** Fluid power systems can deliver constant torque or force regardless of speed changes.

6) ***Economical:*** Not only reduction in required manpower but also the production or elimination of operator fatigue, as a production factor, is an important element in the use of fluid power.

7) ***Low weight to power ratio:*** The hydraulic system has a low weight to power ratio compared to electromechanical systems. Fluid power systems are compact.

8) ***Fluid power systems can be used where safety is of vital importance:*** Safety is of vital importance in air and space travel, in the production and operation of motor vehicles, in mining and manufacture of delicate products.

APPLICATIONS OF FLUID POWER:

1) ***Agriculture:*** Tractors and farm equipments like ploughs, movers, chemical sprayers, fertilizer spreaders.

2) ***Aviation:*** Fluid power equipments like landing wheels on aeroplane and helicopter, aircraft trolleys, aircraft engine test beds.

3) ***Building Industry:*** For metering and mixing of concrete ingredients from hopper.

4) ***Construction Equipment:*** Earthmoving equipments like excavators, bucket loaders, dozers, crawlers, and road graders.

5) ***Defence:*** Missile-launch systems and Navigation controls

6) ***Entertainment:***Amusement park entertainment rides like roller coasters

7) ***Fabrication Industry:*** Hand tools like pneumatic drills, grinders, bores, riveting machines, nut runners

8) ***Food and Beverage:*** All types of food processing equipment, wrapping, bottling

9) ***Foundry:*** Full and semi-automatic moulding machines, tilting of furnaces, die casting machines

10) ***Material Handling:*** Jacks, Hosts, Cranes, Forklift, Conveyor system

TRANSMISSION OF POWER AT STATIC AND DYNAMIC STATES:

A hydrostatic system uses fluid pressure to transmit power. Hydrostatics deals with the mechanics of still fluids and uses the theory of equilibrium conditions in fluid. The system creates high pressure, and through a transmission line and a control element, this pressure drives an actuator (linear or rotational). The pump used in hydrostatic systems is a positive displacement pump. An example of pure hydrostatics is the transfer of force in hydraulics.

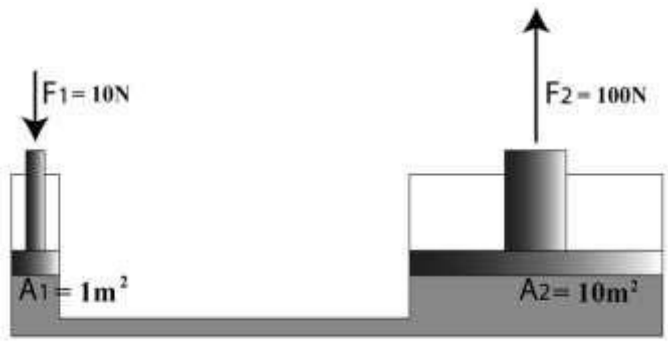
Hydrodynamic systems use fluid motion to transmit power. Power is transmitted by the kinetic energy of the fluid. Hydrodynamics deals with the mechanics of moving fluid and uses flow theory. The pump used in hydrodynamic systems is a non-positive displacement pump. An example of pure hydrodynamics is the conversion of flow energy in turbines in hydroelectric power plants.

In oil hydraulics, we deal mostly with the fluid working in a confined system, that is, a hydrostatic system.

PASCAL'S LAW (MULTIPLICATION OF FORCE):

Pascal's law reveals the basic principle of how fluid power systems perform useful work. This law can be stated as follows:

Pressure applied to a confined fluid is transmitted undiminished in all directions throughout the fluid and acts perpendicular to the surface in contact with the fluid.



The above figure shows how Pascal's law can be applied to produce a useful amplified output force. Consider an input force of 10N is applied to a 1-m^2 area piston. This develops a 10N/m^2 pressure throughout the oil within the housing. This 10N/m^2 pressure acts on a 10-m^2 area piston producing a 100N output force. This output force performs useful work as it lifts the 100N weight.

From Pascal's law we know that,

$$P1 = P2$$

$$\text{i.e.,} \frac{F1}{A1} = \frac{F2}{A2}$$

$$\frac{10}{1} = \frac{F2}{10}$$

$$F2 = 100N$$

FLUIDS FOR HYDRAULIC SYSTEM:

The most important material in a hydraulic system is the working fluid itself. Hydraulic fluid characteristics have a crucial effect on equipment performance and life. It is important to use a clean, high-quality fluid in order to achieve efficient hydraulic system operation.

DIFFERENT TYPES OF HYDRAULIC FLUIDS:

1) ***Water:*** The least expensive hydraulic fluid is water. Water is treated with chemicals before being used in a fluid power system. This treatment removes undesirable contaminates.

2) ***Petroleum Oils:*** These are the most common among the hydraulic fluids which are used in a wide range of hydraulic applications. The characteristic of petroleum based hydraulic oils are controlled by the type of crude oil used.

3) ***Water Glycols:*** These are solutions contains 35 to 55% water, glycol and water soluble thickener to improve viscosity. Additives are also added to improve anticorrosion, anti-wear and lubricity properties.

4) ***Water Oil Emulsions*****:** These are water-oil mixtures. They are of two types' oil-in-water emulsions or water-in-oil emulsions. The oil-in-water emulsion has water as the continuous base and the oil is present in lesser amounts as the dispersed media. In the water-in-oil emulsion, the oil is in continuous phase and water is the dispersed media.

5) ***Phosphate Ester:*** It results from the incorporation of phosphorus into organic molecules. They have high thermal stability. They serve an excellent detergent and prevent building up of sludge.

PROPERTIES OF HYDRAULIC FLUIDS:

1) ***Viscosity:***It is a measure of the fluid's internal resistance offered to flow.

2) ***Viscosity Index:*** This value shows how temperature affects the viscosity of oil. The viscosity of the oil decreases with increase in temperature and vice versa. The rate of

change of viscosity with temperature is indicated on an arbitrary scale called viscosity index.

3) ***Oxidation Stability:*** The most important property of hydraulic oil is its oxidation stability. Oxidation is caused by a chemical reaction between the oxygen of the dissolved air and the oil. The oxidation of the oil creates impurities like sludge, insoluble gum and soluble acidic products. The soluble acidic products cause corrosion and insoluble products make the operation sluggish.

4) ***Demulsibility:*** The ability of a hydraulic fluid to separate rapidly from moisture and successfully resist emulsification is known as Demulsibility.

5) ***Lubricity:*** The ability of the hydraulic fluid to lubricate the moving parts efficiently is called Lubricity.

6) ***Rust Prevention:*** The moisture entering into the hydraulic system with air causes the parts made of ferrous materials to rust. This rust if passed through the precision made pumps and valves may scratch the nicely polished surfaces. So inhibitors are added to the oil to keep the moisture away from the surface.

7) ***Pour Point:*** The temperature at which oil will clot is referred to as the pour point i.e. the lowest temperature at which the oil is able to flow easily.

8) ***Flash Point and Fire Point:*** Flash point is the temperature at which a liquid gives off vapour in sufficient quantity to ignite momentarily or flash when a flame is applied. The minimum temperature at which the hydraulic fluid will catch fire and continue burning is called fire point.

9) ***Neutralization Number:*** The neutralization number is a measure of the acidity or alkalinity of a hydraulic fluid. This is referred to the PH value of the fluid. High acidity causes the oxidation rate in an oil to increase rapidly.

10) Density: It is that quantity of matter contained in unit volume of the substance.

11) Compressibility: All fluids are compressible to some extent. Compressibility of a liquid causes the liquid to act much like a stiff spring. The coefficient of compressibility is the fractional change in a unit volume of liquid per unit change of pressure.

SELECTION OF HYDRAULIC FLUIDS:

A hydraulic fluid has the following four primary functions:

1) Transmit Power

2) Lubricate moving parts

3) Seal clearances between mating parts

4) Dissipate heat

In addition a hydraulic fluid must be inexpensive and readily available. From the selection point of view, a hydraulic fluid should have the following properties:

1) Good lubricity
2) Ideal viscosity
3) Chemical stability
4) Compatibility with system materials
5) High degree of incompressibility
6) Fire resistance
7) Good heat-transfer capability
8) Low density
9) Foam resistance

10) Non-toxicity

11) Low volatility

This is a challenging list, and no single hydraulic fluid possesses all of these desirable characteristics. The fluid power designer must select the fluid that is the closest to being ideal overall for a particular application.

ADDITIVES:

Various additives are added to the fluid to sustain the important characteristics. Few such additives are:

1) ***Anti-foaming:*** They are added to reduce foaming of fluid.

2) ***Anti-wear:*** Wear resistant chemicals are added to the fluid to protect critical hydraulic components from wear.

3) ***Corrosion inhibitor:*** Chemicals are added to protect surfaces from chemical attack by water.

4) ***Biocide:*** Emulsifying chemicals are added to the fluid to inhibit growth of water-borne bacteria.

5) ***Emulsifier:*** These are added to facilitate formation and stabilisation of an emulsion.

6) ***Lubrication Oiliness agents:*** Extreme Pressure (EP) agents are added to the fluid to enhance lubrication characteristics for effective full film boundary lubrication between the mating parts.

7) ***Flocculants:*** Chemicals added to dispersion of solids in a liquid to combine fine particles to form floe or small solid masses in the fluid.

8) ***Deionisation:*** Elements which provide hardness like calcium, manganese, iron, and aluminium salts are removed through deionisation of the water.

9) ***Oxidation inhibitor:*** Anti-oxidation additives are added to provide anti-oxidation characteristics. Oxidation changes the chemical characteristics of the fluid.

10) ***Vapour phase inhibitor:*** Prevention of oxidation or corrosion of metals in contact with the vapour phase of the fluid is ensured by addition of appropriate chemicals.

EFFECT OF TEMPERATURE AND PRESSURE ON HYDRAULIC FLUID:

Viscosity is the most important property of a hydraulic fluid. Temperature has an adverse effect on the viscosity of hydraulic oil. Hence it has to be seen that the operating temperature of a hydraulic system is kept at a reasonably constant level. Otherwise there will be tremendous losses in the system which will reduce the overall efficiency.

A hydraulic fluid that is too viscous generates more friction and heat and usually causes highpressure drop, sluggish operation, low-mechanical efficiency, and high-power consumption. On the other hand low-viscosity fluids permit efficient low-drag operation, but tend to increase wear, reduce volumetric efficiency, and promote leakage.

SEAL:

The seal is an agent which prevents leakage of oil from the hydraulic elements and protects the system from dust/dirt. The major function of the seal is to maintain pressure, prevent loss of fluid from the system and to keep out contamination in the system to enhance its working life and functional reliability over a longer period.

CLASSIFICATION OF SEALS:

According to the method of sealing:

1. Positive sealing: A positive seal prevents even a minute amount of oil from getting past. A positive seal does not allow any leakage whatsoever (external or internal).

2. Non-positive sealing:A non-positive seal allows a small amount of internal leakage, such as the clearance of the piston to provide a lubrication film.

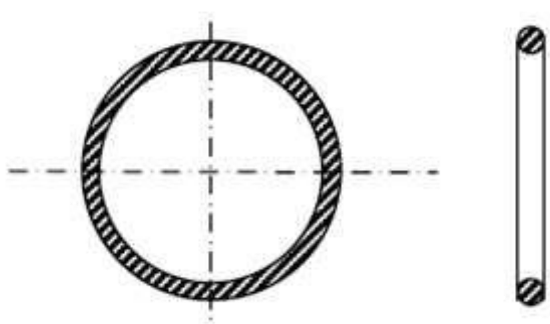
According to the relative motion existing between the seals and other parts:

1. Static seals:These are used between mating parts that do not move relative to one another. These are relatively simple. They are essentially non-wearing and usually trouble-free if assembled properly.

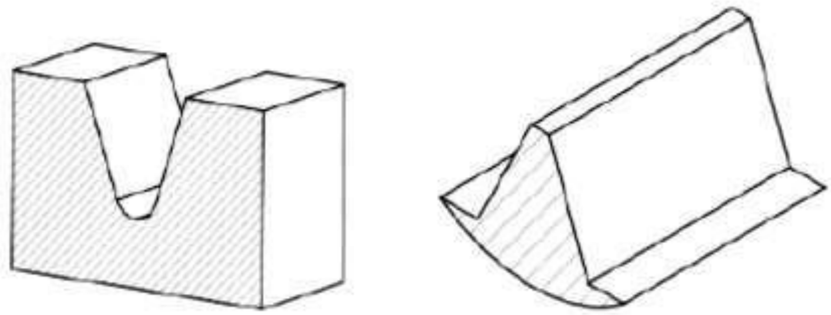
2. Dynamic seals:These are assembled between mating parts that move relative to each other. Hence, dynamic seals are subject to wear because one of the mating parts rubs against the seal.

According to geometrical cross-section:

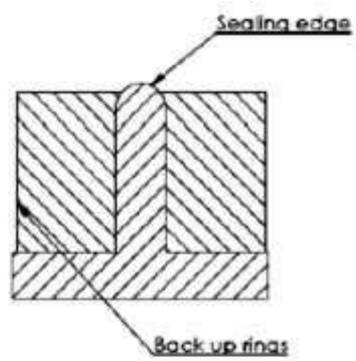
1. O-rings:O-ring is the most widely used seal for hydraulic systems. It is a moulded synthetic rubber seal that has a round cross-section in its free state. O-ring can be used for the most static and dynamic conditions. It gives effective sealing through a wide range of pressures, temperatures and movements.



2. V-ring seal and U-ring seal:V- and U-ring seals are compression-type seals used in virtually all types of reciprocating motion applications. These include piston rods and piston seals in pneumatic and hydraulic cylinder, press rank, jacks and seals on plungers and piston in reciprocating pumps.



3. T-ring seal: T-ring seal is a dynamic seal that is extensively used to seal cylinder-pistons, piston rods and other reciprocating parts. It is made of synthetic rubber moulded in the shape of the cross-section T and reinforced by backup rings on either side. The sealing edge is rounded and seals very much like an O-ring.



4. Piston cup packings: Piston cup packings are designed specifically for pistons in reciprocating pumps and pneumatic and hydraulic cylinders. They offer the best service life for this type of application, require a minimum recess space and minimum recess machining, and can be installed easily and quickly.

5. Piston rings: Piston rings are seals that are universally used for cylinder pistons. Piston rings offer substantially less opposition to motion than synthetic rubber (elastomer) seals.

SEALING MATERIALS:

Various metallic and non-metallic materials are used for fabrication of seals that are used in hydraulic systems. Leather, metals and elastomers are very common seal materials.

1) Leather: This material is rugged and inexpensive. However, it tends to squeal (scream/screech) when dry and cannot operate above 90°C, which is inadequate for many hydraulic systems. Leather does operate well at cold temperatures to about -50°C.

2) Buna-N: This material is rugged and inexpensive and wears wells. It has a rather wide operating temperature range (-45°C to 110°C) during which it maintains its good sealing characteristics.

3) Silicone: This elastomer has an extremely wide operating temperature range (-65°C to 232°C). Hence it is widely used for rotating shaft seals and static seals. Silicone has low tear resistance and hence not used for reciprocating seal applications.

4) Neoprene**:** This material has a temperature range of 50°C to 120°C. it is unsuitable above 120°C because of its tendency to vulcanize.

5) Viton: This material contains 65% fluorine. It has become almost a standard material for elastomer-type seals for use at elevated temperatures up to 240°C. Its minimum operating temperature is 28°C.

6) Tetrafluoroethylene: This material is the most widely used plastic for seals of hydraulic systems. It is a tough, chemically inert, waxy solid, which can be processed only by compacting and sintering. It has excellent resistance to chemical breakdown up to temperatures of 370°C.

PIPES AND HOSES:

In a hydraulic system, the fluid flows through a distribution system consisting of pipes (conductors) and fittings, which carry the fluid from the reservoir through operating components and back to the reservoir.

Hydraulic systems use primarily four types of conductors:

1. Steel pipes

2. Steel tubing

3. Plastic tubing

4. Flexible Hoses

The choice of which type of conductor to use depends primarily on the system's operating pressures and flow-rates.

QUICK ACTING COUPLINGS:

Couplings are precision components, engineered for specific uses with exact dimensions and close tolerances. There are a variety of applications in modern industrial plants for quick connect (QC) couplings both for pneumatically operated tools as well as other fluid power equipments which can be connected rapidly to their power source to permit wide versatility for production needs. For instance, in connecting or disconnecting a tractor and its hydraulically actuated agricultural component.

QCs make changes simple, do not require additional hand tools, take little time and do not require the help of additional trade or skill. They are devices which permit the rapid connection or disconnection of fluid conductors.

FLUID CONDITIONING THROUGH FILTERS AND STRAINERS:

Hydraulic components are very sensitive to contamination. The cause of majority of hydraulic system failures can be traced back to contamination. Hence for proper operation and long service life of a hydraulic system, oil cleanliness is of prime importance. Strainers and filters are designed to remove foreign particles from the hydraulic fluid.

Filters are devices whose primary function is the retention of insoluble contaminants from fluid, by some fine porous medium. Filters are used to pick up smaller contaminant particles because they are able to accumulate them better than a strainer. Particle sizes removed by filters are measured in microns. The smallest sized particle that can be removed is as small as 1 µm.

A strainer is a coarse filter, whose function is to remove large particles from a fluid using a wire screen. Fluid flows more or less straight through it. It does not provide as fine a screening action as filters do, but offers less resistance to flow. The smallest sized particle that can be removed by a strainer is as small as 0.15 mm or 150 µm.

CLASSIFICATION OF FILTERS:

Based on filtering methods:

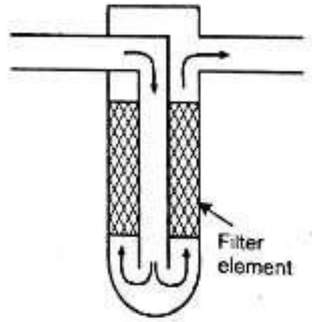
1. **Mechanical:** This type normally contains a metal or cloth screen or a series of metal disks separated by thin spacers. Mechanical filters are capable of removing only relatively coarse particles from the fluid.

2. **Absorbent:** These filters are porous and permeable materials such as paper, wood pulp, cloth, cellulose and asbestos. Paper filters are impregnated with a resin to provide added strength. In this type of filters, the particles are actually absorbed as the fluid infiltrates the material. Hence, these filters are used for extremely small particle filtration.

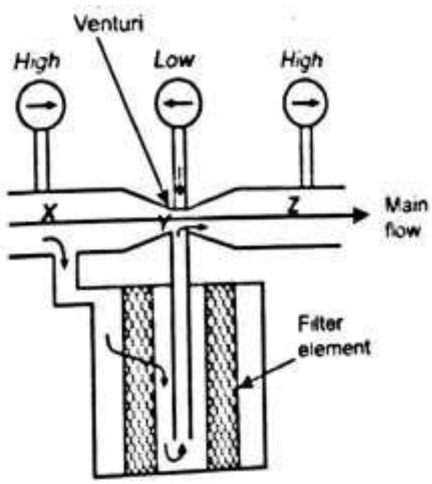
3. **Adsorbent:** Adsorption is a surface phenomenon and refers to the tendency of particles to cling to the surface of the filters. Thus, the capacity of such a filter depends on the amount of surface area available. Adsorbent materials used include activated clay and chemically treated paper.

Depending on the amount of oil filtered by a filter:

1. **Full flow filters:**In this type, complete oil is filtered. Full flow of oil must enter the filter element at its inlet and must be expelled through the outlet after crossing the filter element fully. This is an efficient filter. However, it incurs large pressure drops. This pressure drop increases as the filter gets blocked by contamination.



2. Proportional filters (bypass filters): In some hydraulic system applications, only a portion of oil is passed through the filter instead of entire volume and the main flow is directly passed without filtration through a restricted passage.



BETA RATIO OF FILTERS

Filters are rated according to the smallest size of particles they can trap. By mathematical definition, the beta ratio equals the number of upstream (before the filter) particles of size greater than Nµm divided by the number of downstream (after the filter) particles having size greater than Nµm. Where, N is the selected particle size for the given filter.

$$\text{Beta Ratio} = \frac{\text{No. of upstream particles of size} > N\ \text{m}}{\text{No. of downstream particles of size} > N\ \text{m}}$$

A beta ratio of 1 would mean that no particles above specified N are trapped by the filter. A beta ratio of 50 means that 50 particles are trapped for every one that gets through. Most filters have a beta ratio greater than 75.

$$\text{Beta Efficiency} = \frac{\text{No. of upstream particles - No. of downstream particles}}{\text{No. of upstream particles}}$$

$$\text{Beta Efficiency} = 1 - \frac{1}{\text{Beta Ratio}}$$

CAUSES OF CONTAMINATION:

1. Contaminants left in the system during assembly or subsequent maintenance work.
2. Contaminants generated when running the system such as wear particles, sludge and varnish due to fluid oxidation and rust and water due to condensation.
3. Contaminants introduced into the system from outside. These include using the wrong fluid when topping up and dirt particles introduced by contaminated tools or repaired components.

PROBLEMS CAUSED BY CONTAMINATION:

1. Accelerate component wear, decreasing system performance and service life.
2. Result in sluggish operation and cause moving parts to seize.
3. Damages seals resulting in leakage.
4. Act as a catalyst to accelerate hydraulic fluid oxidation and breakdown thereby shortening fluid life and reducing the useful operating temperature range of the fluid.

CONTAMINATION CONTROL:

There are many ways to reduce the effects of contaminants in a system.

1. Plumb the system with pipes, tubing and fittings that are reasonably free from rust, scale, dirt and other foreign matter.

2. Flush the entire hydraulic system, preferably with the same type of fluid to be used, before normal system operation is begun.

3. Filter the hydraulic oil before using, to minimise introducing contaminants into the system.

4. Provide continuous protection from airborne contamination by sealing the hydraulic system, or installing air filter/breather.

5. Clean or replace filter elements on a routine basis.

6. Maintain fluid viscosity and pH level within fluid suppliers' recommendations.

7. Minimise sources of water entry into the hydraulic system.

8. Avoid introducing thread sealants into the fluid stream.

HEAT EXCHANGERS:

The steady-state temperature of fluid of a hydraulic system depends on the heat-generation rate and the heat-dissipation rate of the system. If the fluid operating temperature in a hydraulic system becomes excessive, it means that the heat-generation rate is too large relative to the heat-dissipation rate. Assuming that the system is reasonably efficient, the solution is to increase the heat-dissipation rate. This is accomplished by the use of coolers, which are commonly called "heat exchangers."

In some applications, the fluid must be heated to produce a satisfactory value of viscosity.

This is typical when, for example, mobile hydraulic equipment is to operate below 0C. In these cases, the heat exchangers are called "heaters." However, for most hydraulic systems, the natural heat-generation rate is sufficient to produce high enough temperatures after an initial warm-up period.

Basically, there are two types of heat exchangers: Air cooled heat exchangers and Water cooled heat exchangers. Air coolers are used where water is not readily available and the air is at least 3° to 5°C cooler than the oil. But water coolers are more compact, reliable, and efficient and use simple temperature controls.

QUESTIONS FROM PREVIOUS YEAR QUESTION PAPERS:

DEC 2015/JAN 2016

1) With a neat sketch, explain the hydraulic circuit and laws plugged to develop the circuit. 2) What are the various functions performed by the hydraulic fluid and list its desirable properties and types of hydraulic fluid.

3) Explain Beta ratio and Beta efficiency.

4) Explain the common location of mounting filters in the hydraulic system.

JUNE/JULY 2016

1) Sketch and explain structure of a hydraulic control system.

2) What are the desirable properties of hydraulic oil? Explain them.

3) Sketch and explain full flow filter.

DEC 2016/JAN 2017

1) State Pascal's law. Explain its applications, with a neat sketch.

2) How are hydraulic seals classified? Explain positive and non-positive seals.

3) With the aid of sketches, explain the following: i) Return line filtering ii) Suction line filtering iii) Pressure line filtering

JUNE/JULY 2017

1) State Pascal's law. With a neat sketch explain basic hydraulic power system.

2) What are the desirable properties of hydraulic fluids? Explain briefly.

3) How hydraulic seals are classified? Explain any one method.

4) What is a filter? What are the methods of filtering? Explain briefly.

DEC 2017/JAN 2018

1) With a neat block diagram, explain the structure of hydraulic power system.
2) What are the advantages of hydraulic system?
3) Write any five desirable properties of a hydraulic fluid.
4) Explain three basic types of filtering methods used in hydraulic system.
5) Explain static seals and dynamic seals with examples.

JUNE/JULY 2018

1) State Pascal's law.
2) What is seal and what are its functions? Explain sealing devices used in hydraulic systems.
3) What is a filter and how they are classified?

ONE TIME EXIT SCHEME – APRIL 2018

1) Define hydraulic system. What are its advantages and disadvantages?
2) Draw a structure of hydraulic system and explain the parts.
3) For a simple hydraulic jack the following data is given. F_1 = 100N, A_1 = 50cm^2, S_1 = 10cm Find load F_2 and displacement S_2 if area of piston that to be lifted is 500cm^2. Also find energy input and energy output.
4) What are the desirable properties of hydraulic oils?
5) Sketch and explain different filtering systems in a circuit.

MODULE 2: PUMPS AND ACTUATORS

Pumps: Classification of pumps, pumping theory of positive displacement pumps, construction and working of Gear pumps, Vane pumps, Piston pumps, fixed and variable displacement pumps, Pump performance characteristics, pump selection factors, problems on pumps.

Accumulators: Types, selection/ design procedure, applications of accumulators. Types of Intensifiers, Pressure switches /sensor, Temperature switches/sensor, Level sensor.

Actuators: Classification cylinder and hydraulic motors, Hydraulic cylinders, single and double acting cylinder, mounting arrangements, cushioning, special types of cylinders, problems on cylinders. Construction and working of rotary actuators such as gear, vane, piston motors, and Hydraulic Motor. Theoretical torque, power, flow rate, and hydraulic motor performance; numerical problems. Symbolic representation of hydraulic actuators (cylinders and motors).

PUMPS

A pump, which is the heart of hydraulic system, converts mechanical energy into hydraulic energy. The mechanical energy is delivered to the pump using a prime mover such as an electric motor. Due to the mechanical action, the pump creates a partial vaccum at its inlet. This permits atmospheric pressure to force the fluid through the inlet line and into the pump.

The pump then pushes the fluid into the hydraulic system.

CLASSIFICATION OF PUMPS:

Pumps are broadly classified into two types

1) Dynamic (non-positive displacement) pumps

2) Positive displacement pumps

1) Dynamic (non-positive displacement) pumps: This type is generally used for lowpressure, high-volume flow applications. Because they are not capable of withstanding high pressures, they are of little use in the fluid power field. Normally their maximum pressure capacity is limited to 250-300psi. This type of pump is primarily used for transporting fluids from one location to another. The two most common types of dynamic pumps are the centrifugal and axial flow propeller pumps.

2) Positive displacement pumps: This type is universallyused for fluid power systems. As the name implies, a positive displacement pump ejects a fixed amount of fluid into the hydraulic system per revolution of pump shaft rotation. Such a pump is capable of overcoming the pressure resulting from the mechanical loads on the system as well as the resistance to flow due to friction.

Positive displacement pumps are further classified into:

i) Fixed displacement pumps: It is the one in which the amount of fluid ejected per revolution (displacement) cannot be varied.

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

The advantages of positive displacement pumps over non-positive displacement pumps are as follows:

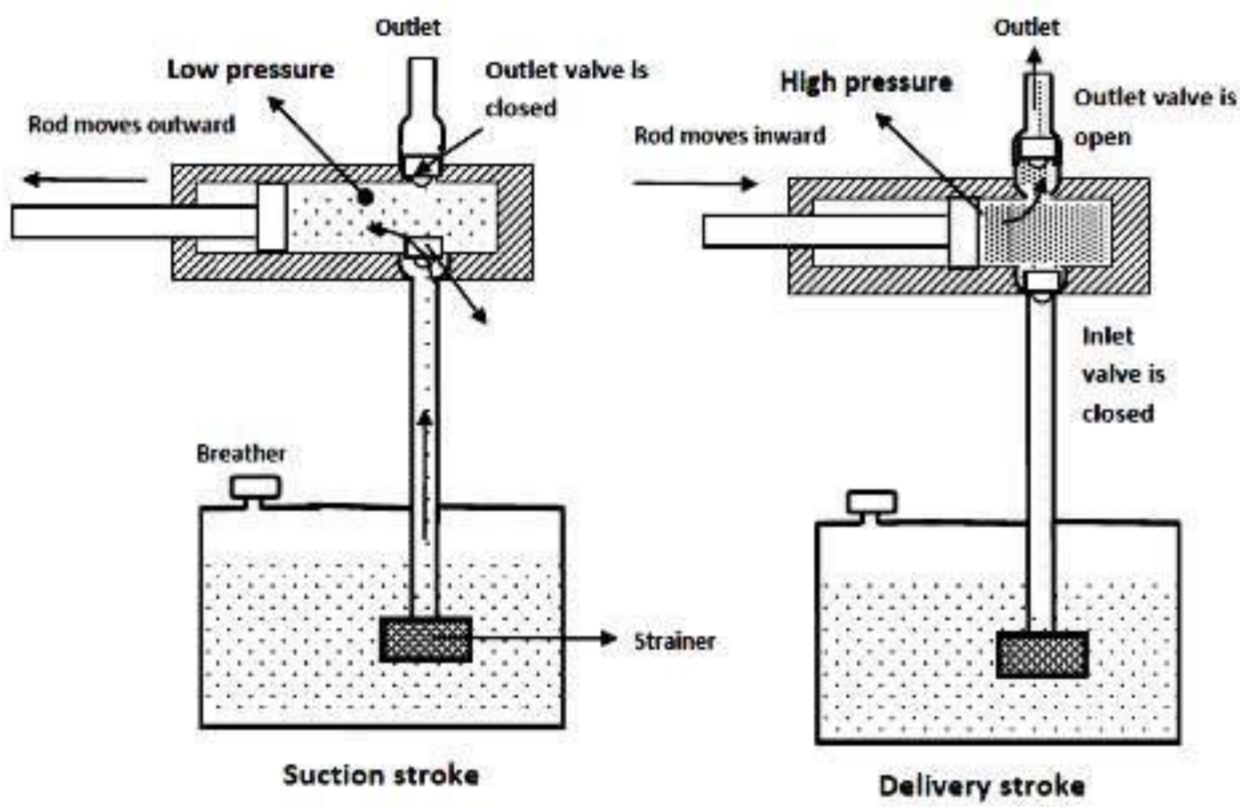
1. They can operate at very high pressures of up to 800 bar (used for lifting oils from very deep oil wells).
2. They can achieve a high volumetric efficiency of up to 98%.
3. They are highly efficient and almost constant throughout the designed pressure range.
4. They are a compact unit, having a high power-to-weight ratio.
5. They can obtain a smooth and precisely controlled motion.

6. By proper application and control, they produce only the amount of flow required to move the load at the desired velocity.

7. They have a great flexibility of performance. They can be made to operate over a wide range of pressures and speeds.

PUMPING THEORY OF POSITIVE DISPLACEMENT PUMPS:

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



1. As the piston moves to the left, a partial vacuum is created in the pump chamber that holds the outlet valve in place against its seat and induces flow from the reservoir that is at a higher (atmospheric) pressure. As this flow is produced, the inlet valve is temporarily displaced by the force of fluid, permitting the flow into the pump chamber (suction stroke).

2. When the piston moves to the right, the resistance at the valves causes an immediate increase in the pressure that forces the inlet valve against its seat and opens the outlet valve thereby permitting the fluid to flow into the system. If the outlet port opens directly to the atmosphere, the only pressure developed is the one required to open the outlet valve (delivery stroke).

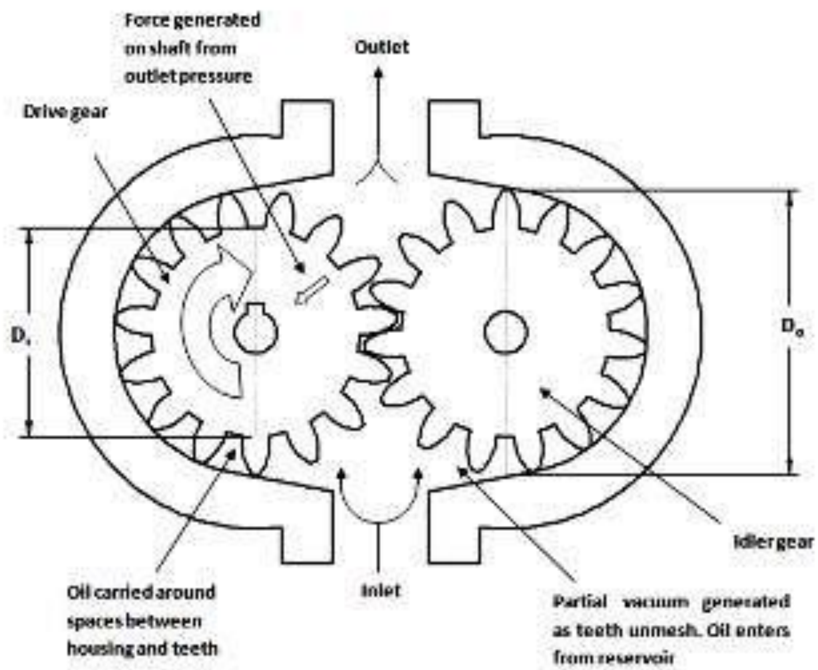
CLASSIFICATION OF POSITIVE DISPLACEMENT PUMPS:

1. **Gear Pumps**
   - External Gear pump
   - Internal Gear pump
2. **Vane Pumps**
   - Balanced vane pump
   - Unbalanced vane pump
3. **Piston Pumps** Axial type
   - Radial type

GEAR PUMPS:

Gear pumps are less expensive but limited to low pressures. It is noisy in operation than either vane or piston pumps. Gear pumps are invariably of fixed displacement type, which means that the amount of fluid displaced for each revolution of the drive shaft is theoretically constant.

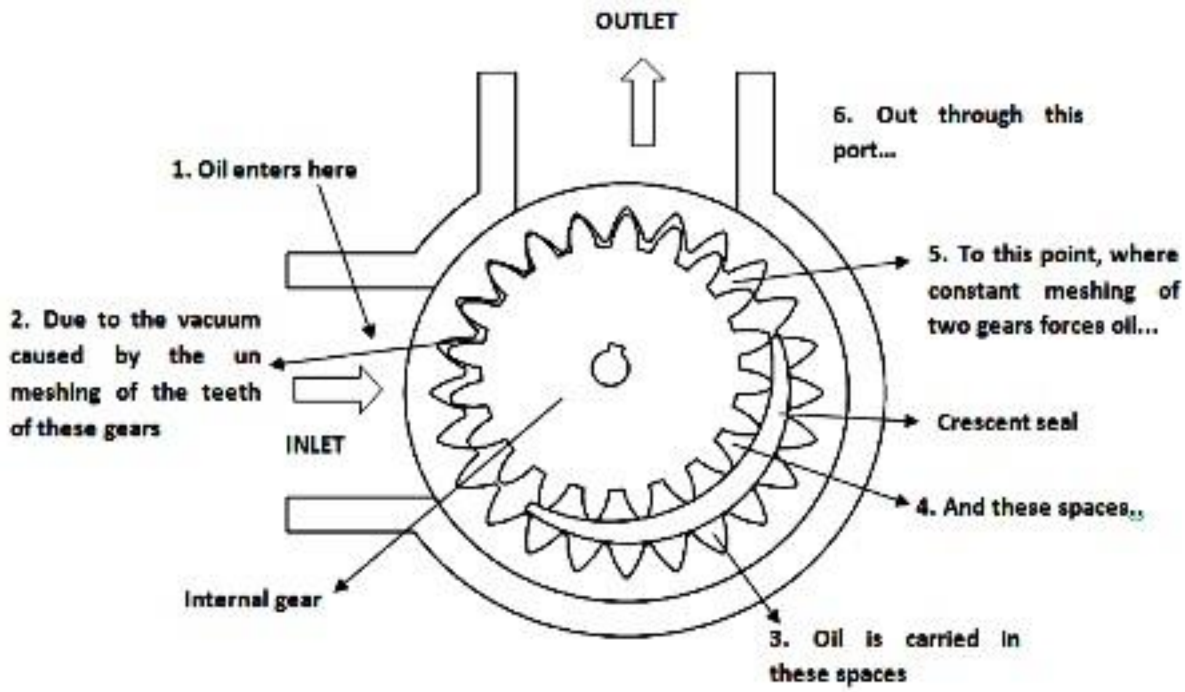
EXTERNAL GEAR PUMPS:



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

INTERNAL GEAR PUMPS:

Internal Gear Pumps consist of two gears: An external gear and an internal gear. The crescent placed in between these acts as a seal between the suction and discharge. When a pump operates, the internal gear drives the external gear and both gears rotate in the same direction. The fluid fills the cavities formed by the rotating teeth and the stationary crescent. Both the gears transport the fluid through the pump. The crescent seals the low-pressure pump inlet from the high-pressure pump outlet. These pumps have a higher pressure capability than external gear pumps.



ADVANTAGES OF GEAR PUMPS:

1.They are self-priming.

2.They give constant delivery for a given speed.

3. They are compact and light in weight.

DISADVANTAGES OF GEAR PUMPS:

1. The liquid to be pumped must be clean, otherwise it will damage pump.

2. Variable speed drives are required to change the delivery.

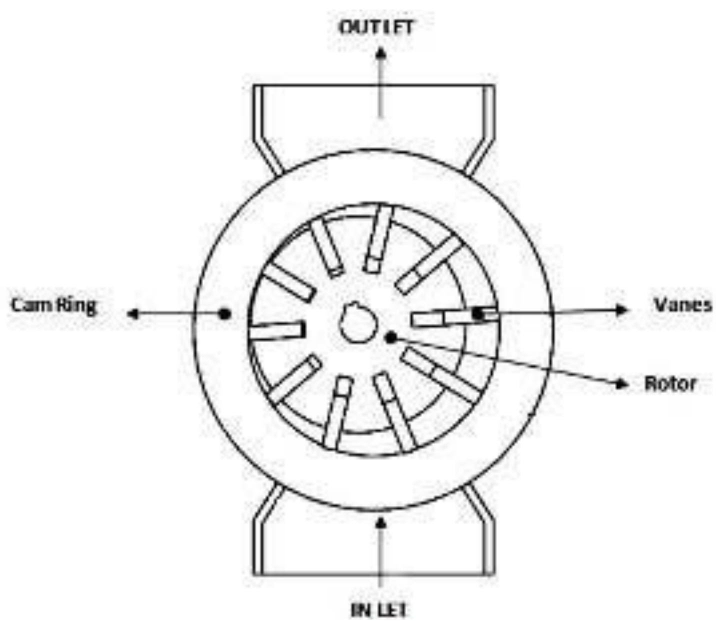
3. If they run dry, parts can be damaged because the fluid to be pumped is used as lubricant.

VANE PUMPS:

Vane Pumps are classified into

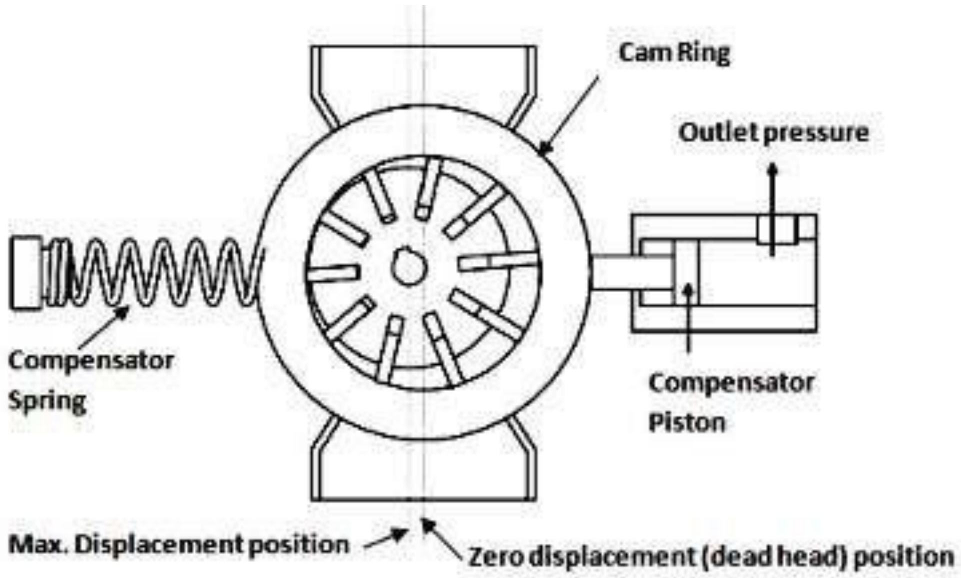
1. **Unbalanced vane pump**
    - Fixed displacement type
    - Pressure compensated variable displacement type
2. **Balanced vane pump**

UNBALANCED FIXED DISPLACEMENT VANE PUMP:



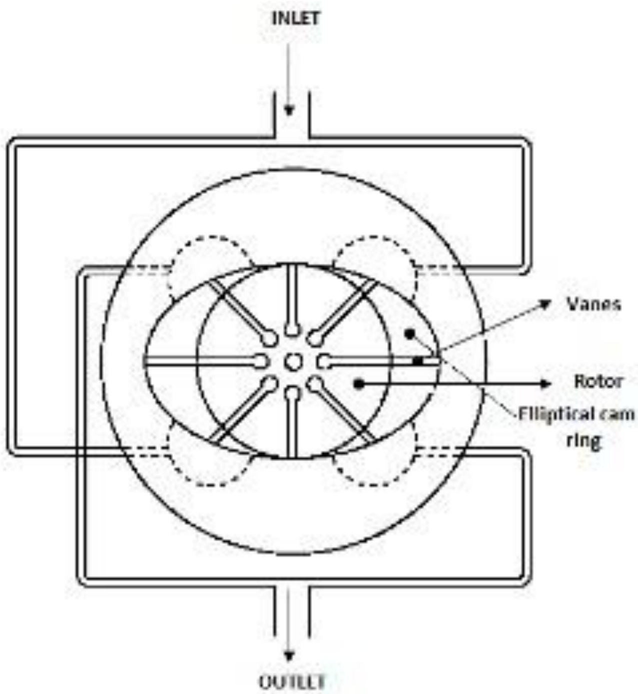
The main components of the pump are the cam surface and the rotor. The rotor contains radial slots splined to drive shaft. The rotor rotates inside the cam ring. Each radial slot contains a vane, which is free to slide in or out of the slots due to centrifugal force. The cam ring axis is offset to the drive shaft axis. When the rotor rotates, the centrifugal force pushes the vanes out against the surface of the cam ring. The vanes divide the space between the rotor and the cam ring into a series of small chambers. During the first half of the rotor rotation, the volume of these chambers increases, thereby causing a reduction of pressure. This is the suction process, which causes the fluid to flow through the inlet port. During the second half of rotor rotation, the cam ring pushes the vanes back into the slots and the trapped volume is reduced. This positively ejects the trapped fluid through the outlet port. The delivery rate of the pump depends on the eccentricity of the rotor with respect to the cam ring.

UNBALANCED PRESSURE COMPENSATED VARIABLE DISPLACEMENT VANE PUMP:



Variable displacement feature can be brought into vane pumps by varying eccentricity between the rotor and the cam ring. Here in this pump, the stator ring is held against a spring loaded piston. The system pressure acts directly through a hydraulic piston on the right side. This forces the cam ring against a spring-loaded piston on the left side. If the discharge pressure is large enough, it overcomes the compensated spring force and shifts the cam ring to the left. This reduces the eccentricity and decreases the flow. If the pressure continues to increase, there is no eccentricity and pump flow becomes zero.

BALANCED VANE PUMP:



The constructional features of a balanced vane pump is as shown in the fig. The rotor and the casing are on the same centre line. Vanes are provided in the slots of the rotor. There are two inlet and outlet chambers around the elliptical cam ring surface. The inlet and outlet chambers are positioned diagonally opposite to each other. The cam ring is elliptical in shape, so that the vanes stroke twice per revolution of the pump shaft. Thus the volume increase and decrease at the inlet and outlet chambers also occur twice per revolution. In fact, the inlet and outlet ports are connected to a common inlet and outlet within the pump housing. In operation, due to the elliptical shape of the cam ring, the oil suction at the inlets and the pumping at the outlets occurs simultaneously. This situation results in equal pressure on the opposite sides of the pump shaft, and the net force acting on bearing will be zero. Thus, it is termed the balanced vane pump.

PISTON PUMPS:

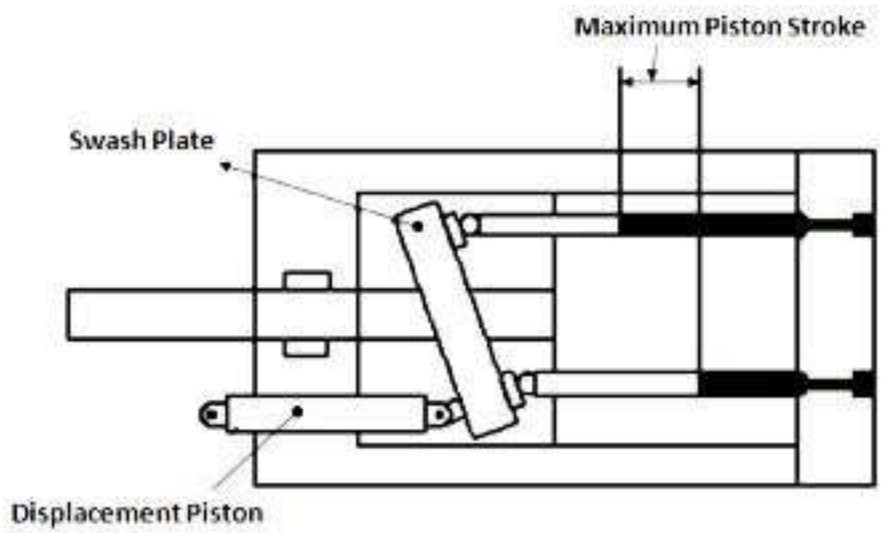
Piston pumps are of following types

1. **Axial Piston Pump**
    - Swash plate type piston pump

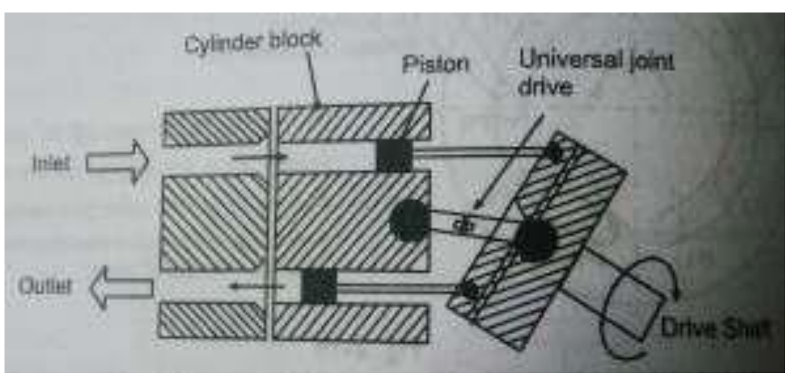
- Bent axis type piston pump

2. **Radial Piston Pump**

SWASH PLATE TYPE PISTON PUMP:



In this type, the cylinder block and drive shaft are located on the same center line. The pistons are connected to a shoe plate that bears against an angled swash plate. As the cylinder rotates, the pistons reciprocate because the piston shoes follow the angled surface of the swash plate. The outlet and inlet ports are located in the valve plate so that the pistons pass the inlet as they are being pulled out and pass the outlet as they are being forced back in. This type of pump can also be designed to have a variable displacement capability. **BENT AXIS TYPE PISTON PUMP:**



In constryction it consists of a cylinder block with arrayed cylindrical openings, housing, pistons and drive shaft. The housing design is such that it creates an offset angle between the centreline of the drive shaft and the centre line of the cylinder block. The pistons are connected to the drive plate with ball and socket joints. The drive plate and the cylinder block are connected with an universal joint, so that the motion is transmitted through the bent axis. The bent axis of the drive shaft leads to the reciprocatory motion of the pistons in the cylinder block. The housing end at the cylinder block is sealed with an end cap, having inlet and outlet ports with feed grooves.

PUMP PERFORMANCE:

The performance of a pump is a function of the precision of its manufacture. An ideal pump is one having zero clearance between all mating parts. Since this is not possible, working clearances should be as small as possible while maintaining proper oil films for lubrication between rubbing parts. The performance of a pump is determined by the following efficiencies:

1) **Volumetric efficiency (η_v):** It is the ratio of actual flow rate of the pump to the theoretical flow rate of the pump.

$$\eta_v = \frac{\text{Actual flow rate}}{\text{Theoretical flow rate}} \times 100$$

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

2) **Mechanical Efficiency (η_m):** It refers to the efficiency of the pump due to energy losses other than due to leakages.

$$\eta_m = \frac{\text{Pump output power (no leakage condition)}}{\text{Actual power input to pump}} \times 100$$

$P \times Q_T$

$$= \times 100 \quad 2\pi NT$$

Where, P = Pump discharge pressure, Pa

QT = Theoretical flow rate, m3/s

T = Torque input to pump, N.m

N = Pump speed, rps

3) **Overall Efficiency (η_o):** Overall efficiency refers to the overall performance of the pump considering possible losses including the leakage loss, friction loss, etc. it is given by the relation:

$$\eta_o = \frac{\text{Actual power output by pump}}{\text{Actual power input to pump}} \times 100$$

It can also be given by,

$$\eta_o = \frac{\eta_v \times \eta_m}{100}$$

$$\eta_o = \frac{P \times Q_A}{2\pi NT} \times 100$$

PUMP SELECTION FACTORS:

The main parameters affecting the selection of a particular type of pump are as follows:

1) Maximum operating pressure.

2) Maximum delivery.

3) Type of control.

4) Pump drive speed.

5) Type of fluid.

6) Pump contamination tolerance.
7) Pump noise.
8) Size and weight of a pump.
9) Pump efficiency.
10) Cost.
11) Availability and interchangeability.
12) Maintenance and Spares.

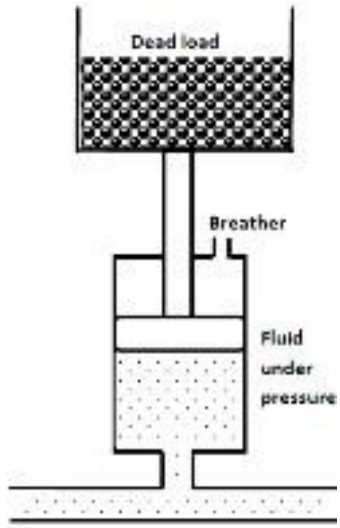
ACCUMULATORS:

A hydraulic accumulator is a device that stores the potential energy of an incompressible fluid held under pressure by an external source. The stored potential energy in the accumulator is a quick secondary source of fluid power capable of doing useful work.

CLASSIFICATION OF HYDRAULIC ACCUMULATORS:

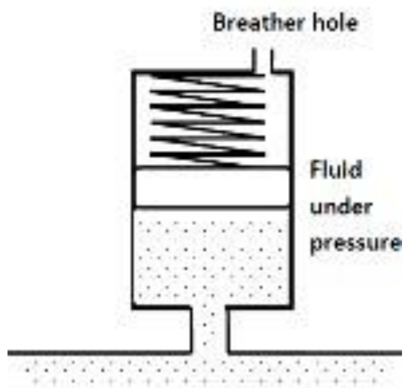
1) Weight loaded or gravity accumulator
2) Spring-loaded accumulator
3) Gas-loaded accumulator
    a) Non-seperator type
    b) Seperator type
        i)Piston type
        ii)Diaphragm type
        iii)Bladder type

WEIGHT LOADED OR GRAVITY ACCUMULATOR:



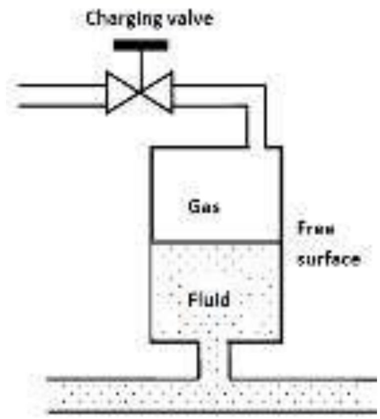
It is a vertically mounted cylinder with a large weight. When the hydraulic fluid is pumped into it, the weight is raised. The weight applies a force on the piston that generates a pressure on the fluid side of piston. The advantage of this type of accumulator over other types is that it applies a constant pressure on the fluid throughout its range of motion. The main disadvantage is its extremely large size and heavy weight. This makes it unsuitable for mobile application.

SPRING LOADED ACCUMULATOR:



A spring-loaded accumulator stores energy in the form of a compressed spring. A hydraulic fluid is pumped into the accumulator, causing the piston to move up and compress the spring. The compressed spring then applies a force on the piston that exerts a pressure on the hydraulic fluid. This type of accumulator delivers only a small volume of oil at relatively low pressure.

GAS LOADED ACCUMULATOR:

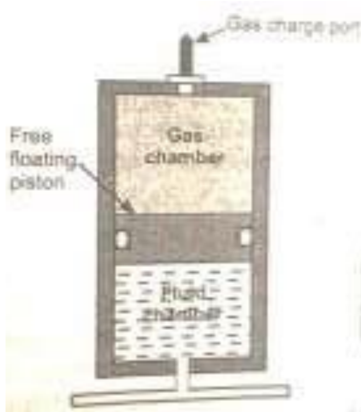


A gas-loaded accumulator is popularly used in industries. Here the force is applied to the oil using compressed air. A gas accumulator can be very large and is often used with water or high water-based fluids using air as a gas charge.

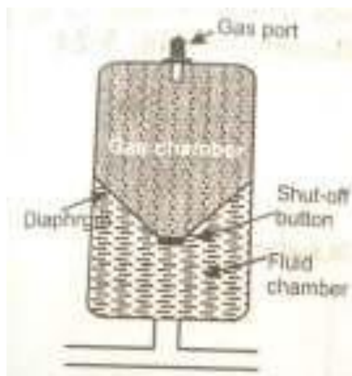
There are two types of gas-loaded accumulators:

- **Non-separator-type accumulator:** Here the oil and gas are not separated. Hence, they are always placed vertically.
- **Separator-type accumulator:** Here the oil and gas are separated by an element. Based on the type of element used to separate the oil and gas, they are classified as follows:

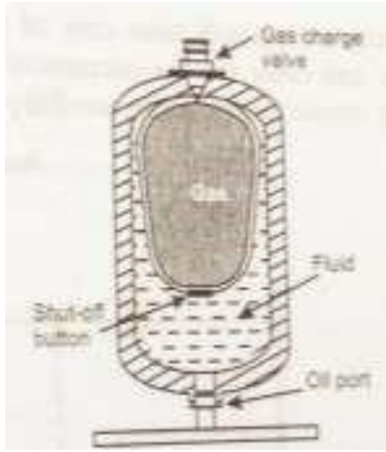
a) Piston type accumulator: It consists of a cylinder with a freely floating piston with proper seals. Its operation begins by charging the gas chamber with a gas (nitrogen) under a pre-determined pressure. This causes the free sliding piston to move down. Once the accumulator is pre-charged, a hydraulic fluid can be pumped into the hydraulic fluid port. As the fluid enters the accumulator, it causes the piston to slide up, thereby compressing the gas that increases its pressure and this pressure is then applied to the hydraulic fluid through the piston.



b) Diaphragm type accumulator: In this type, the hydraulic fluid and nitrogen gas are separated by a synthetic rubber diaphragm. The advantage of a diaphragm accumulator over a piston accumulator is that it has no sliding surface that requires lubrication and can therefore be used with fluids having poor lubricating qualities. It is less sensitive to contamination due to lack of any close-fitting components.



c) Bladder type accumulator: Here the gas and the hydraulic fluid are separated by a synthetic rubber bladder. The bladder is filled with nitrogen until the designed pre-charge pressure is achieved. The hydraulic fluid is then pumped into the accumulator, thereby compressing the gas and increasing the pressure in the accumulator.



ACTUATORS:

An actuator is used to convert the energy of fluid back into the mechanical power. The amount of output power developed depends upon the flow rate, the pressure drop across the actuator and its overall efficiency. Thus, hydraulic actuators are devices used to convert pressure energy of the fluid into mechanical energy.

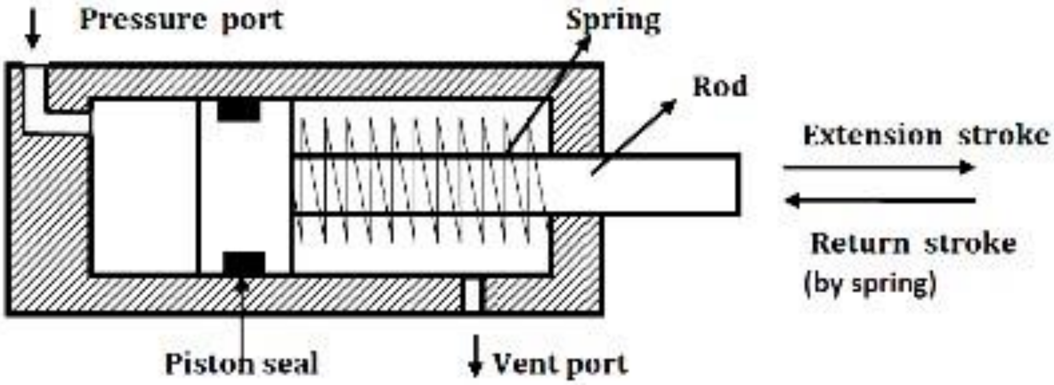
Depending on the type of actuation, hydraulic actuators are classified as follows:

1) **Linear actuator**: For linear actuation (hydraulic cylinders)
2) **Rotary actuator:** For rotary actuation (hydraulic motor)

Hydraulic linear actuators, as their name implies, provide motion in a straight line. They are usually referred to as cylinders, rams and jacks. The function of hydraulic cylinder is to convert hydraulic power into linear mechanical force or motion. Hydraulic cylinders extend and retract a piston rod to provide a push or pull force to drive the external load along a straight-line path. Hydraulic cylinders are of the following types:

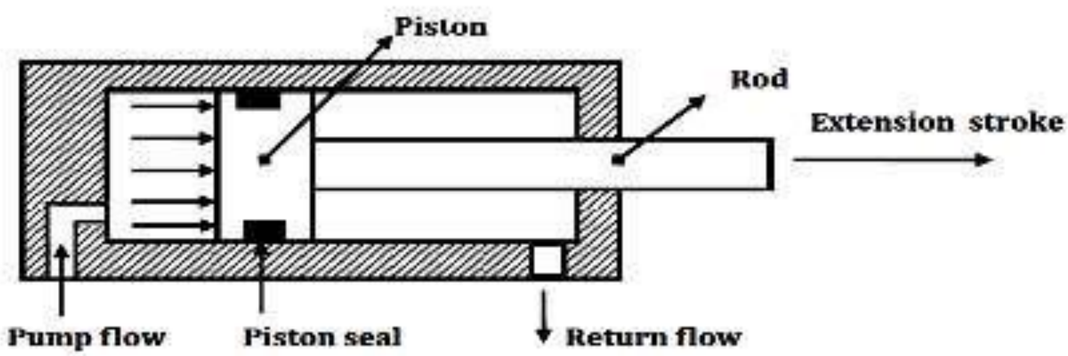
- Single-acting cylinders
- Double-acting cylinders
- Double rod cylinders
- Tandem cylinders
- Telescopic cylinders
- Cushioned cylinders

SINGLE-ACTING CYLINDERS:

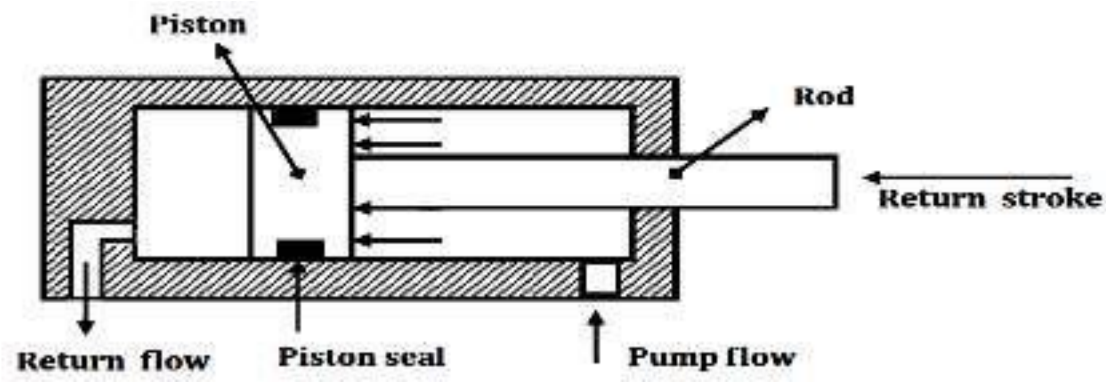


A single-acting cylinder is simplest in design and consists of a piston inside a cylindrical housing called barrel. On one end of the piston there is a rod, which can reciprocate. At the opposite end, there is a port for the entrance and exit of oil. Single-acting cylinders produce force in one direction by hydraulic pressure acting on the piston during extension stroke. The retraction is done either by gravity or by a spring.

DOUBLE ACTING CYLINDERS:



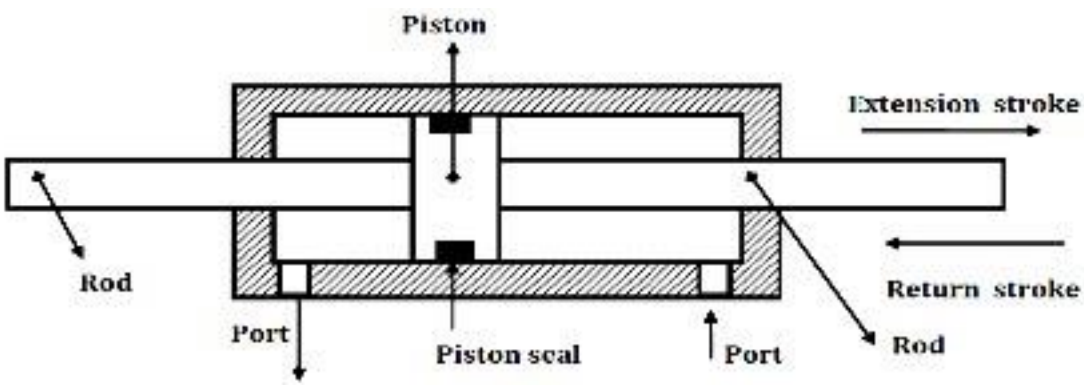
(a)



(b)

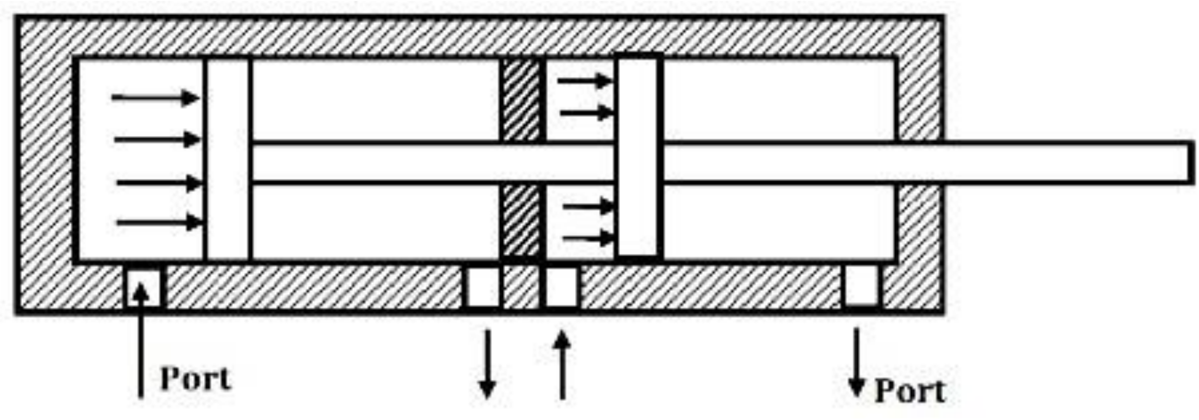
Figure shows the operation of a double-acting cylinder with a piston rod on one side. To extend the cylinder, the pump flow is sent to the blank-end port as in Fig.(a). The fluid from the rod-end port returns to the reservoir. To retract the cylinder, the pump flow is sent to the rod-end port and the fluid from the blank-end port returns to the tank as in Fig.(b).

DOUBLE ROD CYLINDERS:



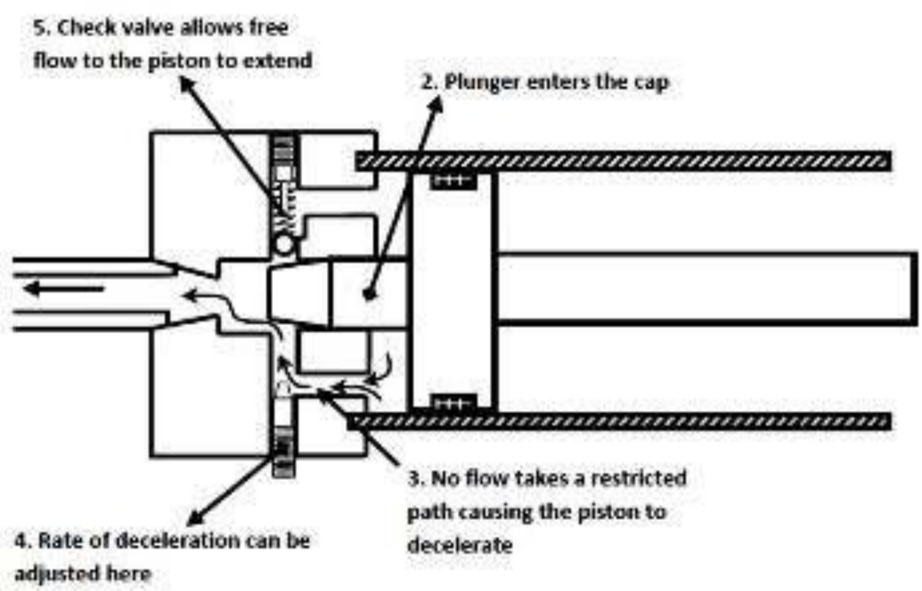
A double-acting cylinder with a piston rod on both sides is a cylinder with a rod extending from both ends. This cylinder can be used in an application where work can be done by both ends of the cylinder, thereby making the cylinder more productive. Double-rod cylinders can withstand higher side loads because they have an extra bearing, one on each rod, to withstand the loading.

TANDEM CYLINDERS:



A tandem cylinder is used in applications where a large amount of force is required from a small-diameter cylinder. Pressure is applied to both pistons, resulting in increased force because of the larger area. The drawback is that these cylinders must be longer than a standard cylinder to achieve an equal speed because flow must go to both pistons.

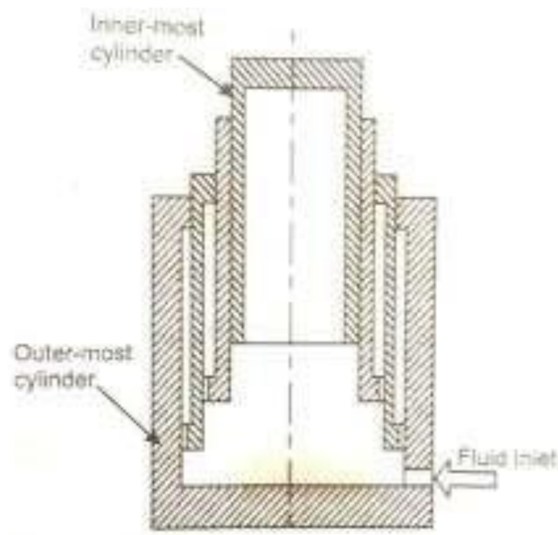
CUSHIONED CYLINDERS:



When the cylinder piston is actuated, the fluid enters the cylinder port and flows through the little check valve so that the entire piston area can be utilized to produce force and motion. For the prevention of shock due to stopping loads at the end of the piston stroke, cushion devices are used. Cushions may be applied at either end or both ends. They operate on the principle

that as the cylinder piston approaches the end of stroke, an exhaust fluid is forced to go through an adjustable needle valve that is set to control the escaping fluid at a given rate.
This allows the deceleration characteristics to be adjusted for different loads.

TELESCOPIC CYINDERS:



It has multiple cylinders that are mounted concentrically one within the other. The design is such that the inner most cylinder extends first, while the next cylinder extends after completion of the full stroke of the cylinder. Thus, each cylinder extends in stage, one after the other. Each stage of the cylinder has a sleeve that fits into the previous stage of the cylinder. The total stroke length achieved will be sum of the strokes of all the stages.

QUESTIONS FROM PREVIOUS YEAR QUESTION PAPERS:

DEC 2015/JAN 2016

1) Explain the working and design of a vane pump.
2) A pump has a displacement volume of $120 cm^3$. It delivers $1.5\times10^{-3}\ m^3/s$ at 1440RPM and 60bar. If the prime mover input torque is 130 N-m and overall efficiency 88%, find

theoretical discharge of the pump, volumetric efficiency of the pump, mechanical effieciency of the pump, overall efficiency.

3) A pump supplies oil at 0.0016 m^3/s at a 40mm diameter double acting hydraulic cylinder. If the load is 500N and the rod dia is 20mm, find i) cylinder power during extension stroke ii) cylinder power during retraction stroke iii) pressure during extension and retraction stroke iv) piston velocity during extension and retraction stroke.

JUNE/JULY 2016

1) Explain the construction and working of an external gear pump.
2) Determine the volumetric efficiency of a gear pump of external diameter and internal diameter of gears 75mm and 50mm respectively and width of gear teeth 50mm, if the actual discharge is 30LPM at 1800rpm. [LPM = Litres per minute] 3)Sketch and explain double acting cylinder.

DEC 2016/JAN 2017

1) Explain the working of unbalanced vane pump. Also obtain an expression for its theoretical discharge.
2) A pump having a displacement of 25cm^3, operates with a pressure of 250bar and speed of 1390rpm. Volumetric efficiency of 0.85 and mechanical efficiency of 0.80. calculate i) pump delivery in LPM ii) input power at pimp shaft in KW iii) Drive Torque at pump shaft
3) An 8cm diameter hydraulic cylinder has 4cm diameter rod. If the cylinder receives the flow at 100LPM and 12Mpa. Find i) extension and retraction speeds ii) extension and retraction load carrying capacities.

JUNE/JULY 2017

1) With neat sketch explain the construction and working of a gear pump.

2) Determine the volumetric efficiency of a gear pump of external and internal diameters 75mm and 50mm respectively. Width of the gear teeth is 50mm. if the actual discharge is 30×10^{-3} m^3/min at 1800rpm.

3) With a neat sketch explain the working of linear actuator for single acting cylinder.

DEC 2017/JAN 2018

1) A gear pump has a 75mm outside diameter, a 50mm inside diameter and a 25mm width. If the volumetric efficiency is 90% at rated pressure, what is the corresponding actual flow rate? The pump speed is 1000rpm.

2) A pump has a displacement volume of 100 cm^3. It delivers 0.0015 m^3/s at 1000rpm and 70bars. If the prime mover input torque is 120N-m. Determine
   - i) What is the overall efficiency of the pump?
   - ii) What is the theoretical torque required to operate the pump?

3) A pump supplies oil at 75.8 litres/min to a 50.8mm diameter double-acting hydraulic cylinder. If the load is 4448 N (extending and retracting) and the rod diameter is 25.4mm, find

   i) The hydraulic pressure during the extension and retraction stroke ii) The piston velocity during the extension and retraction stroke iii) The cylinder power during extension and retraction stroke 4)Explain with a neat sketch a Gear Pump.

JUNE/JULY 2018

1) With a neat diagram, explain the working principle of a typical hydraulic gear pump.

2) What is actuator? State its broad classification.

3) Explain the following single acting cylinders with neat sketches.

   i) Gravity Type ii) Spring Type iii) Telescopic iv) Tandem

CRASH COURSE – MAY 2017

1) What is the pressure compensated vane pump? How does it work? Explain with neat sketch.

2) A pump supplies oil at $0.0016m^3/s$ to a 40mm double acting hydraulic cylinder. If the load is 5000N (extending and retracted) and the rod diameter is 20mm, find the hydraulic pressure during extension and retraction stroke, piston velocity during extension and retraction stroke, cylinder power during the extension and retraction stroke.

ONE TIME EXIT SCHEME – APRIL 2018

1) Give the classification of pumps. With a neat sketch explain swash plate type piston pump.
2) A pump has a displacement of $98.4cm^3$. It delivers 0.00152 m^3/s of oil at 1000rpm and 70bar. If the prime mover input torque is 124.3N-m. Find i) Overall efficiency of pump; ii) theoretical torque required to operate the pump.
3) With a neat sketch, explain external gear pump.

MODULE 3: COMPONENTS AND HYDRAULIC CIRCUIT DESIGN

Components: Classification of control valves, Directional Control Valves-symbolic representation, constructional features of poppet, sliding spool, rotary type valves solenoid and pilot operated DCV, shuttle valve, and check valves.

Pressure control valves - types, direct operated types and pilot operated types.

Flow Control Valves - compensated and non-compensated FCV, needle valve, temperature compensated, pressure compensated, pressure and temperature compensated FCV, symbolic representation.

Hydraulic Circuit Design: Control of single and Double -acting hydraulic cylinder, regenerative circuit, pump unloading circuit, double pump hydraulic system, counter balance valve application, hydraulic cylinder sequencing circuits, cylinder synchronizing circuit using different methods, hydraulic circuit for force multiplication; speed control of hydraulic cylinder metering in, metering out and bleed off circuits. Pilot pressure operated circuits.

Hydraulic circuit examples with accumulator.

COMPONENTS

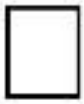
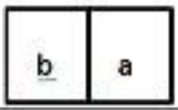
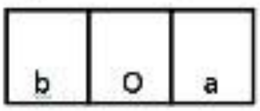
One of the most important consideration in any fluid power systems is the control. If the control components are not properly selected, the entire system will not function as required. Fluid power is controlled primarily through the use of control devices called valves. There are three types of valves:

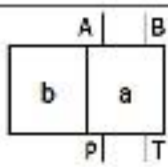
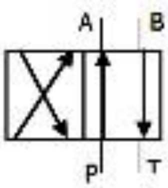
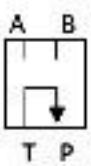
1. Direction control valves
2. Pressure control valves
3. Flow control valves

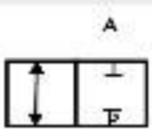
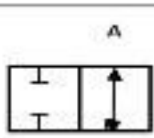
- The direction control valves determine the path through which fluid traverses in a given circuit.
- The pressure control valves protect the system against the excessive pressure, which may occur due to higher actuator loads or closing of valves.
- The flow control valves are used to control flow rate in various lines of a hydraulic circuit to control the actuator speeds.

DIRECTION CONTROL VALVES:

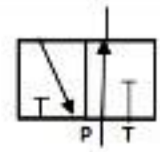
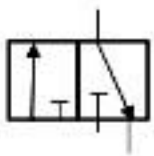
Symbolic Representation:

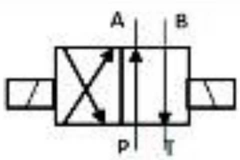
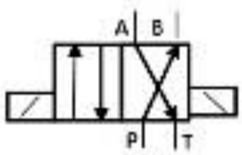
	Each individual switching portion is shown in a square
	Flow path is indicated by means of arrow within a square
	Closed position
	Two-position valve
	Three-position valve

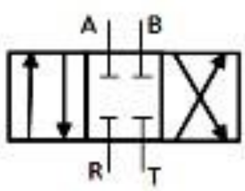
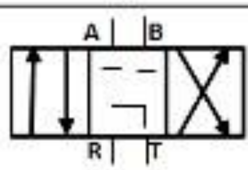
	Ports added to the two-position valve
	Two flow paths
	Two ports are connected, two ports are closed

2/2-way valve: 2-ports and 2-position DCV	
	Normally closed position: P is not connected to A. When the valve is not actuated, the way is closed.
	Normally open position: P is connected to A. When the valve is not actuated, the way is open.

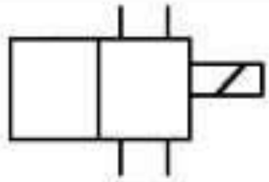
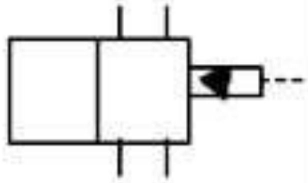
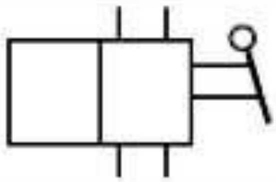
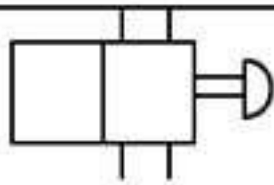
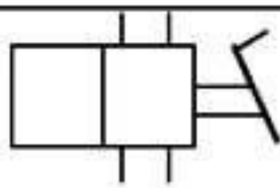
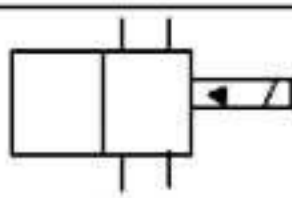
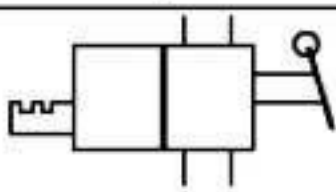
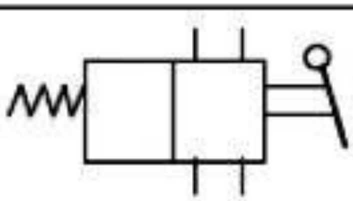
3/2-way valve: 3ports and 2 position DCV

	Normally open position: P is connected to A. When the valve is not actuated, the way is open.
	Normally open position: P is connected to A. When the valve is actuated, the way is closed

4/2-way valve – 4-port and 2-position DCV	
	P is connected to A B is connected to T
	Position 2: P is connected to B A is connected to T

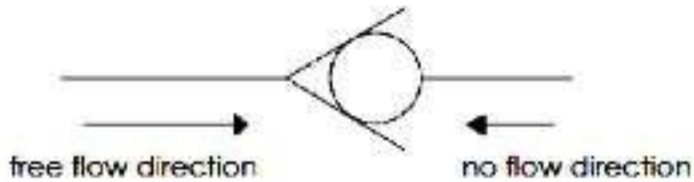
4/3-way valve – 4-port and 3-position DCV	
	P, T, A, B
	Mid-position pump reticulating: P to T, A and B closed

Actuating Devices:

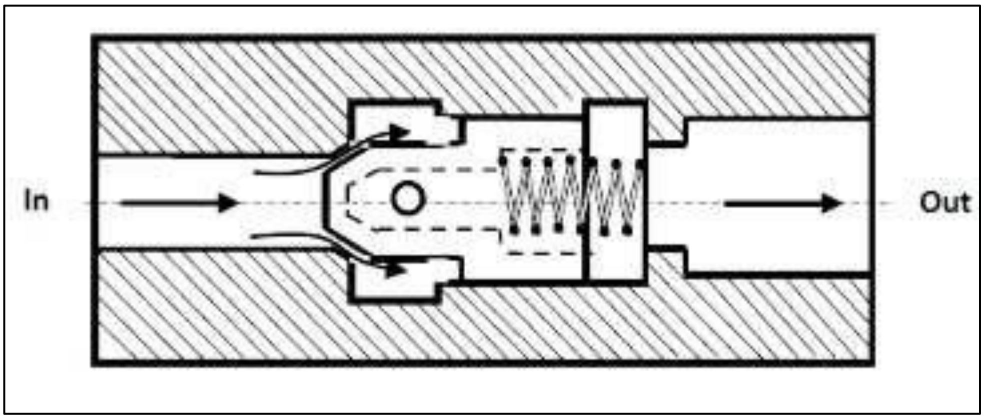
	Solenoid operated
	Pilot operated
	Manual operated
	Push button
	Foot operated
	Pilot-operated solenoid
	Two-position detent
	Spring return

Check Valve:

The simplest DCV is a check valve. A check valve allows flow in one direction, but blocks the flow in the opposite direction. Figure shows the graphical symbol of a check valve along with its no-flow and free-flow directions.



Poppet Check Valve:



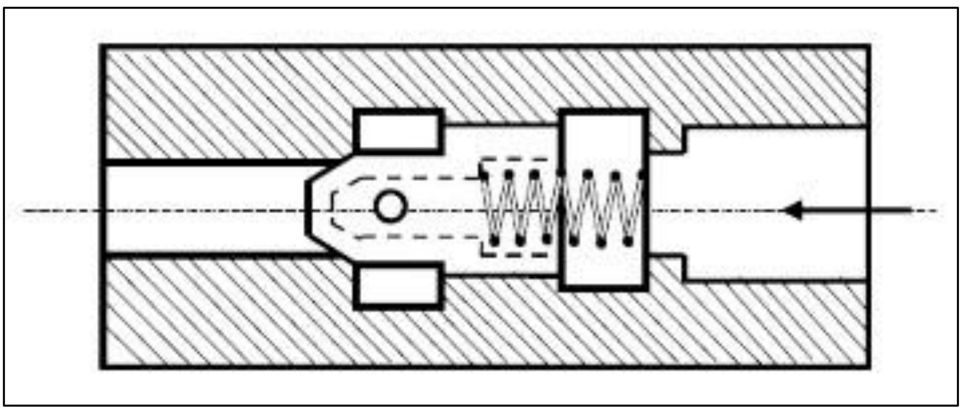
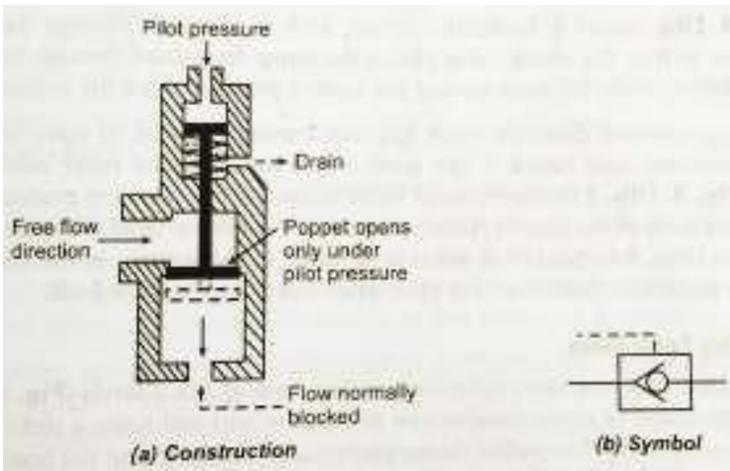


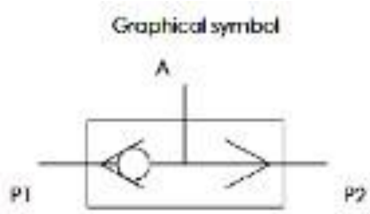
Figure shows the operation of a poppet check valve. A poppet is a specially shaped plug element held on a valve seat by a light spring. Fluid flows through the valve in the space between the seat and poppet. In the free flow direction, the fluid pressure overcomes the spring force. If the flow is attempted in the opposite direction, the fluid pressure pushes the poppet in the closed position. Therefore, no flow is permitted.

Pilot operated check valve (Pilot operated DCV):

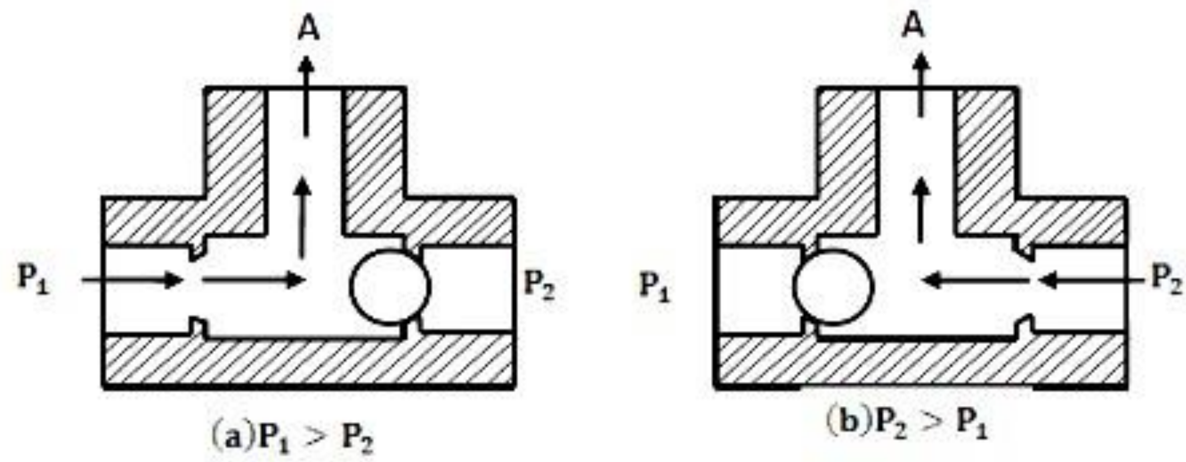
The pilot-operated check valve can permit flow in both the directions. In the normal operation, it functions like a check valve allowing free flow in one direction and blocking the flow in reverse direction. But when the pilot pressure is applied at the pilot port, it opens up the check valve and thus allows flow in the reverse direction. To achieve this function, the pilot piston is attached to the main poppet valve. The poppet is kept in normally closed condition with the help of a light spring.



Shuttle Valve:



A shuttle valve allows two alternate flow sources to be connected in a one-branch circuit. The valve has two inlets P1 and P2 and one outlet A. Outlet A receives flow from an inlet that is at a higher pressure. Figure shows the operation of a shuttle valve. If the pressure at P1 is greater than that at P2, the ball slides to the right and allows P1 to send flow to outlet A. If the pressure at P2 is greater than that at P1, the ball slides to the left and P2 supplies flow to outlet A.

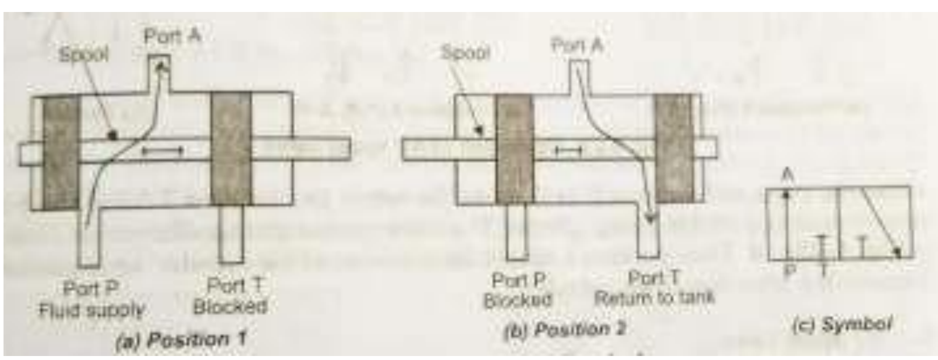


Sliding Spool Valve:

Aspool is a step machined cylinder member, having 2 or 3 lands. The lands are machined to close dimensional tolerances and will have a sliding fit in the bore of the valve body. The openings formed between the lands on the spool act as the flow passages between the connecting ports.

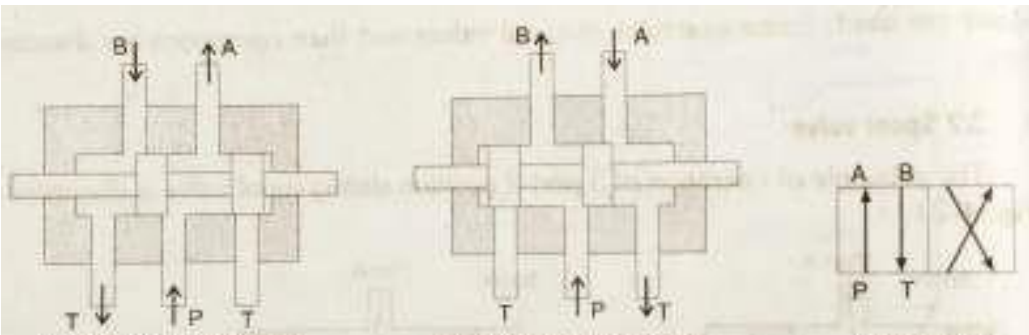
3/2 Spool valve:

It has a cylindrical body with three ports P, T and A. Port P receives the fluid into the cylinder, Port A is connected to an actuation system and Port T is connected to the return line.



In operation, in the position 1, the fluid supply under pressure is connected to port P and port T is closed. That means pressure now flows through port A, and activates the device connected in that line. When the spool is moved to the position 2, the port P is closed, there by cutting the supply, while port is opened. Since there is pressure in the line (through port A), the pressure is relieved through the open port T and the fluid freely flows out the sump. **4/2 Spool Valve:**

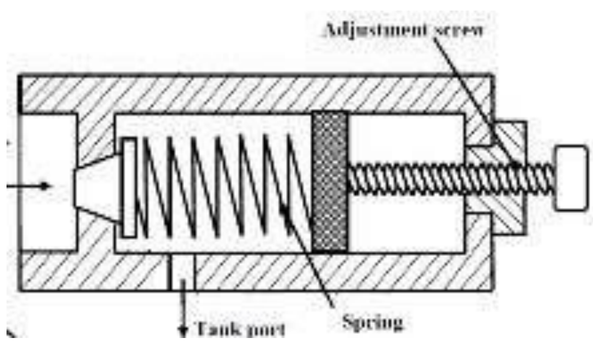
In position 1, the spool is connecting ports P to A, and ports B to T. This allows the pressure flow from P to A, while return from B to T. In position 2, the spool is connecting ports P to B and ports A to T. This allows the pressure flow from P to B, while return from A to T. Such a valve is used in double acting cylinder. Thus, position 1 causes the extension of the cylinder, while position 2 causes the retraction of the cylinder.



(a) Position 1 (P-A, B-T) (b) Position 2 (P-B, A-T) (c) Symbol

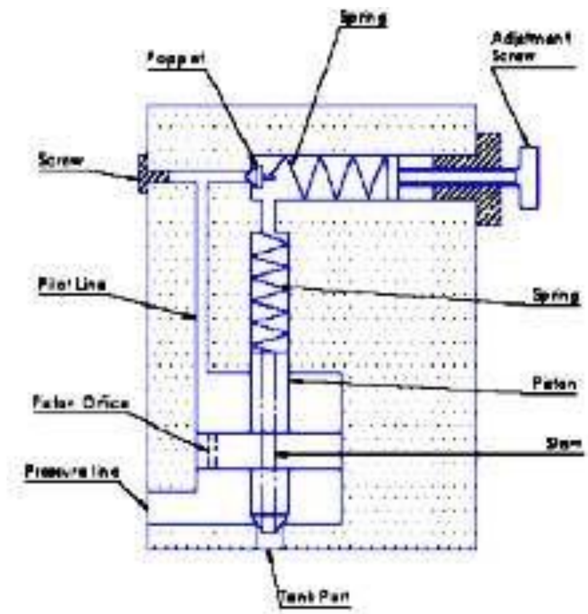
PRESSURE CONTROL VALVES:

Pressure Relief Valves:



The most widely used type of pressure control valve is the pressure-relief valve because it is found in practically every hydraulic system. It is normally a closed valve whose function is to limit the pressure to a specified maximum value by diverting pump flow back to the tank. A poppet is held seated inside the valve by a heavy spring. When the system pressure reaches a high enough value, the poppet is forced off its seat. This permits flow through the outlet to the tank as long as this high pressure level is maintained.

Compound Pressure Relief Valve (Pilot Operated Pressure Control Valve):

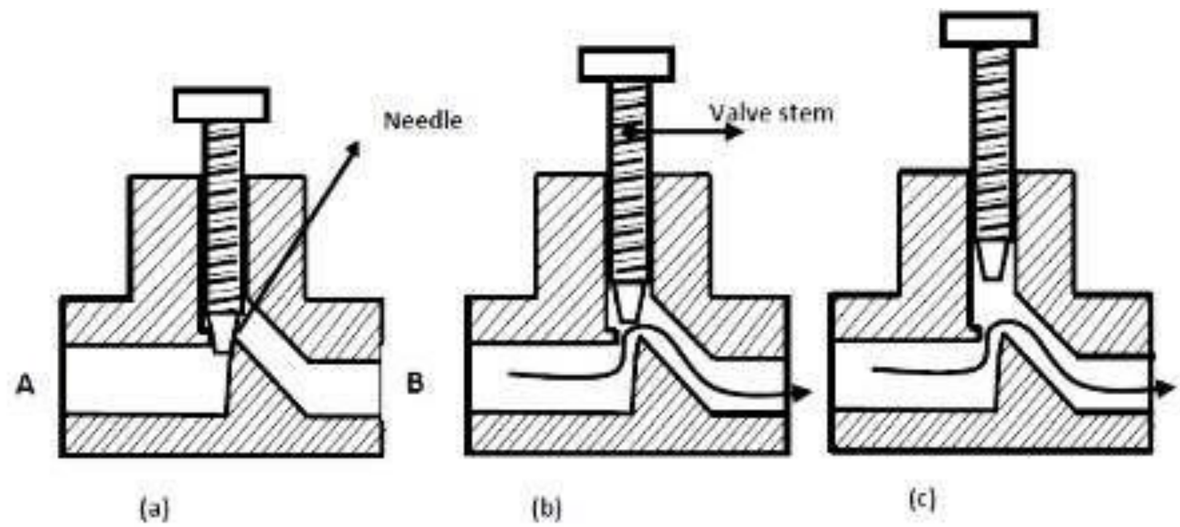


The pilot-operated pressure-relief valve has a pressure port that is connected to the pump line and the tank port is connected to the tank. The pilot relief valve is a poppet type. The main relief valve consists of a piston and a stem. The main relief piston has an orifice drilled through it. The piston has equal areas exposed to pressure on top and bottom and is in a balanced condition due to equal force acting on both the sides. It remains stationary in the closed position. The piston has a light bias spring to ensure that it stays closed. When the pressure is less than that of relief valve setting, the pump flow goes to the system. If the pressure in the system becomes high enough, it moves the pilot poppet off its seat. A small amount of flow begins to go through the pilot line back to the tank. Once flow begins through the piston orifice and pilot line, a pressure drop is induced across the piston due to the restriction of the piston orifice. This pressure drop then causes the piston and stem to lift off their seats and the flow goes directly from the pressure port to the tank.

Flow Control Valves:

Non-Pressure Compensated Flow Control Valves:

Non-pressure-compensated flow-control valves are used when the system pressure is relatively constant and motoring speeds are not too critical. The operating principle behind these valves is that the flow through an orifice remains constant if the pressuredrop across it remains the same. In other words, the rate of flow through an orifice depends on the pressure drop across it.

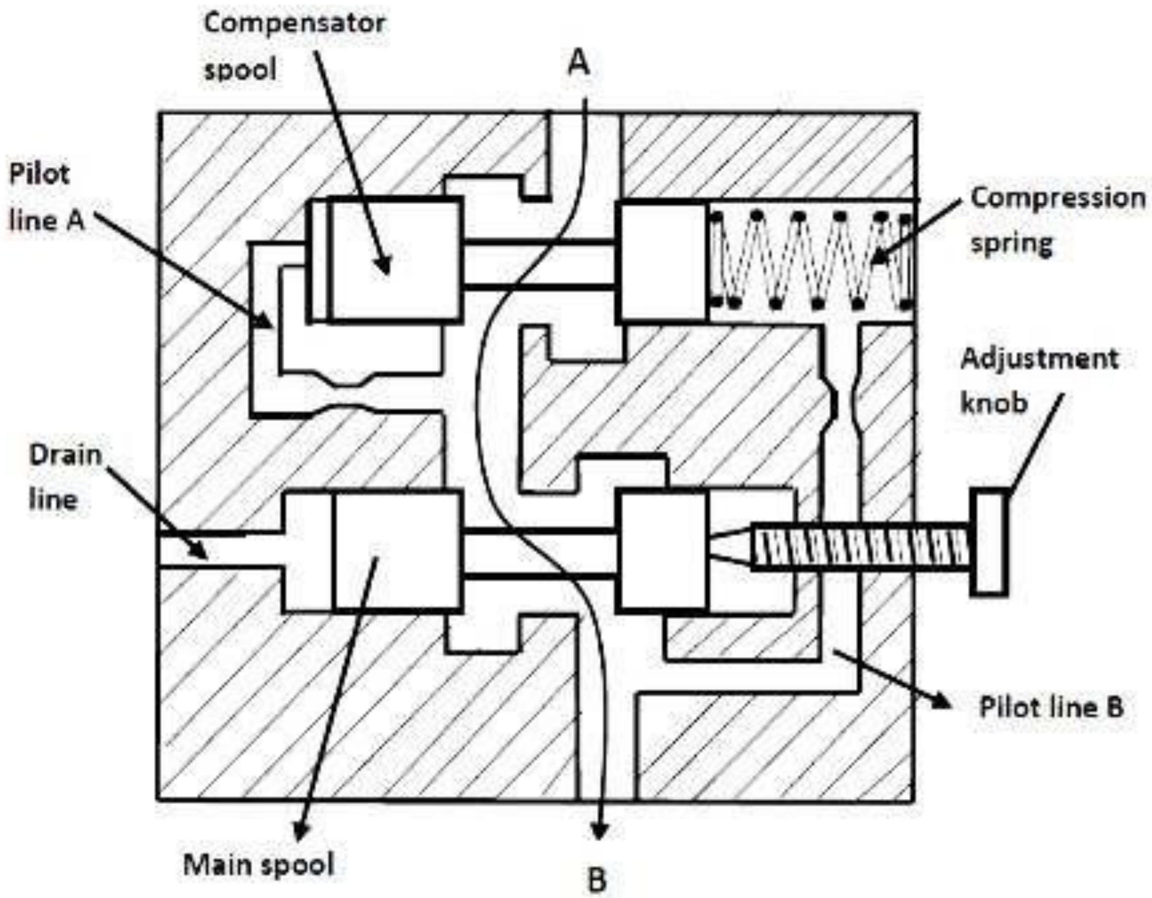


Non-pressure-compensated needle-type flow-control valve. (a) Fully closed: (b) partially opened: (c) fully opened.

It is the simplest type of flow-control valve. It consists of a screw (and needle) inside a tubelike structure. It has an adjustable orifice that can be used to reduce the flow in a circuit. The size of the orifice is adjusted by turning the adjustment screw that raises or lowers the needle.
For a given opening position, a needle valve behaves as an orifice.

Pressure Compensated Flow Control Valve:

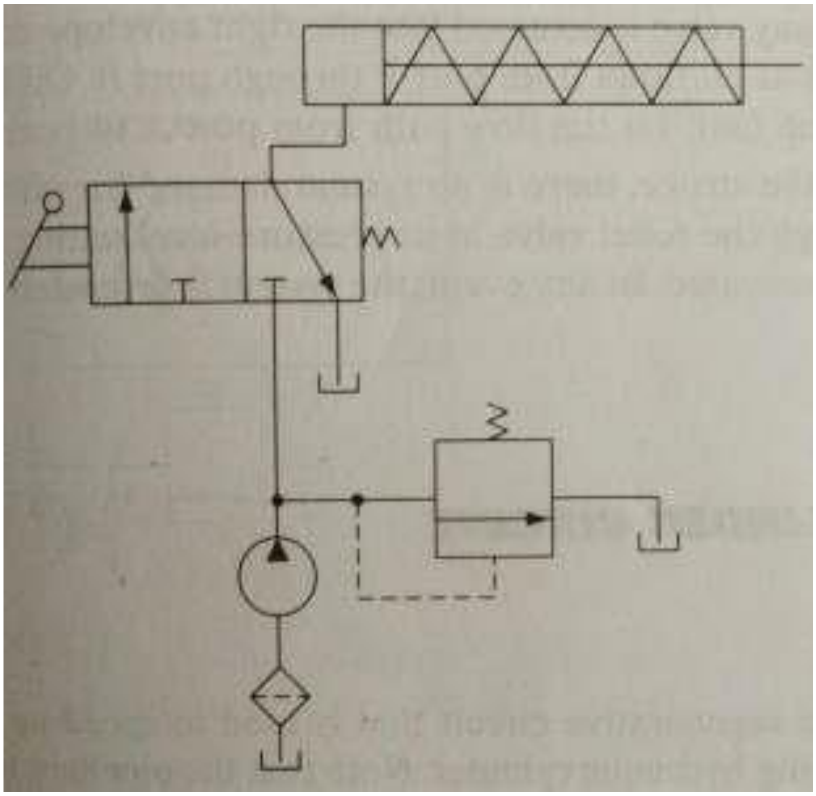
A pressure-compensated flow-control valve consists of a main spool and a compensator spool. The adjustment knob controls the main spool's position, which controls the orifice size at the outlet. The upstream pressure is delivered to the valve by the pilot line A. Similarly, the downstream pressure is ported to the right side of the compensator spool through the pilot line B. The compensator spring biases the spool so that it tends toward the fully open position. If the pressure drop across the valve increases, that is, the upstream pressure increases relative to the downstream pressure, the compensator spool moves to the right against the force of the spring. This reduces the flow that in turn reduces the pressure drop and tries to attain an equilibrium position as far as the flow is concerned.



In the static condition, the hydraulic forces hold the compensator spool in balance, but the bias spring forces it to the far right, thus holding the compensator orifice fully open. In the flow condition, any pressure drop less than the bias spring force does not affect the fully open compensator orifice, but any pressure drop greater than the bias spring force reduces the compensator orifice. Any change in pressure on either side of the control orifice, without a corresponding pressure change on the opposite side of the control orifice, moves the compensator spool. Thus, a fixed differential across the control orifice is maintained at all times. It blocks all flow in excess of the throttle setting. As a result, flow exceeding the preset amount can be used by other parts of the circuit or return to the tank via a pressure-relief valve.

HYDRAULIC CIRCUITS:

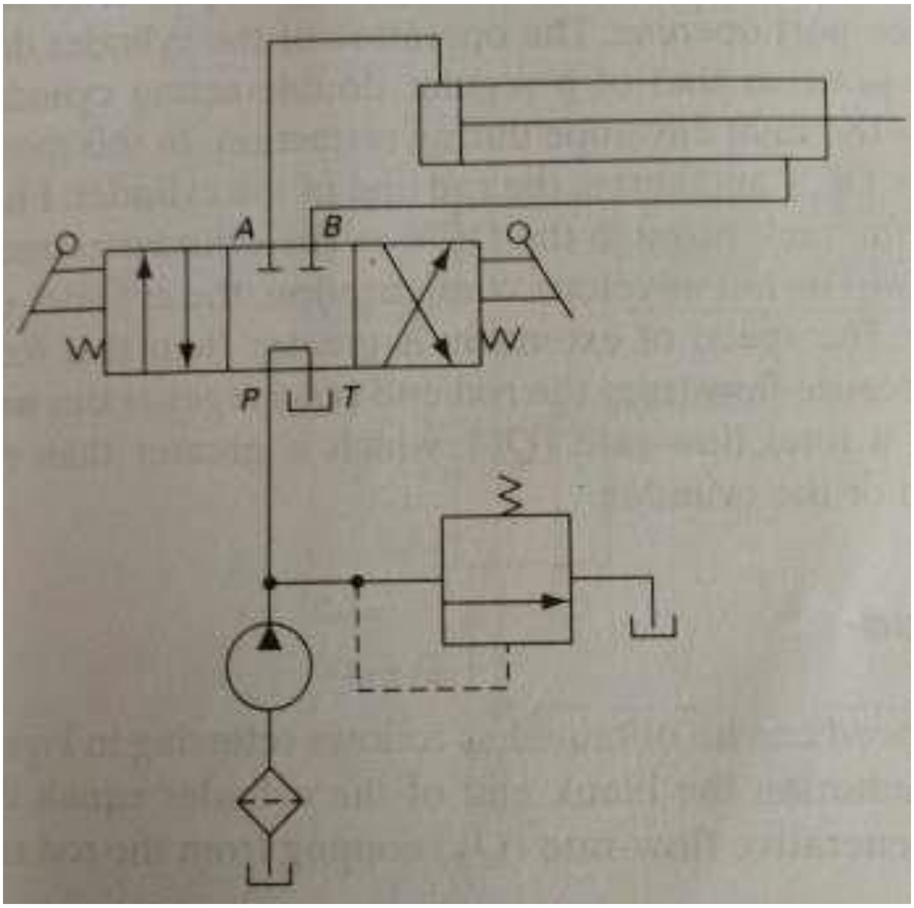
Control of a Single-Acting Hydraulic Cylinder:



The circuit has a filter, pump, pressure relief valve, a DCV and a spring return single acting cylinder. In operation, with the cylinder in normally retracted position (under spring pressure), when the valve is operated manually, the pressure port opens, the pump flow is directed to the piston end of the cylinder and causes extension of cylinder. Once, the extension is achieved, PRV opens-out and flow starts to pass through the PRV in the bypass line. When the DCV is deactuated, the pressure port is blocked, and the oil from the piston end of cylinder is routed to tank line. The cylinder starts retracting under spring pressure, and the oil flows back to the tank.

Control of a Double-Acting Hydraulic Cylinder:

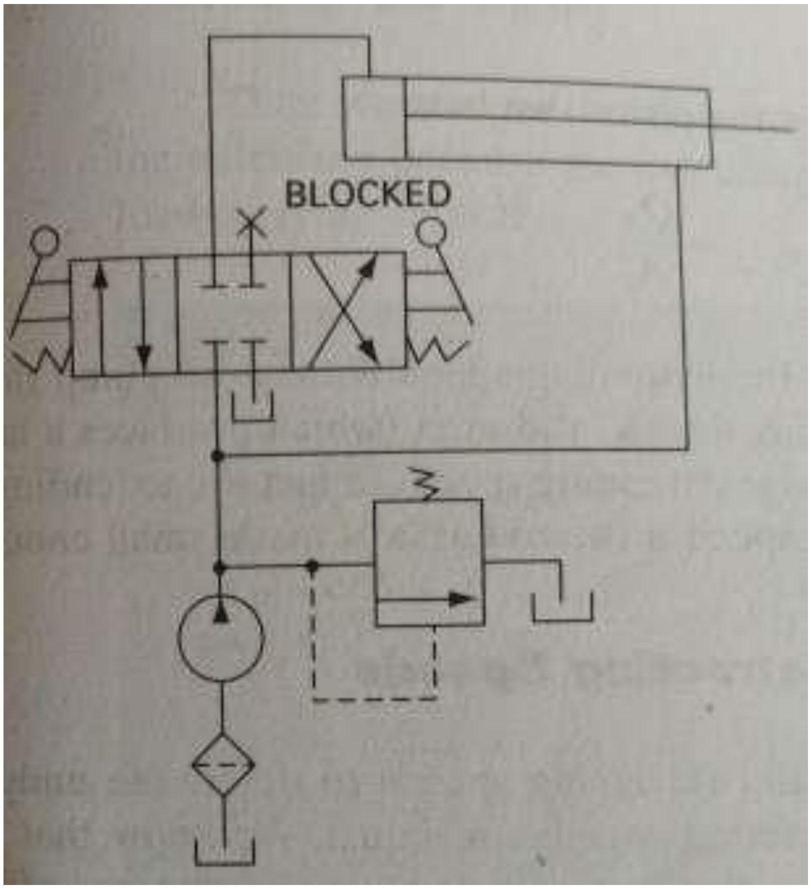
Four-way DCVs are commonly used to control the operation of double acting cylinders. Here the valve shown in three positions: under extension (left envelope), neutral position (central envelope) and under retraction (right envelope).



With the envelope in neutral position, the pump flow will continuously flow back to the tank through the DCV. Hence with this, the actuator and the pump are not pressurised. When the valve is actuated to the left envelope position, the pressure line is connected to the piston end cylinder port, while rod-end cylinder port is directed to the tank line. Under the pump pressure the cylinder extends and at the same time, the oil from the rod end freely flows back to the tank through the DCV. At the end of the stroke until the DCV is deactivated, the flow goes through the PRV. When the valve is actuated to the right envelope position, the pressure line is connected to the rod-end port, and the piston-end port is connected to the tank line. This causes cylinder retraction, with the oil from piston-end flowing freely back into the tank. At the end of the stroke, the pressure builds up, the PRV opens out and the fluid flows through the relief line.

Regenerative Cylinder Circuit:

Figure shows a regenerative circuit that is used to speed up the extending speed of a doubleacting hydraulic cylinder.

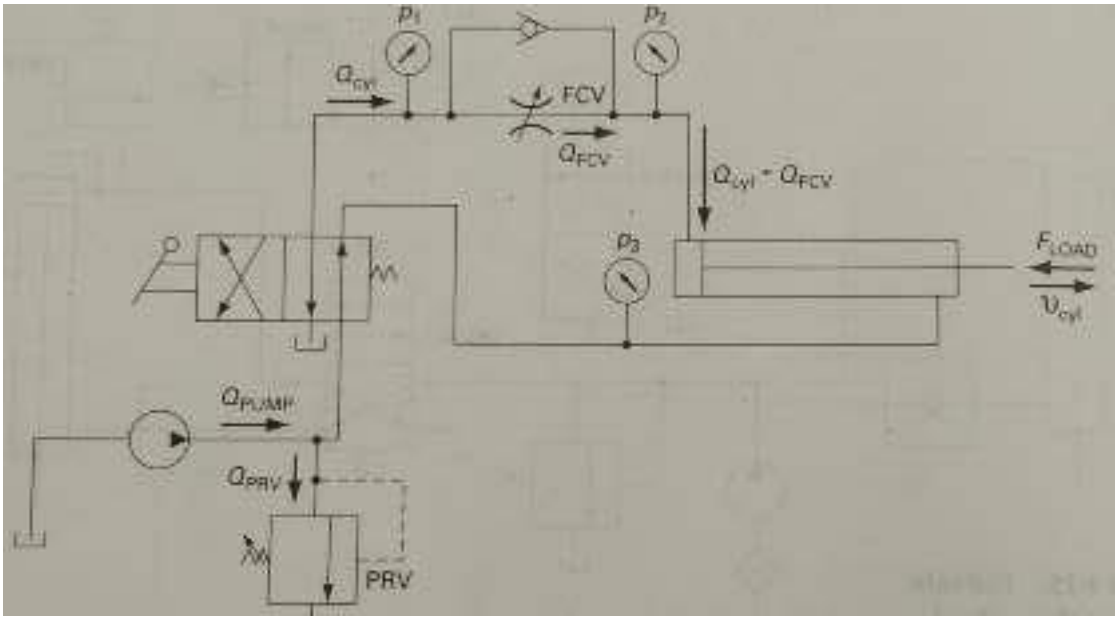


Note that the pipelines to both ends of the hydraulic cylinder are connected in parallel and that one of the ports of the four-way valve is blocked. Fluid flows through the DCV via the right envelope during retraction. In this mode, fluid from the pump bypasses the DCV and enters the rod end of the cylinder. Fluid in the blank end drains back to the tank through the DCV as the cylinder retracts.

When the DCV is shifted into its left envelope configuration, the cylinder extends. The speed of extension is greater than the that for a regular double-acting cylinder because flow from the rod end regenerates with pump flow to provide a total flow rate, which is greater than the pump flow rate to the blank end of the cylinder.

Meter-in Circuit:

Cylinder speeds can be controlled with the use of Flow Control Valves (FCV). The use of FCV to control the inlet flow to the cylinder hence the speed control is termed meter-in control.



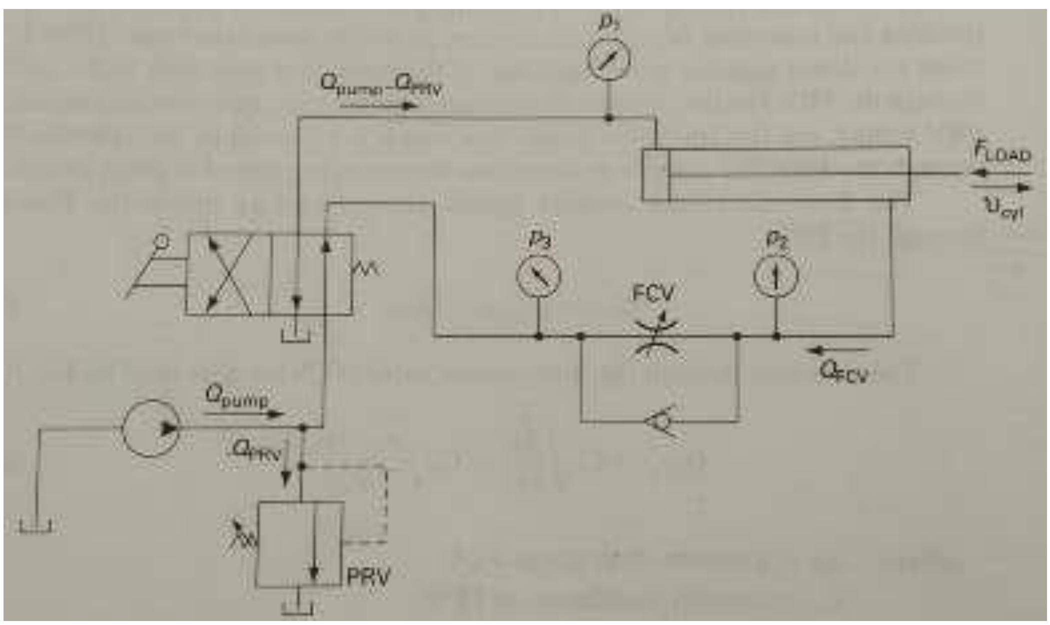
The operation of the cylinder to control its extension speed is explained with respect to two valve positions. When the DCV is actuated manually to its right envelope mode, the flow from the pressure line is directed to the piston-end port of the cylinder through the FCV. Note that though there is a check valve, it is in closed position and the flow is forced to pass through the metering orifice. Thus depending upon the orifice opening the flow is metered to the inlet port. Hence the extending speed of the cylinder is controlled.

When the DCV is actuated manually to its left envelope mode, the flow lines are reversed. The pressure line is directed to the rod-end port in the cylinder while piston-end port is connected to the tank line. The cylinder starts retracting as the flow enters the rod-end port, and at the same time the flow from the piston-end passes through the FCV. Note that the check valve opens-out, thus the flow bypasses the orifice valve and passes through the least resistance path, that is through the check valve without any restriction. Thus in retraction, the cylinder moves back at its full design speed.

Meter-out Circuit:

The use of FCV to control the outlet flow from the cylinder hence its speed is termed as meter-out circuit. The operation of the cylinder to control its extension speed is explained with respect to two valve positions.

When the DCV is actuated manually to its right envelope mode, the flow from the pressure line is directed directly to piston-end port of the cylinder. As the cylinder extends, the fluid from the rod-end of the cylinder is forced out of the port. Since there is a FCV, the flow has to pass through it. As there is a restriction to the flow through the FCV, the flow rate is metered. Though the piston is pushing the fluid out with full force, it is resisted by the FCV hence the extension speed is controlled. Note that though there is a check valve along with the FCV, it is a one-way valve and remains closed when the fluid is being forced out of rodend port to the tank line.

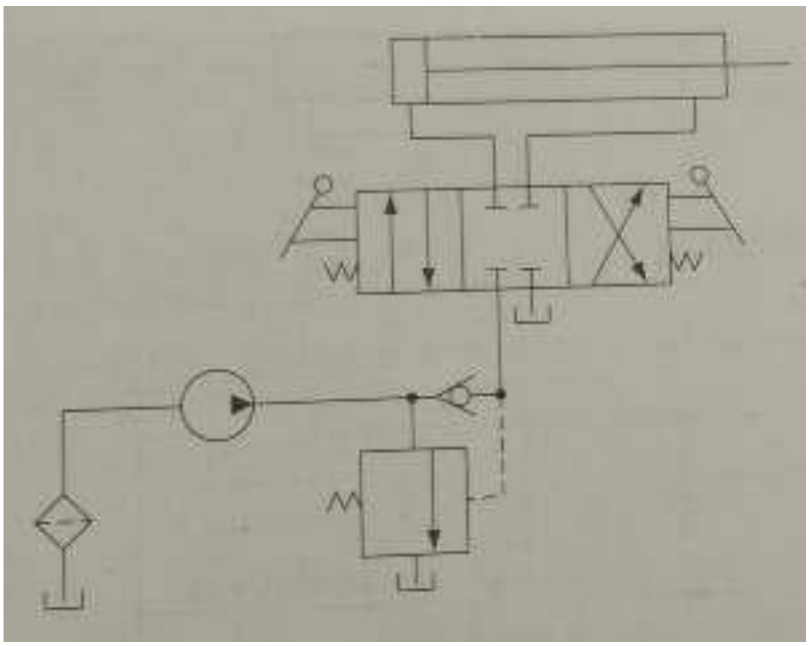


When the DCV is actuated to the left envelope mode, the flow lines are reversed. The pressure line is directed to rod-end port of the cylinder, while the piston-end port is connected to the tank line. The fluid under pressure enters rod-end port through the FCV, but bypassing the orifice. Instead it flows through the check valve, which now opens out due to favourable direction of flow. There is no restriction of flow through the check valve in this direction, hence full flow enters the cylinder, and it retracts with full design speed.

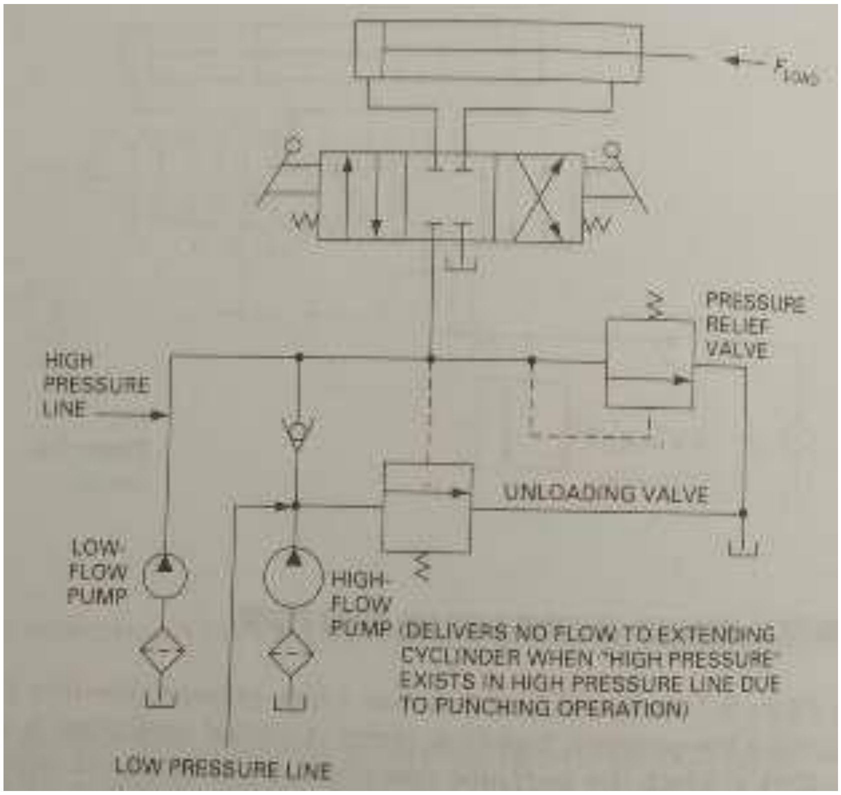
Pump Unloading Circuit:

An unloading valve is used to unload a pump in the circuit. The unloading valve opens when the cylinder reaches the end of its extension stroke because the check valve keeps high pressure oil in the pilot line of the unloading valve. When the DCV is shifted to retract the cylinder, the motion of the piston reduces the pressure in the pilot line of the unloading valve.

This resets the unloading valve until the cylinder is fully retracted, at which point the unloading valve unloads the pump.



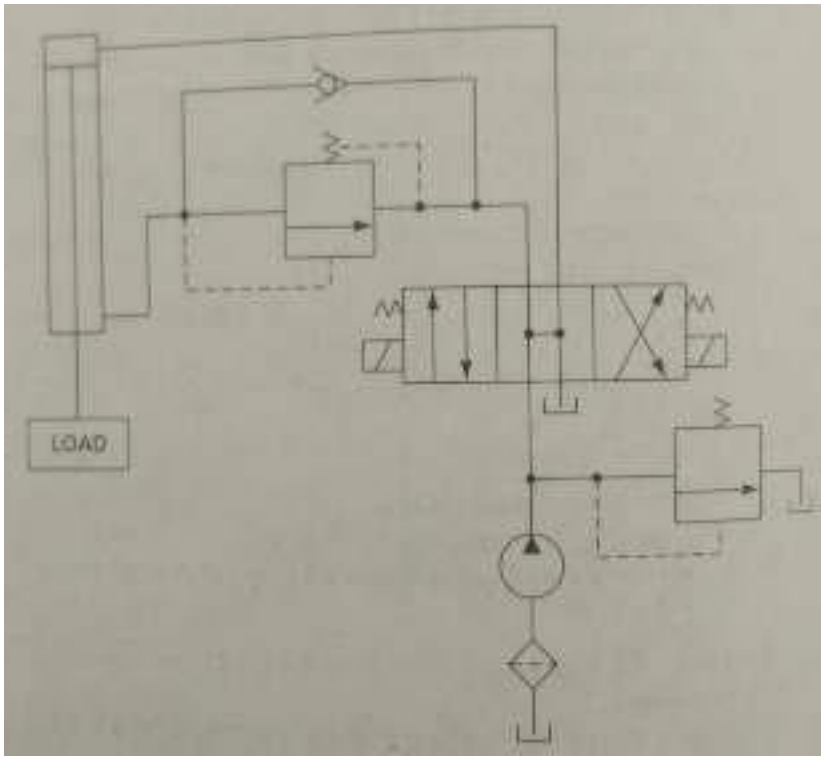
Double-Pump Hydraulic Circuit:



It uses a high pressure, low flow pump in conjunction with a low pressure, high flow pump. A typical application is a sheet metal punch press in which the hydraulic ram must extend rapidly over a great distance with very low pressure but high flowrate requirements. This rapid extension of the cylinder occurs under no load as the punching tool (connected to the end of the cylinder piston rod) approaches the sheet metal strip to be punched. However, during the short motion portion when the punching operation occurs, the pressure requirements are high due to the punching load. During the punching operation, the cylinder travel is small and thus the flowrate requirements are low.

The circuit eliminates the necessity of having a very expensive high pressure high flow pump. When the punching operation begins, the increased pressure opens the unloading valve to unload the low pressure pump. The purpose of the relief valve is to protect the high pressure pump from overpressure at the end of the cylinder stroke and when the DCV is in spring centred mode. The check valve protects the low pressure pump from hig pressure, which occurs during the punching operation, at the end of cylinder stroke, and when the DCV is in its spring centred mode.

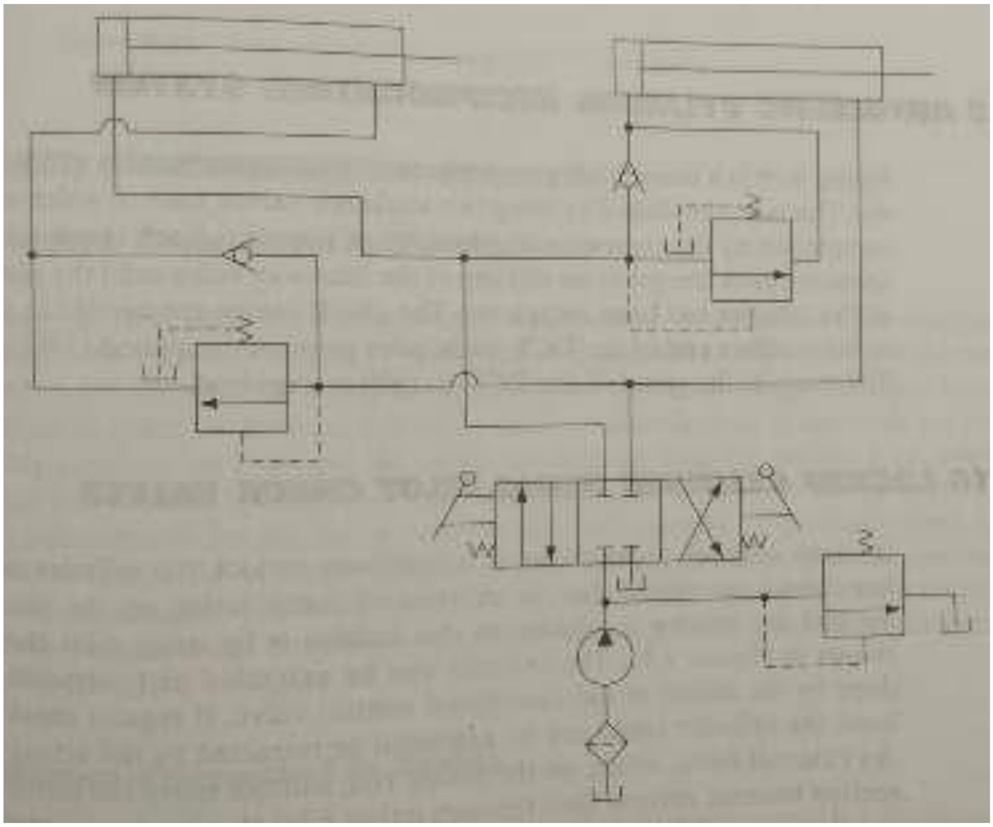
Counterbalance Valve Application Circuit:



Here a counterbalance or backpressure valve is used to keep a vertically mounted hydraulic cylinder in the upward position while the pump is idling. The counterbalance valve is set to open at somewhat above the pressure required to prevent the vertical cylinder from descending due to the weight of its load. This permits the cylinder to be forced downward when pressure is applied on the top. The open centre directional control valve unloads the pump.

Hydraulic Cylinder Sequencing Circuits:

A sequence valve causes operations in a hydraulic circuit to behave sequentially. When the DCV is shifted into its left envelope mode, the left cylinder extends completely, and then the right cylinder extends. If the DCV is then shifted into its right envelope mode, the right cylinder retracts fully, and then the left cylinder retracts. This sequence of cylinder operation is controlled by the sequence valves. The spring centered position of the DCV locks both cylinders in place.



QUESTIONS FROM PREVIOUS YEAR QUESTION PAPERS:

DEC 2015/JAN 2016

1) Write the symbols representing various centre flow paths for two position four way valves.
2) Explain the operational features of the compound pressure relief valve.
3) Explain the construction and operation of a simple needle valve and also explain the expression for the flow rate through flow control valve.
4) Explain the concept of Meter in and Meter out circuit. List the advantages and limitations of each of the circuit
5) Explain regenerative circuit with a neat diagram and deuce regenerative speed of the cylinder.

JUNE/JULY 2016

1) Briefly classify valves based on the type of function performed.
2) Sketch and explain the constructional features of poppet valve.
3) Sketch and explain pressure compensated flow control valve.

4) Sketch and explain the operation of a hydraulic circuit for the control of a spring return single acting cylinder.
5) What is regenerative circuit? Sketch schematically regenerative circuit to increase the extension speed of a double acting cylinder.

DEC 2016/JAN 2017

1) Explain the working principle of pilot operated check valve with a neat sketch. Illustrate the graphical symbol of the valve.
2) Explain with the aid of sketches:
   i) Non-compensated flow control valve ii) Compensated flow control valve
3) Explain the concept of Meter In and Meter Out circuit.
4) With a neat sketch, explain hydraulic circuit for sequencing of two cylinders.

JUNE/JULY 2017

1) Explain pressure reducing valve with graphical symbol.
2) Explain with a sketch non-compensated flow control needle valve.
3) With circuit diagram explain meter in circuit for controlling the speed of hydraulic cylinders.
4) Describe with a circuit diagram the construction and working of a counterbalance valve in hydraulic circuit.

DEC 2017/JAN 2018

1) Explain with neat sketch of 3/2 poppet valve with symbolic representation.
2) Explain with neat sketch of pilot operated pressure relief valve.
3) Explain with a neat sketch the working of shuttle valve with symbolic representation.
4) Explain with a neat circuit diagram, the working of double pump hydraulic system.
5) Explain with a neat circuit diagram, the counter balance valve application.

JUNE/JULY 2018

1) How control valves are classified?
2) Explain with a neat sketch the working of a Direct Acting Pressure Relief valve.
3) Describe the working of 5/3 DC valve with 4 ways with neat sketches. Also draw its graphical symbol.
4) What is the principle and purpose of regenerative circuit? Explain the working of a typical regenerative circuit with neat sketch.

CRASH COURSE – MAY 2017

1) With the aid of an appropriate hydraulic circuit explain the principle of unloading valve.
2) With the aid of neat sketch explain briefly the following:

i) Pressure reducing valve ii) Pressure compensated flow controlled valve.

Give the graphic symbol for each.

3)Describe with the aid of an appropriate hydraulic circuit hydraulic cylinder sequencing.

ONE TIME EXIT SCHEME – APRIL 2018

1) Give the classification of hydraulic control valve. With a neat sketch, explain simple pressure relief valve and give its graphical symbol.
2) Explain compensated and non-compensated flow control valve. Also draw the symbol.
3) With a neat sketch, explain pump unloading circuit.
4) With neat sketch, explain hydraulic cylinder sequencing circuit used in hydraulic drill press.

MODULE 4: PNEUMATIC POWER SYSTEMS

Introduction to Pneumatic Systems: Pneumatic power system, advantages, limitations, applications, choice of working medium. Characteristics of compressed air and air compressors. Structure of pneumatic control system, fluid conditioners – dryers and FRL unit.

Pneumatic Actuators: Linear cylinder – types of cylinders, working, end position cushioning, seals, mounting arrangements and applications. Rotary cylinders – types, construction and application, symbols.

Pneumatic Control Valves: DCV such as poppet, spool, suspended seat type slide valve, pressure control valves, flow control valves, types and construction, use of memory valve, Quick exhaust valve, time delay valve, shuttle valve, twin pressure valve, symbols.

INTRODUCTION

The working concept of a pneumatic system is similar to that of a hydraulic power system.
Pneumatic systems use pressurised gas, mostly air, to transmit motion and power.

CHOICE OF WORKING MEDIUM:

The choice of the working medium depends basically on the type of application. Some of the general, broad rules followed in the selection of a working medium are listed below:

i)When a system needs high speed, medium pressure and less accuracy a pneumatic system is good. If the system requires high pressure and high accuracy, a fluid system with oil is good.ii)When the power requirements are very high, like in a power press, oil hydraulics is the option.

iii) Location of the system also plays a role in the selection of a working medium. For location with severe temperature variations, oil hydraulic system will do better, where an air system may lead to severe condensation problems.

iv) Another issue related to the selection of working medium is that of fire/electric hazards. Air being non-explosion in nature, it is preferred where fire/electric hazards are expected. Oil systems are more prone to fire and electrical hazards and are not recommended in such areas.

CHARACTERISTICS/ADVANTAGES OF COMPRESSED AIR (PNEUMATIC SYSTEMS):

i) Air is available in abundance at all locations.

ii) Air can be transported from the source to the point of utilisation very conveniently through piping layout, and there are no limitations on the distance.

iii) Compressed air can be stored conveniently in a reservoir and used whenever required. iv) Compressed air is free from explosion and electrical hazard problems.

v) Air is clean and has no leakage/messy problems like hydraulic fluids.

vi) Generally, temperature variations do not affect the performance of air systems, as long as good air treatment systems (filter, regulator, lubricator) are maintained.

vii) Most components of air system are simple and compact in design.

DISADVANTAGES OF COMPRESSED AIR (PNEUMATIC SYSTEMS):

i) **Power:** Air as a working medium is not useful for high power and high precision applications, since it is compressible in nature.

ii) **Lubrication:** Air is not a good lubricating medium unlike the hydraulic fluid.

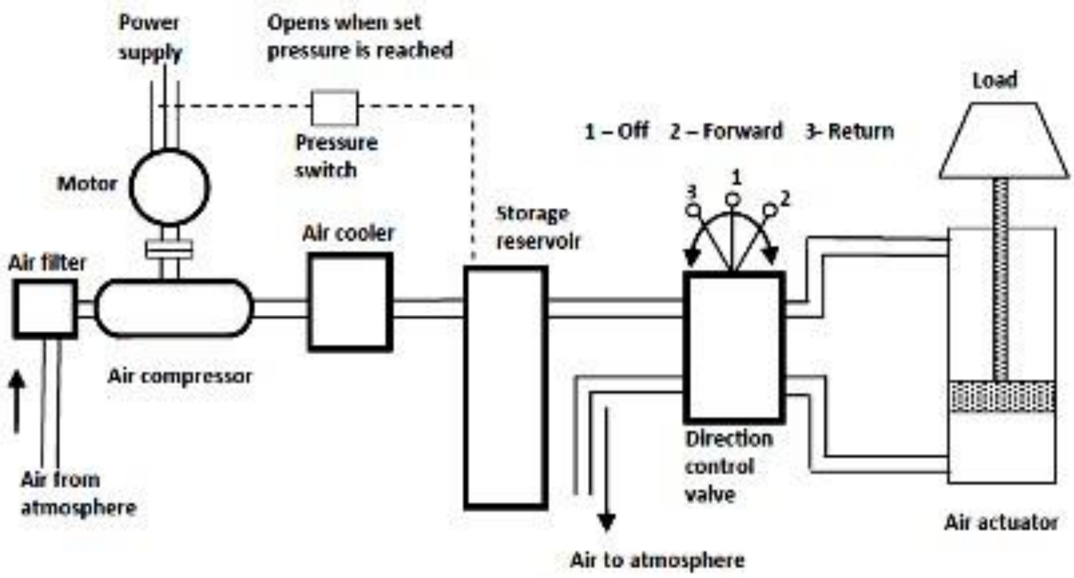
iii) **Heat Dissipation:** Air due to its low conductivity, cannot dissipate heat as much as a hydraulic fluid.

iv) **Sealing:** Air cannot seal the fine gaps between the moving parts unlike the hydraulic fluid.

v) **Noise & Condensation:** Air as a working medium is always noisy, and is prone to severe condensation problems with temperature variations.

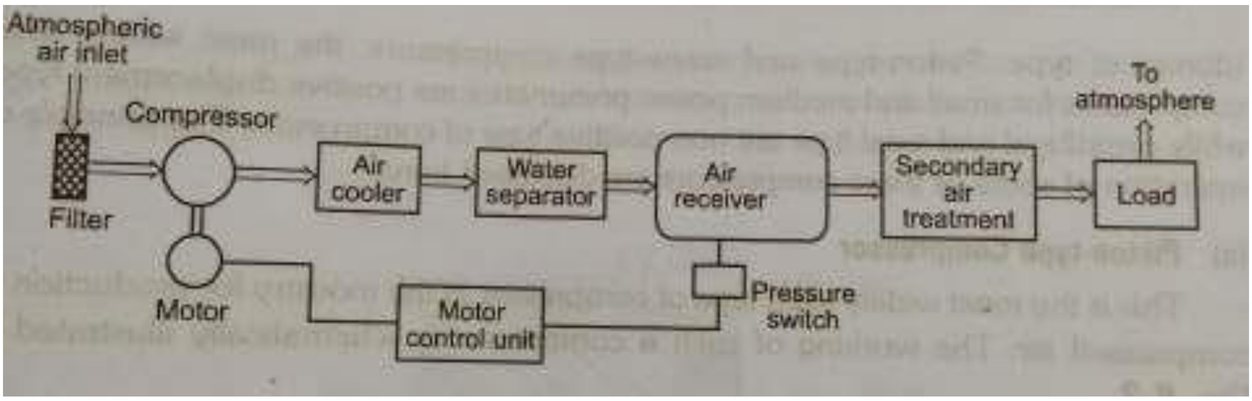
STRUCTURE OF A PNEUMATIC SYSTEM:

In this system, an electric motor drives an air compressor. The atmospheric air is sucked by the compressor through the filter. The purpose of the filter is to separate air from suspended and other dust particles. The compressor line is provided with a pressure switch, to protect the system pressure rising beyond the safe level by stopping the electric motor supply. Since the compression process increases the temperature of the compressed air, the air is passed through an air cooler to cool the air to environmental condition. This air is then stored in a storage reservoir, usually a large cylindrical steel container. From the reservoir, the compressed air is supplied to various systems for use.



PRODUCTION OF COMPRESSED AIR:

Compressed air is produced using compressors and stored in a reservoir. Before the atmospheric air is drawn into the compressor, it passes through a filter to remove the atmospheric dirt and other particles so that only clean air enters the compressor. In the compressor unit run by an electric motor, the volume of the drawn air is reduced so that its pressure increases. This increase in pressure is associated with an increase in temperature of the compressed air. Hence an air cooler is use to cool the air before it is sent to reservoir.



Since the atmospheric air is humid, after compression and cooling, it condenses into small droplets. This moisture causes corrosion and operational problems. A separator is used to remove water particles from the compressed air. This air after cooling and separation (i.e., primary treatment) is sent to the reservoir. Once the reservoir is filled with compressed air and pressure reaches a safe limit value, it is sensed by a pressure switch, which in turn switches the compressor-motor off. With usage the pressure drops down, which is again sensed by the pressure switch, and in turn switches the motor on.

In pneumatic systems, unlike the hydraulic systems, the compressed air has no lubricating ability. Thus, the stored air before being sent to do some work is mixed with an oil mist. This not only provides lubrication to mating parts, but also reduces the corrosive problems. In practice, the compressed air after mixing with oil mist is further subjected to filtering and moisture separation again to make the air further clean. This treated air is then sent to the control valves and to the actuators to do the work.

PERFECT GAS LAWS:

The laws that determine the interactions of pressure, volume and temperature of a gas are called the “perfect gas laws”. Even though perfect gases do not exist, air behaves very closely to that predicted by Boyle’s law, Charle’s law, Gay-Lussac’s law and general gas law for the pressure and temperature ranges experienced by pneumatic systems.

Boyle’s Law:

It states that if the temperature of a given amount of gas is held constant, the volume of the gas will change inversely with the absolute pressure of the gas.

$$\frac{V_1}{V_2} = \frac{P_2}{P_1}$$

Charles’ Law:

It states that if the pressure on a given amount of gas is held constant, the volume of the gas will change in direct proportion to the absolute temperature.

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

Gay-Lussac’s Law:

It states that if the volume of a given gas is held constant, the pressure exerted by the gas is directly proportional to its absolute temperature.

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

General Gas Law:

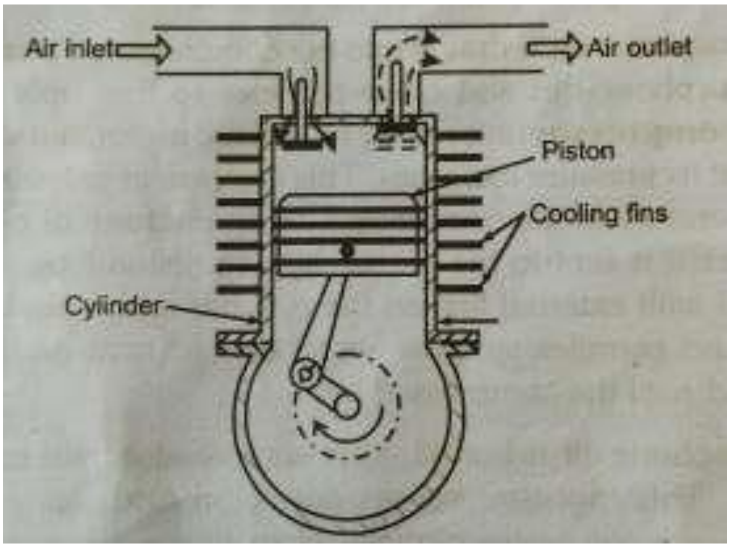
It contains all three gas parameters (pressure, temperature and volume), since none are held constant during a process from state 1 to state 2. It is defined as

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

COMPRESSORS:

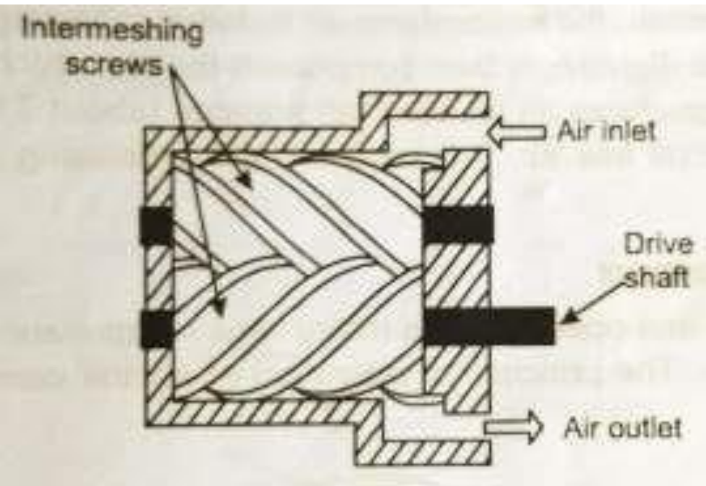
Compressors are the source of pneumatic power. These can be classified into two categories: positive displacement and non-positive displacement type. Piston-type and screw-type are positive displacement type and most widely used compressors for small and medium power pneumatic applications, while centrifugal and axial type are non-positive type.

Piston-type Compressor:



This is the most widely used type of compressor in the industry for production of compressed air. It has a piston-cylinder arrangement, with inlet and outlet valves. The piston is driven by a crank and connecting rod, which converts the rotary motion of the motor into reciprocating motion of the piston. In operation, in the first cycle (the half revolution of the shaft) the inlet valve opens, the atmospheric air is drawn-in by the piston as it moves down. In the next cycle (the second half revolution of the crank shaft), the inlet valve gets closed, the outlet valve opens and the air is compressed as the piston moves up in the cylinder. The air compression process is accompanied with an increase in temperature. The air is cooled by providing fins around the cylinder.

Screw-type Compressor:



A screw compressor is a rotary type compressor, which is simple in construction and operation. It has two intermeshing rotating screws with close working tolerances. These screws are housed in a casing with inlet and outlet ports. In operation as the screw rotate, the atmospheric air is drawn-in, trapped between the rotating/meshing screws, which is carried along the screws up to the outlet port. Since, the screws mesh continuously, the air compression and delivery occurs continuously without any pulsation. For wear free and reduced noise operation some kind of lubrication forming a thin oil film is used. The oil injected to the chamber lubricates the screw surfaces and forms a seal so that air is compressed efficiently, as the screws mesh continuously.

FLUID CONDITIONERS:

The compressed air gets contaminated due to atmospheric dust, lubricant, moisture and so on. If this air is used directly it may block the control valves, damage the components and/or cause corrosion related problems. Hence, before it is actually used for pneumatic application the air is prepared by removing various contaminants. Fluid conditioners include filters, regulators, lubricators and air dryers.

Air Filters:

Filters are provided both at the compressor inlets and in the pneumatic lines before the valves/actuators. Intake filters are mostly paper type elements, which prevent the entry of atmospheric contaminants into the compressor and minimise damage to the compressor components. The other filter, termed the air-line filter is used in the pneumatic lines to remove contaminants, mainly fine dirt and moisture. The air-line filters protect the pneumatic control valves and other devices.

Air Dryer:

The air filter can only remove condensed water particles from air. The vapour passes through the air-filter and causes problems as it condenses at other components. In a compressed air, the relative humidity

(RH) and dew point are higher. Both the RH and the dew point are dependent on the temperature and pressure. Whenever the temperature drops and/or the pressure increases the water condenses. This problem can be reduced by keeping the humidity of air below 100%, for which air-dryers are used.

Lubricators:

Unlike the hydraulic systems, the dry air in the pneumatic systems cannot provide a lubrication effect in the devices. Generally, oil in the form of fine mist is added to the clean dry air during the secondary treatment. For this air lubricators are used.

Air Pressure Regulator:

In pneumatic systems the flow velocities are quite high, which may lead to considerable pressure drops between the air receiver and the loading point. Hence, it is a common practice to maintain a higher pressure in the reservoir than that is required at the actuator. The required pressure at the loading point is then achieved using pressure regulation locally using air pressure regulators.

Air pressure regulators are similar to pressure reducing valves used in hydraulic systems. Air pressure regulators in pneumatic systems are used to adjust the supply pressure to a required level for a given load irrespective of the air flow, i.e., to maintain a constant pressure at the load: that means, if the air flow is higher, it senses the pressure and reduces the flow rate to the required level to maintain the pressure. Similarly, if the supply pressure drops, the regulator increases the flow rate so as to increase the pressure to the required level.

PNEUMATIC ACTUATORS

Pneumatic actuators convert the air pressure into linear or rotary motion depending upon their design. Similar to hydraulic actuators, pneumatic cylinders are also use for gripping/moving of objects in various industrial applications. Pneumatic actuators which are designed to produce linear motion are termed linear air cylinders. Actuators which are designed to produce rotary motion are termed rotary cylinders or more popularly air motors.

Linear Cylinders:

Classification of Air Cylinders:

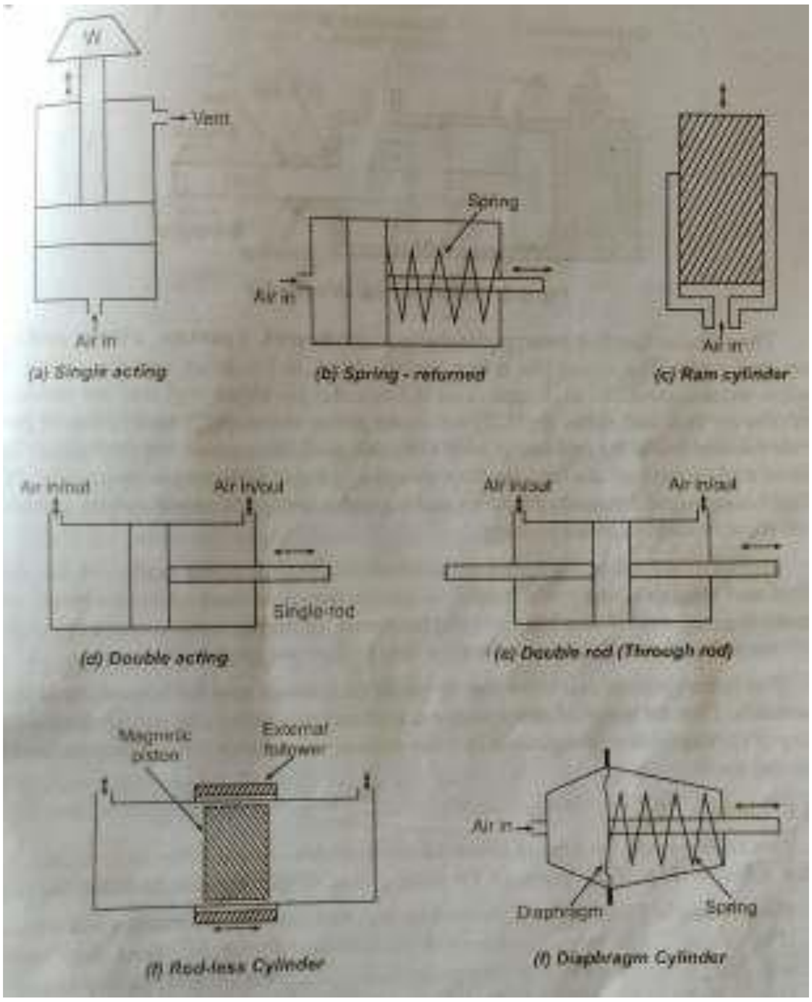
Linear pneumatic cylinders, popularly known as air cylinders are used for the generation of straight rectilinear motion. Thus, they are useful to move an object or apply a force on an object in a straight line.

Pneumatic cylinders are briefly classified as follows:

1) **Single acting cylinder:** It is a cylinder in which air pressure is applied on to the piston side only and extension takes place by the air pressure in one direction. The return stroke is mostly by gravity.

2) **Spring Return Cylinder**: It is a single acting cylinder in which movement in one direction is under air pressure, while the return stroke is accomplished by a spring.

3) **Ram Cylinder:** in this the cylinder rod itself forms the movable element termed as ram. It is usually single acting and return stroke is either under gravity or assisted by return cylinders.



4) **Double acting cylinder:** it is a cylinder in which the ait pressure is applied alternately on either side, so that

5) **Double rod or through-rod cylinder:** In a double-rod or through-rod cylinder, the piston-rod extends/retracts on either end of the cylinder.

6) **Rod-less cylinder:** In this, there is no rod connected to the piston. Usually, the piston is a magnetic type, while an external follower (magnetic) follows the piston due to magnetic coupling.

7) **Diaphragm Cylinder:** For short stroke lengths, small cylinders with a rubber or metal diaphragm is used instead of a piston. The main advantage of such cylinders is that there is no leakage between the inlet and outlet chambers; and there is no frictional loss.

SEALS:

Seals are used to avoid leakage and for smooth, wear free operation. Depending upon the type of construction, seals are used at different locations in a linear cylinder.

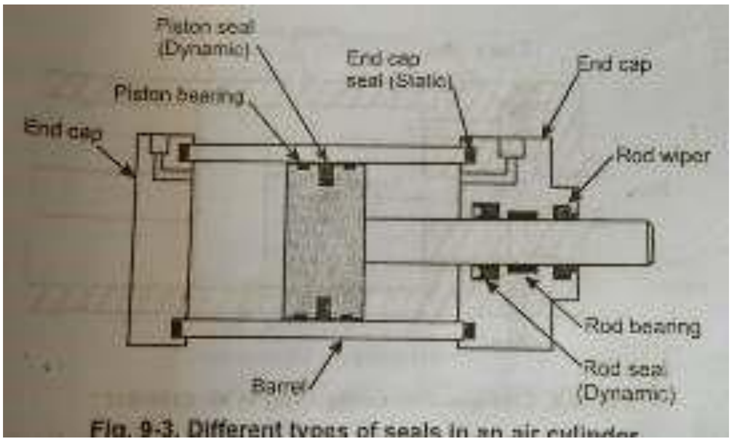
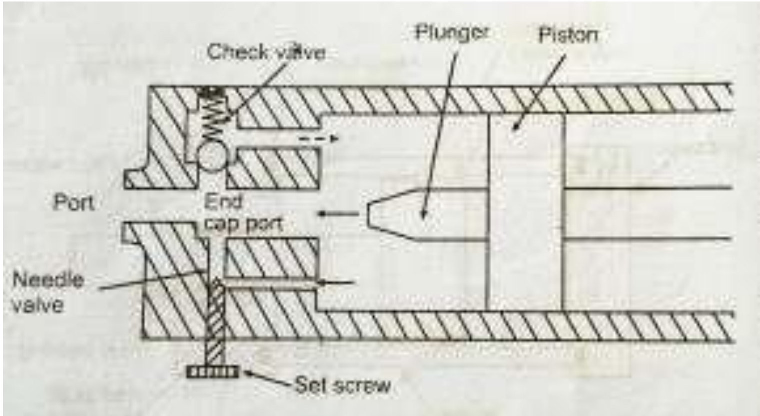


Fig. 9-3. Different types of seals in an air cylinder

1) **Piston Seals:** Piston seals or piston rings are used betweenthe pistonand the barrel. These rings can be either metallic or non-metallic. Steel rings coated with zinc phosphate or manganese phosphate give a good life and operate smoothly. Non-metallic rings made of PTFE (polyterafloroethylene), widely known as Teflon is chemically stable and tough. Because of its very low coefficient of friction (0.04), it is ideal in pneumatic cylinders, and can perform well without lubrication also.
2) **Piston Cups:** In some constructions, the piston is provided with piston cup seals. Compared to piston with rings, cup seals are much simpler in design and easy to assemble. They have an L-section, held on either side of a backing plate. For a single acting cylinder one cup is used on the pressure side, while for a double acting cylinder two cups, one on either side are used. The cups are held between the backing plate and retainer clamp. Leather or some synthetic materials are used for sealing cups.
3) **Rod Seals:** Rods are provided with three varieties of seals: (i) a dynamic seal (synthetic material) to prevent leakage of air; (ii) a rod bearing (Teflon) to support the rod in the end cap: and (iii) a rod wiper (synthetic) to prevent entry of atmospheric contaminants. In very dusty environments, rubber bellows are also used to protect the cylinder from the dust and other external particles.
4) **End Cap Seal:** Depending upon the design, either O-rings or die-cut gaskets are used to seal the end cap and the barrel. Synthetic rubbers and leather are commonly used for this purpose.

END POSITION CUSHIONING:

Normal single-acting and double-acting cylinders, while moving heavy loads, may undergo sudden impacts at the end of strokes. This sudden deceleration may cause damage to the load, or cylinder or to the pneumatic system itself. To avoid this problem, end-position cushioning is provided in cylinders.



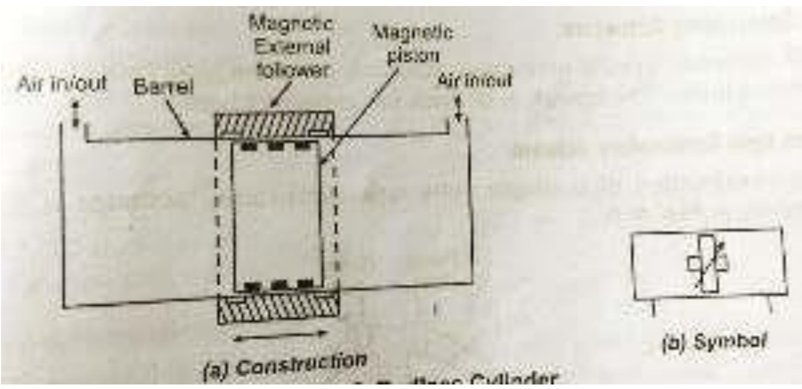
In this, the piston end is provided with a plunger (or a cushioning piston), the air inlet port is such that it matches with the cushioning plunger size. At the end of stroke, the cushioning piston mates with the inlet port and blocks the direct flow path for the air.

The exhaust air now passes through a small, adjustable restricted opening. Since air cannot pass out easily, the restricted flow through small openings provides a cushioning effect to the decelerating cylinder. Thus, in the last part of the stroke, the piston speed gets reduced gradually, which otherwise would have been stopped instantly. The area of the restricted flow path, hence the cushioning effect can be adjusted with an adjustable screw.

For the onward stroke, since the main entry is blocked by the cushioning plunger, a by-pass check valve is provided. The air passes freely through the check valve against a bias spring pressure. During cushioning action (in the retraction mode), the check valve is nonoperational, hence no air can escape through it.

RODLESS CYLIDERS:

As the name suggests, these are cylinders without any rod extending from them. A rodless cylinder has a barrel with rodless piston. In some applications, where there is not enough space is available for the rod extension, or where the stroke length required is too high, then rodless cylinders are quite useful.



In this, the piston is rodless, and is freely movable within the cylinder barrel. The piston has no positive/rigid connection to the external member for actuation. The piston has a set of annular magnets fitted around it. The external member/actuator is a magnetic follower, and it is linked to the piston due to magnetic coupling between them. As the piston moves under fluid pressure, the external sliding member moves in synchronisation with it. The load to be moved is mounted on a carriage, which in turn is connected to the magnetic slide. Hence, when the slide moves the carriage along with the load moves in the direction of movement of the piston.

Advantages:

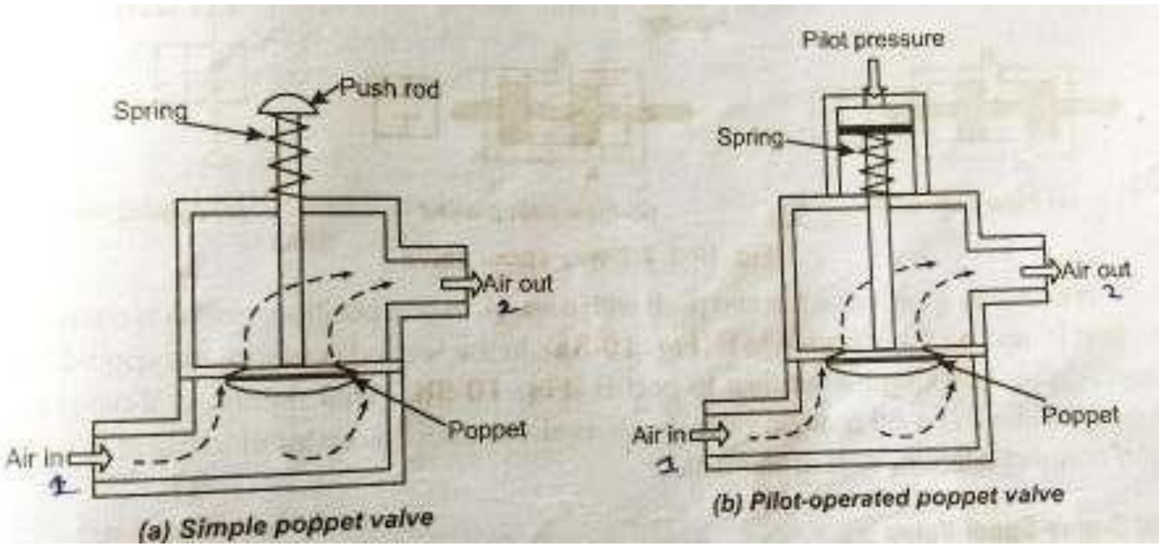
1) The construction of the cylinder is simple as the barrel is sealed from both ends.
2) Such a cylinder has no rod extending from the cylinder and convenient for space contained applications.
3) The cylinder can be used for extreme stroke lengths
4) Flatbed carriages can be used for carrying the loads.
5) The construction can be made compact by concealing the cylinder below the carriage.

PNEUMATIC CONTROL VALVES

Classification of Pneumatic valves:

1) Direction Control Valves
   a) Poppet Valves
   b) Spool (slide) Valves
2) Flow control Valves
3) Pressure control Valves
4) Non-return Valves
   a) Check Valve
   b) Shuttle Valve
   c) Quick Exhaust Valve

Poppet Valves:



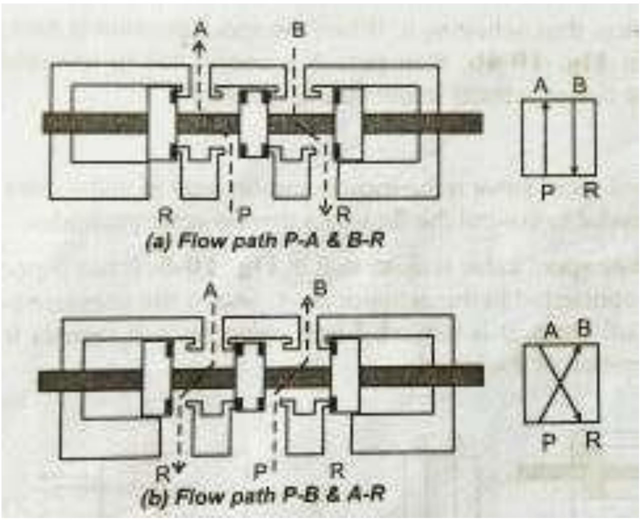
(a) Simple poppet valve (b) Pilot-operated poppet valve

In poppet valves (also termed seat valves) are used to control the air flow. In a simple poppet valve, the poppet is operated manually. It has a cylindrical arrangement with two ports (1 and 2). The ports are separated by a poppet, seated on a valve seat. The poppet is held in a closed position (in the normally closed valve) under the action of a spring. Port 1 is connected to the high pressure air supply, while port 2 is connected to the actuator or other pneumatic device. When the push rod is pressed down against the spring pressure, the poppet opens up from the seat, and allows the air to flow from port 1 to port 2.

In a pilot operated poppet valve, the poppet is moved under the action of a pilot pressure. This has the advantage of remote operation, and also application of higher pressure for large size poppet valves.

Suspended Seat type valve:

It has a suspended disc seat which performs the port opening and closing operations. The advantage of the suspended seat valve is that the sealing can be performed with relatively small switching movement.



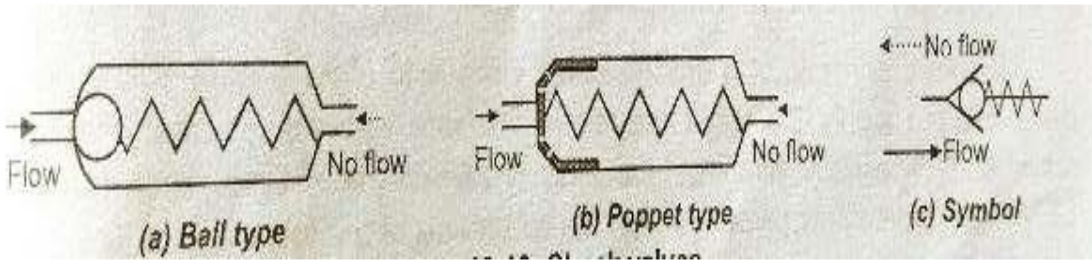
(a) Flow path P-A & B-R
(b) Flow path P-B & A-R

In this the main disc seat seal connects port P to either to port A or port B. The secondary seat discs seal the exhaust port B whichever is not functional. Such valves are generally provided with manual override buttons at each end of the spool to manually move the spool.

NON-RETURN VALVES:

Check valve:

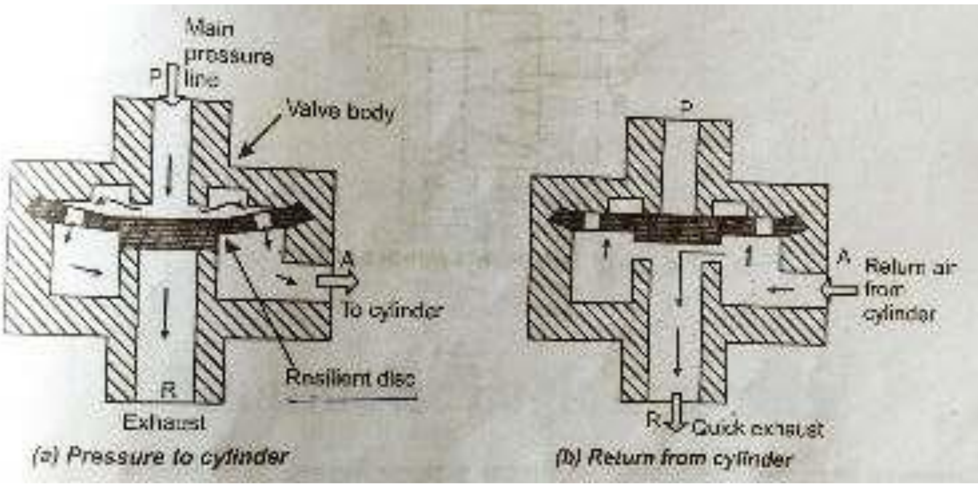
Check valves allow free flow of air in one direction and block any flow in the reverse direction.



The ball and poppet are held under light bias spring pressure against the seat. The valve opens at low cracking pressures in the forward direction and allows the free flow of air. If the air is stopped, the ball/poppet closes the valve under spring pressure and hence do not permit any flow in the reverse direction. Check valves are quite useful in fluid power circuits and are widely used in by pass lines to permit flow in one direction.

Quick Exhaust Valve (QEV):

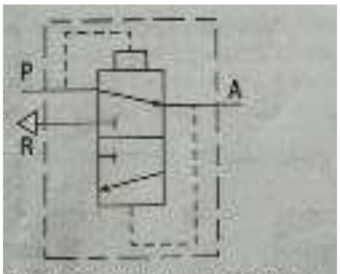
Quick exhaust valve is a special purpose valve used in pneumatic systems. It is designed to increase the actuation speed of a cylinder, above that of the normal speed by the unrestricted increased flow rate of air.



The basic principle of a quick exhaust valve is to allow a normal flow to the cylinder in the supply line, while increase the flowrate (above the normal rate) in the return line. It basically eliminates the entry of return/exhaust air through the usual DCV route, where flow passes through the constraints of the tubes and valves.

It consists of a cylindrical body with three ports. The port P is connected to the pressure line (inlet), the port A is connected to the cylinder, and port R is connected to the exhaust. Though all the ports are interconnected, there is an intermediate resilient disc, which allows the flow between only two ports at a time.

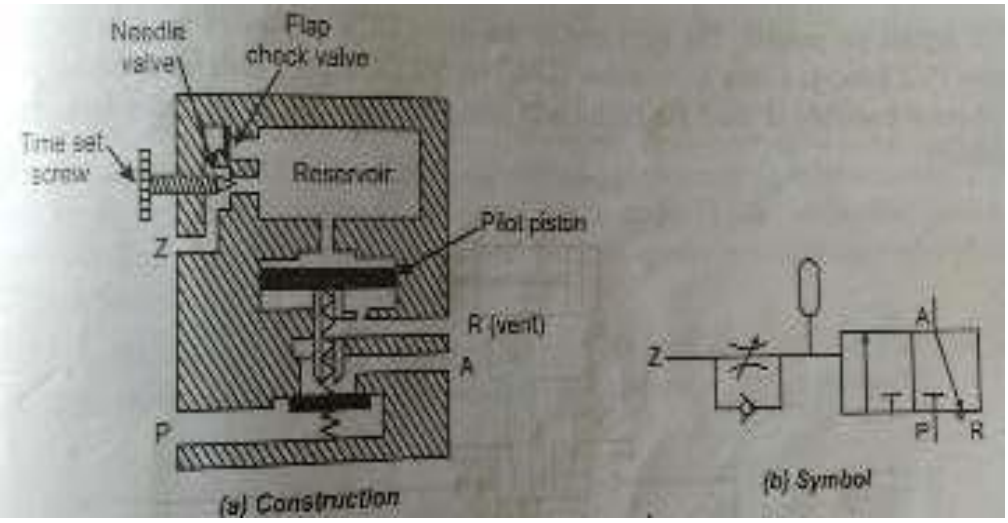
In operation, when the inlet line pressure is applied to the port P, the disc under pressure opens-up to port A, while sealing the exhaust port. The openings in the disc are sufficient enough to allow a normal flow rate from port P to port A, which causes the cylinder actuation at the normal design speed. When the cylinder performs the return stroke the supply line is blocked, because of this resilient disc springs back to its NC position thus blocking the port P. at this position port A allows the return air, by connecting to the exhaust line (R). Since, it gives a large opening between the cylinder return and exhaust port, under spring return (in a single acting cylinder) or under the return line pressure (in a double acting cylinder), the air is exhausted freely through the valve. Due to this unrestricted excess flow rate the cylinder retracts at a higher speed than the normal design speed.



0-13. Graphical symbol of QEV

Time Delay Valve:

The principle of construction of a time delay valve is similar to a 3/2 pilot operated valve. The pilot valve is designed to operate against a spring pressure, once the pilot chamber pressure exceeds the spring pressure. The main valve is held in a closed position (in a NC type valve) by a bias spring. The flow rate can be set by the needle valve screw.



In operation, the air is allowed to the pilot chamber reservoir through the needle valve. The reservoir size and the flow rate through the needle valve decide the time required to build-up a pressure in the reservoir. Once the pressure reaches the spring pressure, it actuates the main poppet valve and allows the main line pressure (P) to enter the cylinder port (A).

When the pilot pressure is removed, a flap check valve opens up and the pilot valve is vented quickly to atmosphere. At the same time, the pilot valve retracts under spring pressure, the main poppet valve closes (stopping the air supply from P to A), while the port A us connected to the exhaust line R.

QUESTIONS FROM PREVIOUS YEAR QUESTION PAPERS:

DEC 2015/JAN 2016

1) Explain the laws for a perfect gas that governs the compressible nature of air.
2) Explain the basic structure of pneumatic system with its components.
3) Explain briefly with a neat sketch 3/2-way spool type direction control valve.
4) With a neat diagram, explain the construction and the functioning of the spool valve or quick exhaust valve employed in pneumatic system.

JUNE/JULY 2016

1) What are the characteristics of compressed air? Explain them.
2) Sketch and explain structure of pneumatic control system.
3) Sketch and explain rod less cylinder.
4) What are flow control valves? Draw graphical symbols of FCV
5) Sketch and explain construction and principle of operation of a quick exhaust valve.

6) List different types of compressor. Explain with a neat sketch production of compressed air.

DEC 2016/JAN 2017

1) Sketch and explain the cushion assembly for a pneumatic cylinder.
2) Differentiate between hydraulic and pneumatic systems.
3) Write short notes on:
   i) Cylinder mounting arrangement ii) Rod less cylinder
4) Explain with a suitable sketch:
   i) Shuttle valve ii) Quick Exhaust valve

JUNE/JULY 2017

1) What are the types of pneumatic actuators? With sketch explain the construction and working principle of single acting cylinder.
2) Differentiate hydraulic and pneumatic system.
3) What is cushioning? Sketch and explain the cushioning of cylinder.
4) With a neat sketch and symbol explain 3/2 direction control poppet valve.
5) Explain quick exhaust valve with circuit diagram.
6) Explain the three stages of preparation of compressed air.

DEC 2017/JAN 2018

1) State five disadvantages of using air instead of hydraulic oil.
2) Explain with schematic sketch of FRL unit with ANSI symbol.
3) Explain the characteristics of compressed air.

JUNE/JULY 2018

1) What is cushioning of cylinders? Why cushioning is necessary? Explain the working of a typical cushioned cylinder.
2) Explain the different operational type principles used for the construction of Rod less cylinders.
3) What is the function of a time delay valve? Explain the constructional features of a typical time delay valve with neat sketch.

CRASH COURSE – MAY 2017

1) Give complete classification of pneumatic cylinder.
2) What is an FRL unit? Give the graphic symbol of it.
3) Explain with neat sketch solenoid controlled pilot operated direction control valve.

ONE TIME EXIT SCHEME – APRIL 2018

1) With a neat sketch explain the structure of pneumatic system.
2) Write a neat sketch explain FRL unit.
3) With a neat sketch explain rod-less cylinder.
4) Explain with a neat sketch:

   i) Time delay valve ii) Shuttle

   valve iii) Poppet valve iv)

   Solenoid valve **MODEL**

   QUESTION PAPER – 1

1) Sketch and explain the mechanism of end position cushioning.
2) State the advantages and disadvantages of pneumatic systems.
3) Explain the different types of seals with neat sketch.
4) Explain with a neat sketch the construction and operation of a typical quick exhaust valve to increase the actuation speed of a cylinder in a pneumatic system.
5) Explain the working of suspended seat type valve with a neat sketch.

MODEL QUESTION PAPER – 2

1) Explain the characteristics of compressed air.
2) Explain with a neat sketch the working of single and double acting pneumatic cylinder.
3) Explain with a neat diagram the structure of Pneumatic control system.
4) Explain with a suitable circuit diagram the application of a memory valve.
5) Explain the working of shuttle valve and time delay valve with a neat sketch.

Module- 5

Pneumatic control circuits

Simple Pneumatic Control: Direct and indirect actuation pneumatic cylinders, speed control of cylinders - supply air throttling and exhaust air throttling.

Signal Processing Elements: Use of Logic gates - OR and AND gates in pneumatic applications. Practical examples involving the use of logic gates.

Multi- Cylinder Application: Coordinated and sequential motion control, motion and control diagrams. Signal elimination methods, Cascading method- principle, Practical application examples (up to two cylinders) using cascading method (using reversing valves).

Electro- Pneumatic Control: Principles - signal input and output, pilot assisted solenoid control of directional control valves, use of relay and contactors. Control circuitry for simple signal cylinder application.

Module- 5

Pneumatic control circuits

Simple Pneumatic Control: Direct and indirect actuation pneumatic cylinders, speed control of cylinders - supply air throttling and exhaust air throttling.

Signal Processing Elements: Use of Logic gates - OR and AND gates in pneumatic applications. Practical examples involving the use of logic gates.

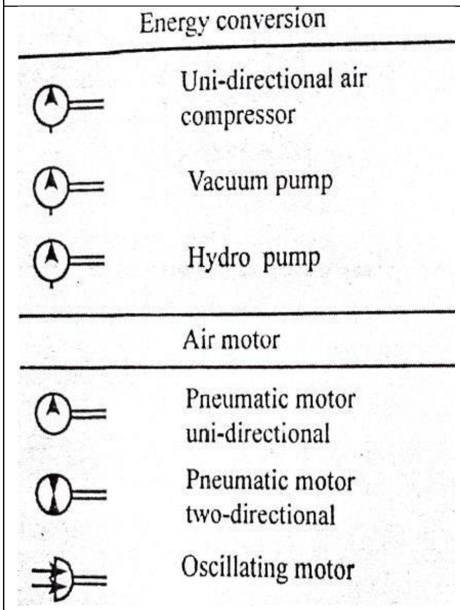
Multi- Cylinder Application: Coordinated and sequential motion control, motion and control diagrams. Signal elimination methods, Cascading method- principle, Practical application examples (up to two cylinders) using cascading method (using reversing valves).

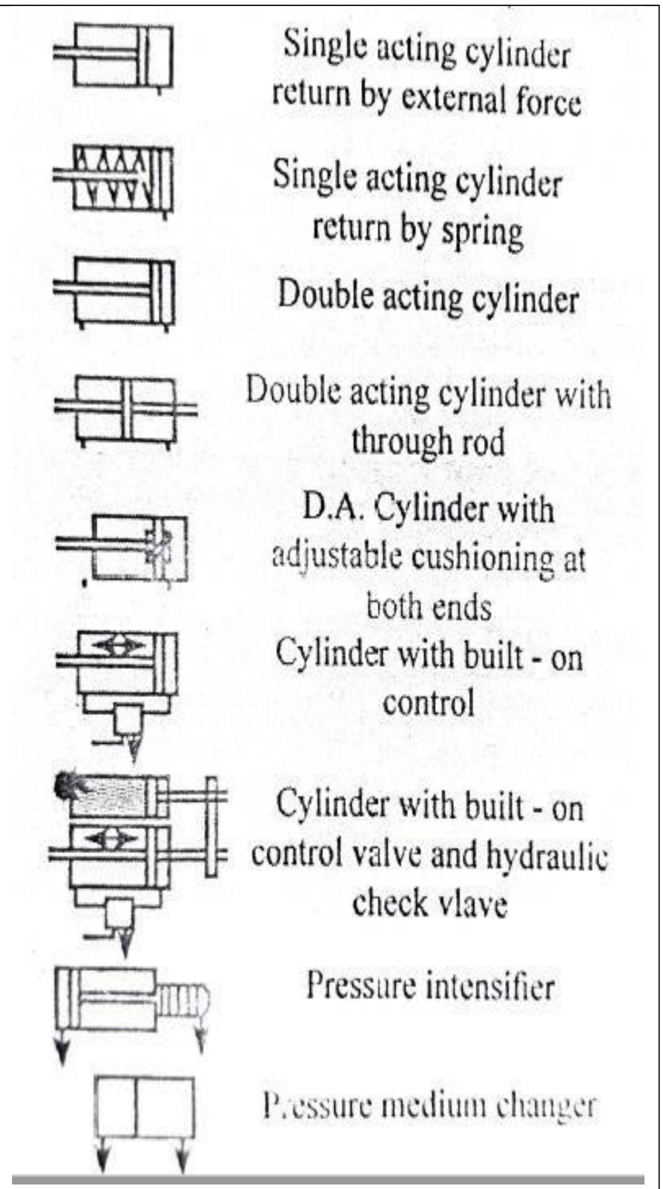
Electro- Pneumatic Control: Principles - signal input and output, pilot assisted solenoid control of directional control valves, use of relay and contactors. Control circuitry for simple signal cylinder

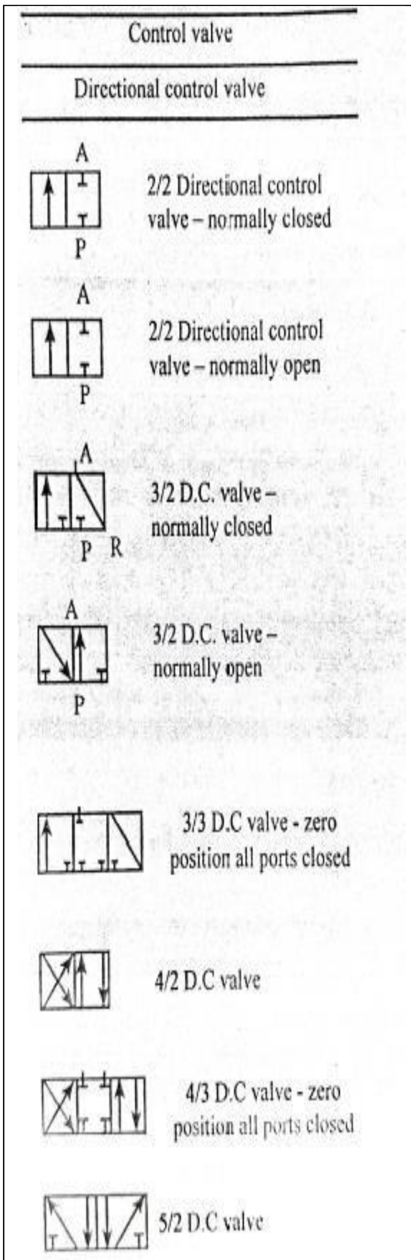
A pneumatic circuit consists of a variety of components, such as compressors, receivers, filters, pressure regulators, lubricators, mufflers, air driers, actuators, control valves, and conductors, arranged so that a, useful task can be performed. In a pneumatic circuit the force delivered by a cylinder and the torque delivered by a motor are determined by the pressure levels established by pressure regulators placed at the desired locations in the circuit. Similarly, the linear speed of a pneumatic cylinder and the rotational speed of an air motor are determined by flow control valves placed at desired locations in the circuit. The direction of flow path is established by the proper location- of directional control valves. After the pressurized air is spent driving actuators, it is then exhausted back into the atmosphere. Pneumatic circuits have the following functions

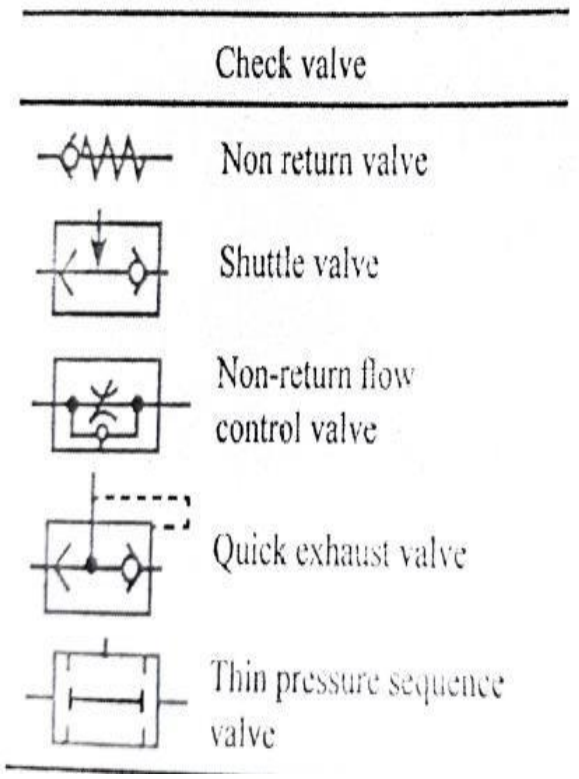
1. To control the entry and exit of compressed air in the cylinders.
2. To use one valve to control another valve.
3. To control actuators or any other pneumatic devices.

Symbols used in Fluid Circuit









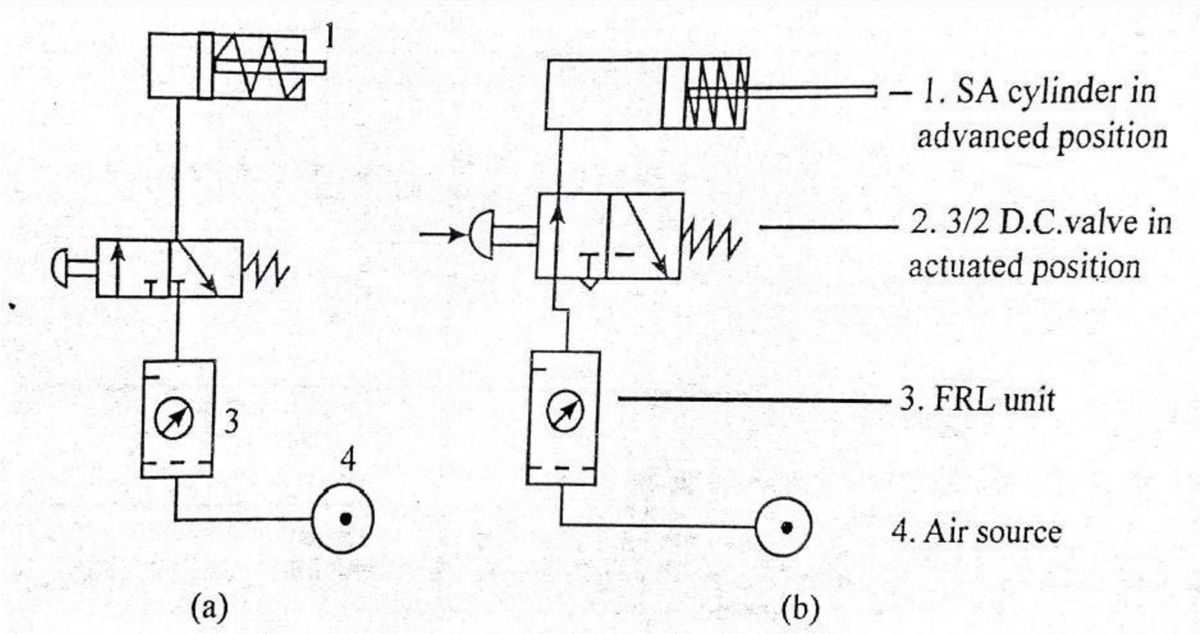
Simple Pneumatic Control

Direct control of single acting cylinder

Direct control of single acting cylinder Pneumatic cylinders can be directly controlled by actuation of final directional control valve. These valves can be controlled manually or electrically. This circuit can be used for small cylinders as well as cylinders which operate at low speeds where the flow rate requirements are less.

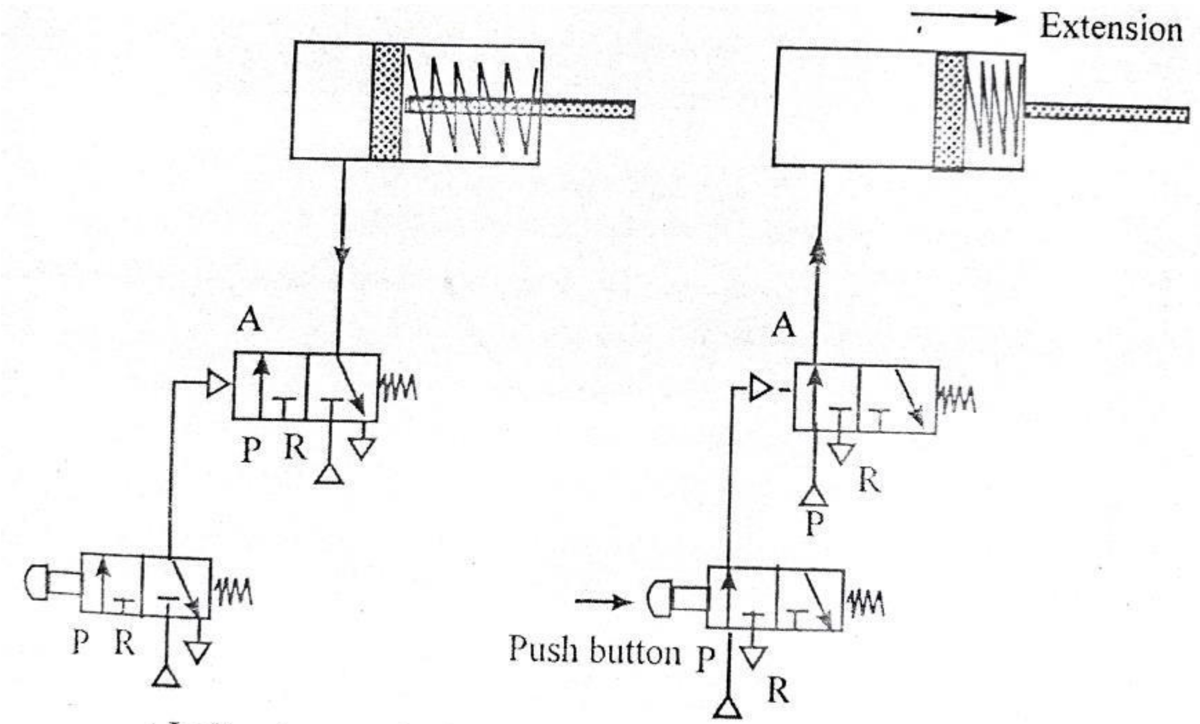
When the directional control valve is actuated by push button, the valve switches over to the open position, communicating working source to the cylinder volume. This results in the

forward motion of the piston rod. When the push button is released, the reset spring of the valve restores the valve to the initial position. The cylinder space is connected to exhaust port there by piston retracts due to spring or gravity.



Direct control of a single control (a) Normal position, (b) Actuated position.

Indirect control of single acting cylinder



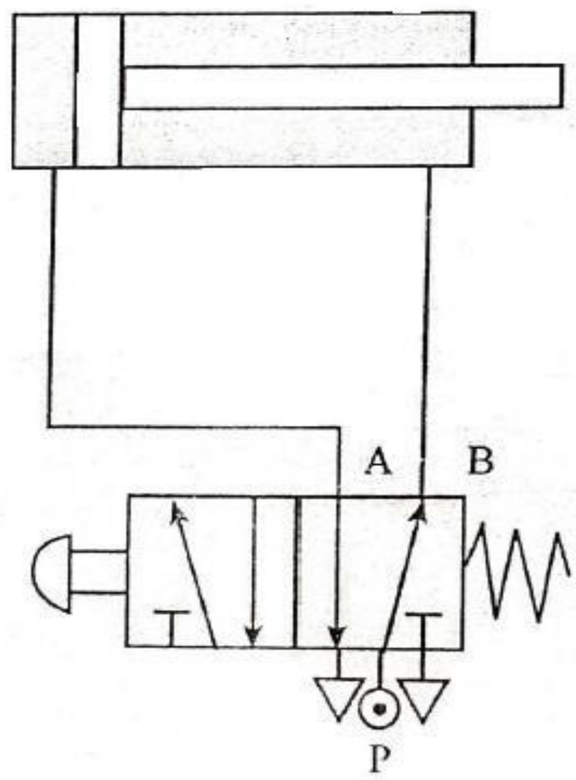
Indirect control of a single acting cylinder: (a) Normal position, (b) Actuated position.

Circuit diagram shown in figure is suitable for large single cylinders as well as cylinders operating at high speeds. The final pilot control valve is actuated by normally closed 3/2 (Three-way Two-position) push button operated valve. The final control valves handle large quantity of air.

When the push button is pressed, 3/2 normally closed valve generates a pilot signal which controls the final valve thereby connecting the working medium to blank end side of the cylinder so as to advance the cylinder. Note that compressor and FRL units here in the circuit are replaced by a simple triangle. A triangle or a circle with a center dot can be used to represent air source in the pneumatic circuit design.

When the push button is released, pilot air from final valve is vented to atmosphere through 3/2 NC — DCV. The signal pressure required can be around 1-1.5 bar. The working pressure passing through the final control valve depends on the force requirement which will be around 6-10 bar. Single piloted valves are rarely used in applications where the piston has to retract immediately on taking out the set pilot signal.

<u>Direct control of Double Acting Cylinder</u>

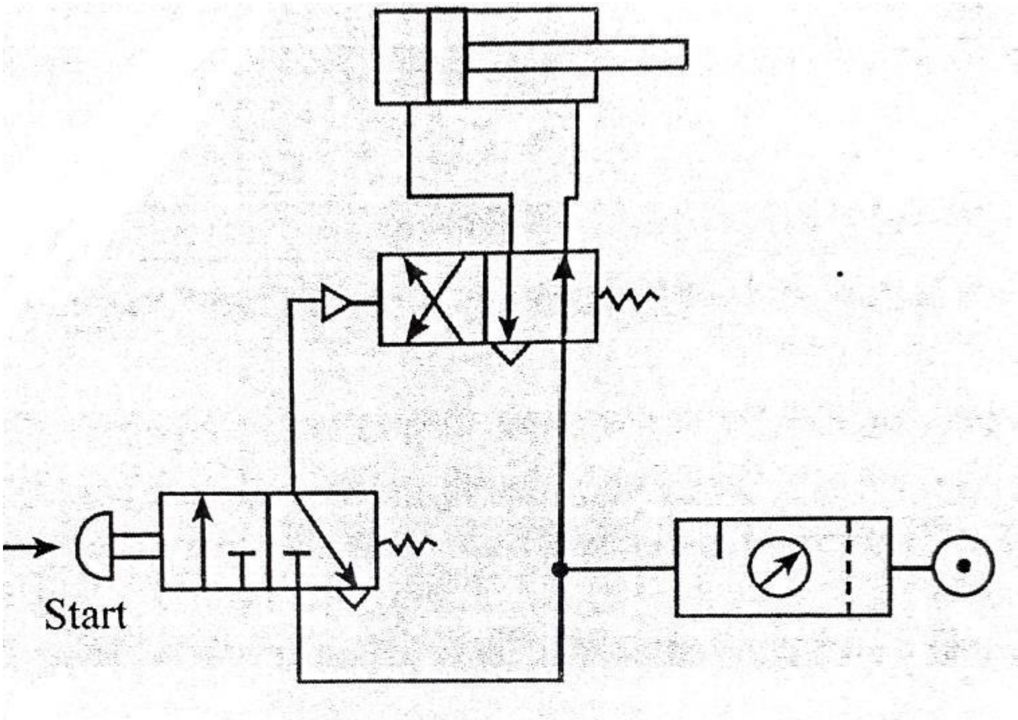


Direct control of a double acting cylinder

As per the construction of double acting cylinder there is no return spring in it. Hence the spring forces are not available to it for retraction of the piston rod as it is in the case of a single acting spring return cylinder.

Here both the forward and return motions of the cylinder are controlled by air pressure and hence a 3/2 DCV is used. Usually, when a double acting cylinder is not operated, outlet B and inlet P will be connected. In this circuit, whenever the push button is pressed manually, the double acting cylinder will extend and retracts when the push button is released.

<u>Indirect control of Double Acting Cylinder</u>



Indirect control of Double acting cylinder

A double acting cylinder can be controlled indirectly using 4/2 pilot operated DCV. This pilot operated valve may be termed as the main valve. The signal provided to the pilot operated valve by means of an air impulse. This operation is therefore also called an impulse operation.

To control the main valve a 3/2 DCV or 2/2 DCV must be used. In the circuit shown in figure two DCV's are connected to a common air source. In the normal position the cylinder will be in the retracted position. To extend the cylinder a pilot signal should be sent to the main valve by actuating push button of the 3/2 DCV. When the push button is released air flow from reservoir to actuator is disconnected, as a result the cylinder retracts.

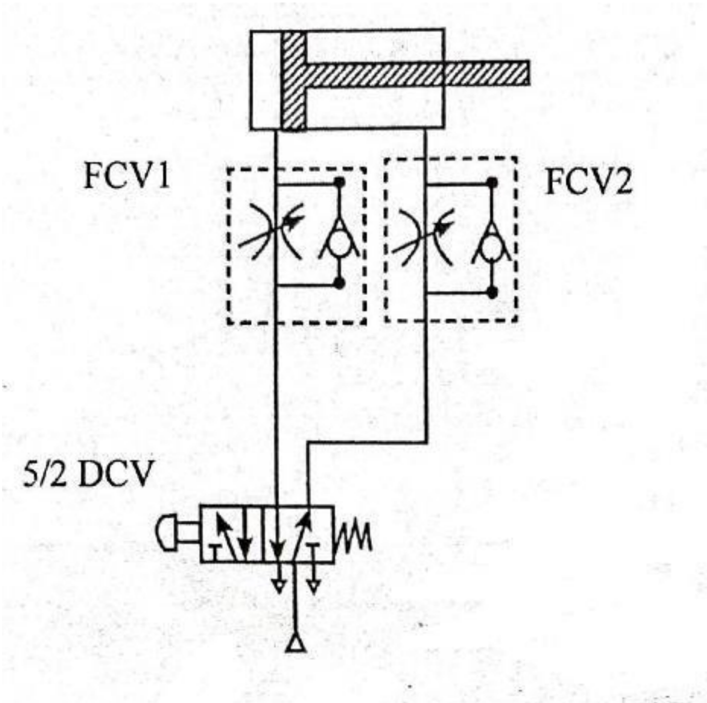
Speed control of
cylinders

It is always necessary to reduce the speed of cylinder from maximum speed based on selected size of final control valve to the nominal speed depending on the application. Speed control of Pneumatic Cylinders can be conveniently achieved by regulating the flow rate supply or exhaust air. The volume flow rate of air can be controlled by using flow control valves which can be either two way flow control valve or one way flow control valve. This is also known as a throttle valve or a flow restrictor.

There are two types of throttling circuits for double acting cylinders:

1. Supply air throttling
2. Exhaust air throttling

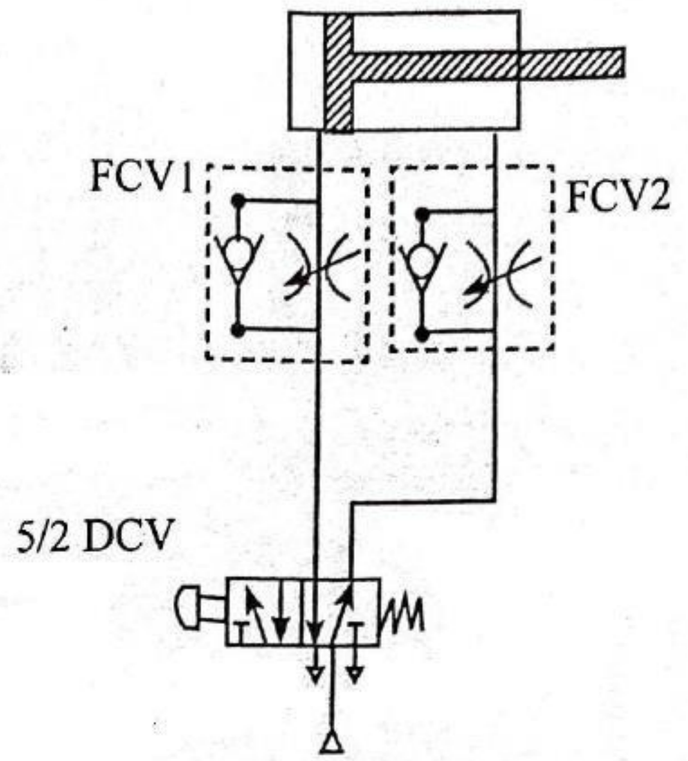
Supply air throttling



Supply Air throttling

This method of speed control of double acting cylinders is also called meter—in circuit for supply air throttling, one way flow control valves are installed so that air entering the cylinderis throttled. The exhaust air can escape freely through the check valve of the throttle valve onthe outlet side of the cylinder. There is no air cushion on the exhaust side of the cylinder piston with this throttling arrangement. As a result, considerable differences in stroking velocity may be obtained even with very small variations of load on the piston rod. Any load in the direction of operating motion will accelerate the piston above the set velocity. Therefore supply air throttling can be used for single acting and small volume cylinders.

Exhaust air throttling



Exhaust air throttling

In exhaust air throttling flow control valves are installed between the cylinder and the main valve in such a way that the exhaust air leaving the cylinder is throttled in both directions of the motion of the cylinder. This method of speed control of double acting cylinders is also called meter-out circuit. The supply air can pass freely through the corresponding check valves in each case. In this case, the piston is loaded between two cushions of air while the cylinder is in motion and hence a smooth motion of the cylinder can be obtained. The first cushion effect is due to supply air entering the cylinder through check valve, and second cushion effect is due to the exhaust air leaving the cylinder through the throttle valve at a slower rate. Therefore, exhaust air throttling is practically used for the speed control of double acting cylinders.

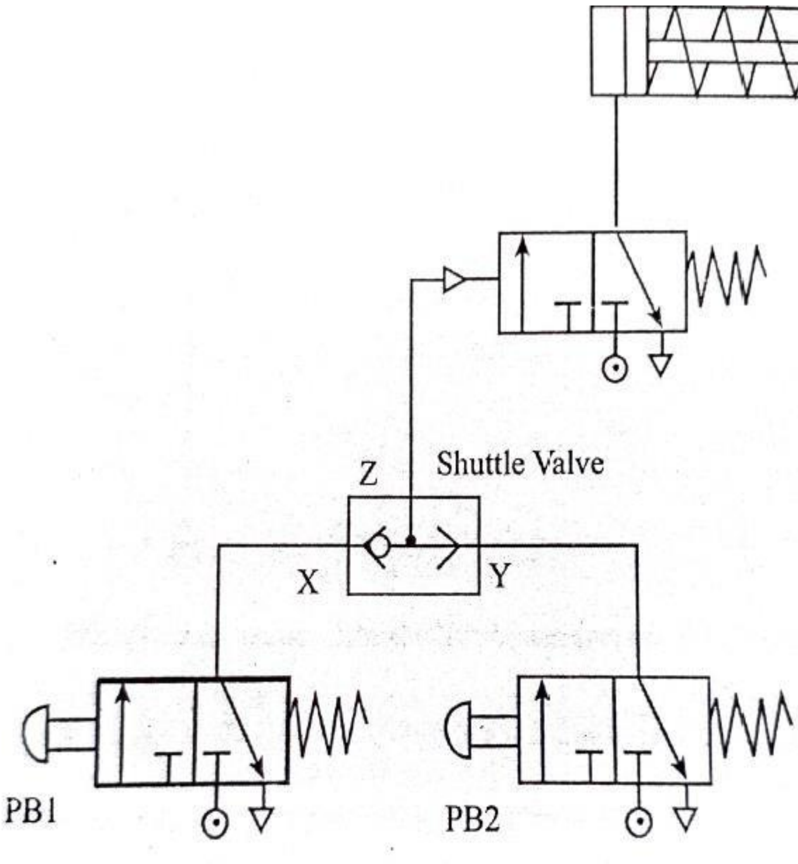
Signal Processing Elements

To meet the requirement of various conditions in pneumatic applications, signal processing devices are often used. The following gates or valves are used, depending on the required conditions.

1. OR Gate—Shuttle Valve—Used to select one of the two input signals.
2. AND Gate-Two Pressure Valve-To combine two input signals i.e. to satisfy two conditions at the same time.
3. NOT Gate-3/2way, normally open, pilot operated Directional Control Valve-used to negate the function.

OR Function

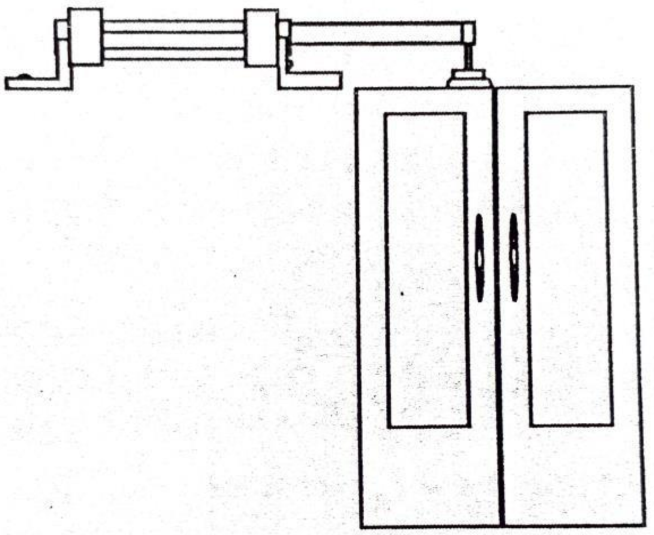
The single acting cylinder in Figure can be operated by two input signals. If compressed air signal is applied to input X or input Y, will produce a signal at output Z. If there is no input signal, there is no output signal. If signals arc present at both inputs, signal with the higher pressure readies the cylinder.



Cylinder actuation with OR function

Two 3/2 push button actuated DCV's are connected to the inlet ports (X and Y) of the shuttle valve. The output (Z) of the shuttle valve is connected to pilot port of the 3/2 DCV. This in turn connected to the blank end side of the single acting cylinder. On pressing either of the pests buttons PB1 or PB2 the compressed air will be delivered by the shuttle valve to 3/2 DCV through the pilot signal. Pilot signal from the shuttle valve actuates the DCV to allow the compressed air to the actuator inlet port. This results in extension of cylinder.

When the 3/2 push button valves return under spring pressure, they remove the pressure from the 3/2 pilot operated valve, it also retracts under spring pressure allowing the valve to return to its initial position and exhaust the actuator as shown in the circuit diagram. Examples include manual operations and applications relying on automatic circuit signals, thatis, when either control valve PB1 or PB2 is operated, the cylinder will work (extend or retract).

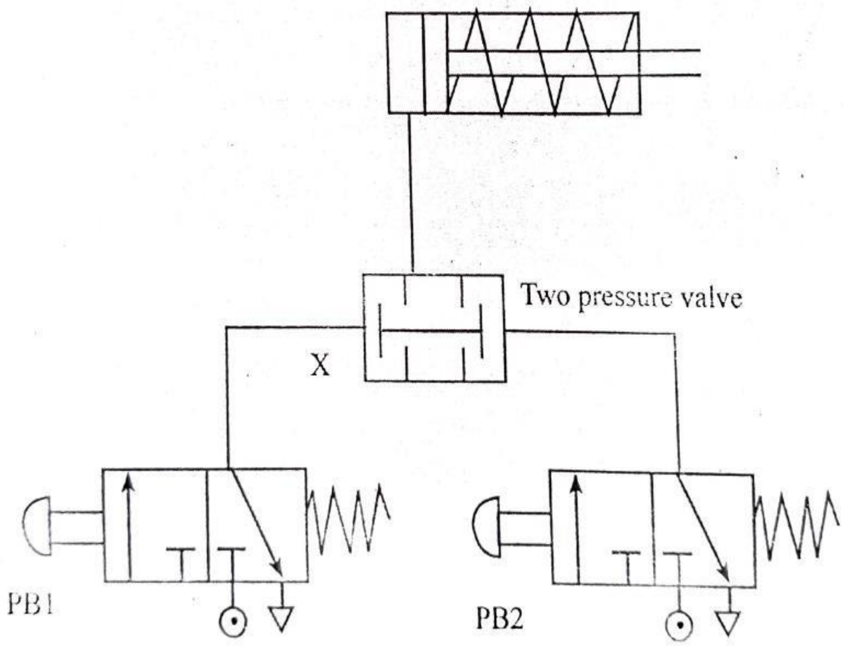


OR function in door opening/closing application

One application of OR gate can be utilized in door closing of a CNC machine during machining process. A double acting cylinder is used to open and close the door. One input may be from the manual push button and another can be from the program itself. Here both input signals are connected to a shuttle valve which in turn connected to the cylinder. Door will be closed if any one input signal is present.

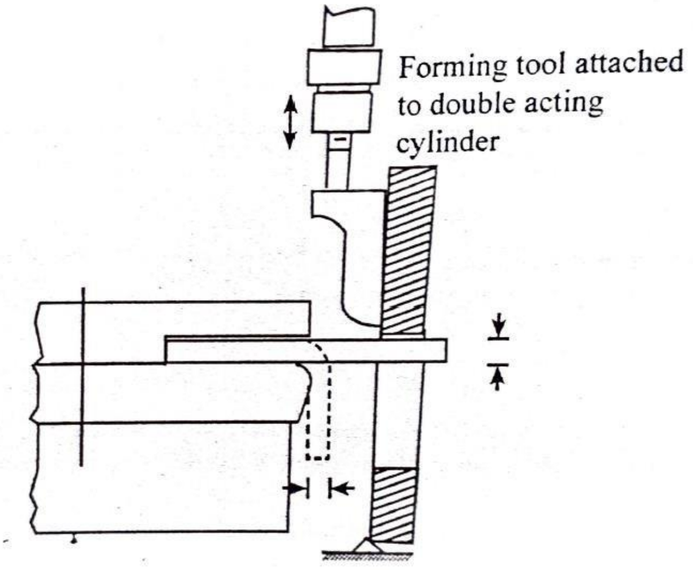
<u>AND Function</u>

Another name for an AND function is interlock control. This means control is possible only when two conditions are satisfied. A classic example is a pneumatic system that works only when its safety door is closed and its manual control valve is operated. The flow passage will open only when both control valves are operated. Fig. shows the circuit diagram of an AND function circuit. The cylinder will work only when both valves PB 1 and PB2 are operated.



AND function

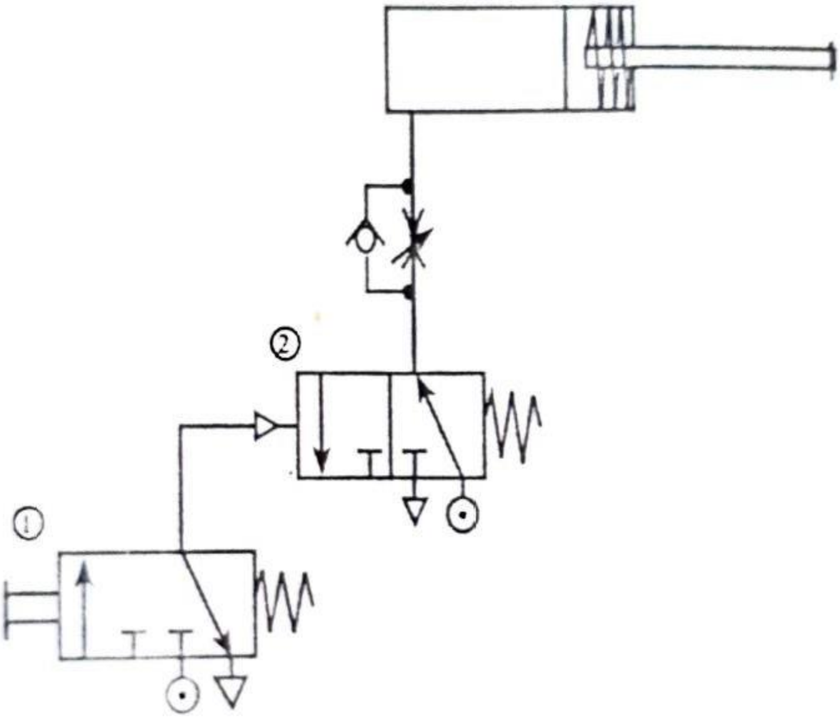
The two pressure valve circuit is equivalent to the two input signaling devices connected in series (PB1 and PB2) one after the other (3/2 way valve, N/C). The signal output is passed all the way through only if both signal elements arc operated at a time.



AND function application in forming operation

In order to maintain a safe operating environment for the forming machine operator, the forming machine that is shown in figure has to be operated by two push button valves at the same time. Operation of the two push button valves causes the forming tool of an edge folding device to fall down rapidly. If both or even just one push button is released, the double acting cylinder slowly returns to the initial position.

NOT Function



pneumatic circuit using NOR function

In order to hold or lock an operating conveyor or a similar machine, the cylinder must be locked (extended) until a signal for cancelling the lock is received. Therefore, the signal for cancelling the lock should be operated by a normally open type control valve. Figure shows how the normally closed type control valve 1 can be used to cut off the normally open type control valve 2 and achieve the goal of changing the signal. Another name for a NOT function is inverse control.

Multi- Cylinder Application

In the majority of pneumatic applications, more than one cylinder is used in a circuit. Depending upon the application, multiple cylinders may be required to operate at different time intervals and can be expected to exert different forces. There are a wide variety of pneumatic circuit designs that enable this type of operation to meet the requirements of an application.

Circuit design methods

There are two primary methods of circuit design:

I. Trial and error method

2. Methodological design

Trial and error methods are also called as intuitive methods because these methods do not have any methodological approach but they dependent on past experience and knowledge of the designer. Trial and error methods require more time for designing complex circuits. It is also important to note that design with this method is dependent on personal influences of designer such as ability, mood, knowledge of pneumatic systems, etc. and it also relies on whether one give more weightage either to least expensive solution or more reliable solution.

On the other hand methodological design follows a certain set rules and instructions to arrive at optimum solution. This method consists of a precisely defined steps and designers influence is less, whereas some theoretical knowledge about the technique that is being followed is required. A methodological circuit design takes lesser time provides reliable solution. Control is always independent of personal influences of designer. It is also worth noting that more components are required when we are designing a circuit by using these techniques than in circuits designed by intuitive methods. The additional cost of component is however compensated by saving of time in completing a project and reduced maintenance costs.

At this stage when both the methods have their own advantages and disadvantages, it is difficult to decide which method is to be adopted. But again it is worth noting that regardless of the method or technique used to design a circuit diagram one should have acquired sound knowledge about pneumatic valves, switches, fluidic elements and means of actuation.

Some of the commonly used techniques in pneumatic multi cylinder circuit design are

1. Coordinated and sequential motion control
2. Signal elimination methods

Coordinated and sequential motion control

In majority of the pneumatic applications more than one cylinder is used. The movements of these cylinders are coordinated as per the required sequence. Normally limit switches are used for confirming the cylinder position and the resultant actuation of the final control element. The activation of limit switches of different cylinders will provide set or reset signal to the final control valves for further controlling the movement of various cylinders. The limit switches have to be arranged in the proper location with the help of motion diagram. In a coordinated motion control, the multi cylinders operate in such a way that there is no conflict between the opposing pilot signals across the DCV's.

Motion sequence representation

An automatic system constitutes working elements and control elements. It is required that motion schedule and start and stop conditions of the elements in a system must be known and interpreted clearly. Understanding what is to be done is very important for final results. So it becomes important to show the sequence of operation of various elements in a pneumatic system in the form of graph. There are two types of diagrams, which are used to represent functional sequences:

1. Motion diagrams
2. Control diagrams

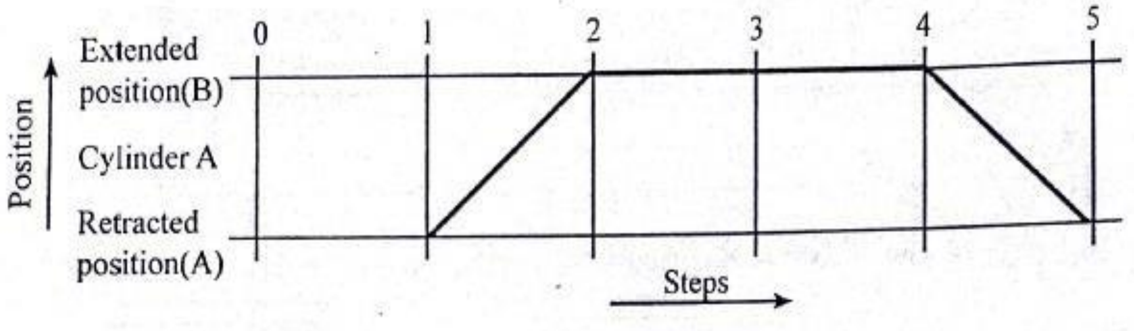
Motion diagrams are graphical representation of all the conditions of working elements; those do not take part in controlling. Similarly control diagrams are those, which provide information about control elements only.

Motion Diagrams

Motion diagrams are of following type

- Position step diagram.
- Position time diagram.

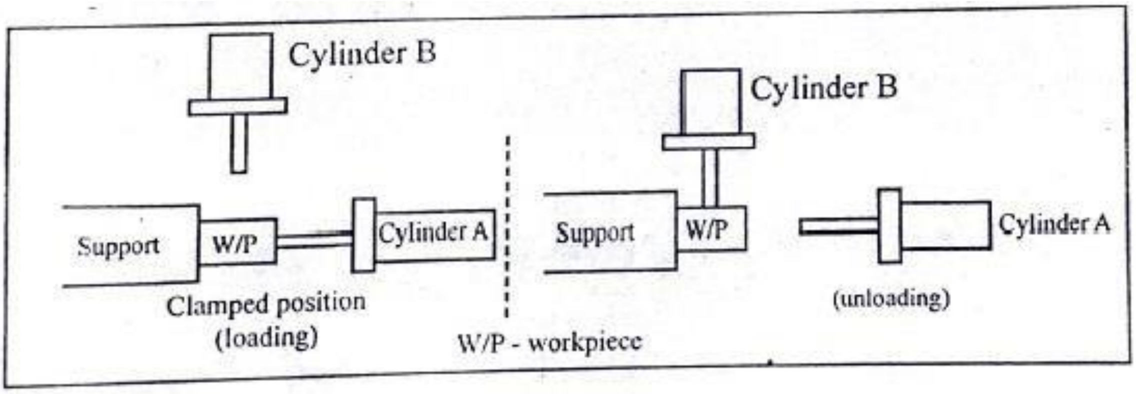
Position step diagram



Position step diagram

This diagram is drawn only by considering the two positions of a double acting pneumatic cylinder 'A'. Position 'A' is retracted or rear position of piston rod and position B represents the extended or forward position of the piston rod. Position is plotted against steps (change in position of any component). Steps are plotted on X-axis and position is plotted on Y-axis. On actuating or operating any particular switch/element in system, there are two possibilities. The position of piston rod either changes or remains same. Only these two cases can be shown with this diagram.

Example showing how to draw position step diagram.



Multi cylinder application.

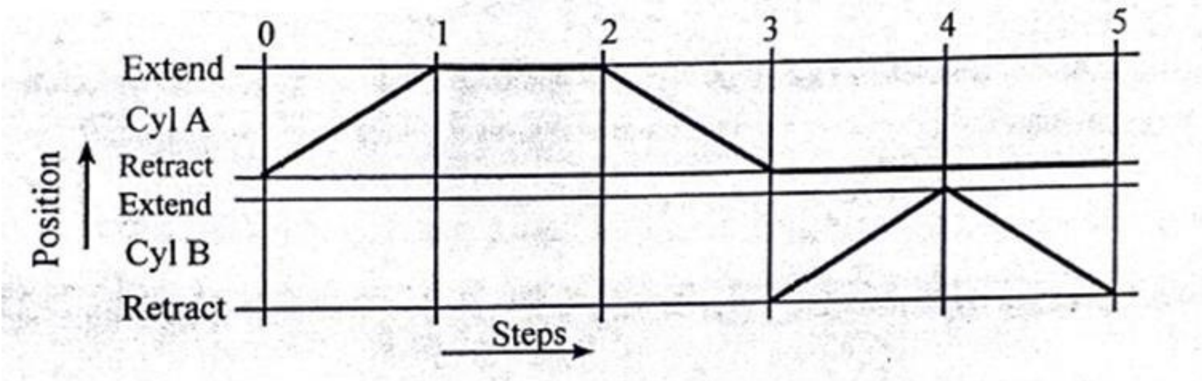
In the given example the series of operation to be carried out are

3. Cylinder A clamps the workpiece
4. Machine operation performed on the workpiece
5. Cylinder A proceeds backwards. Cylinder B proceeds forward and pushes workpiece on conveyor.
6. After pushing the workpiece on conveyor cylinder B travels back

Sequence operation:

Step	Cylinder A	Cylinder B
0-1	Extends	-
1-2	-	-
2-3	Retracts	-
3-4	-	Extends
4-5	-	Retracts

Position step diagram for the above example

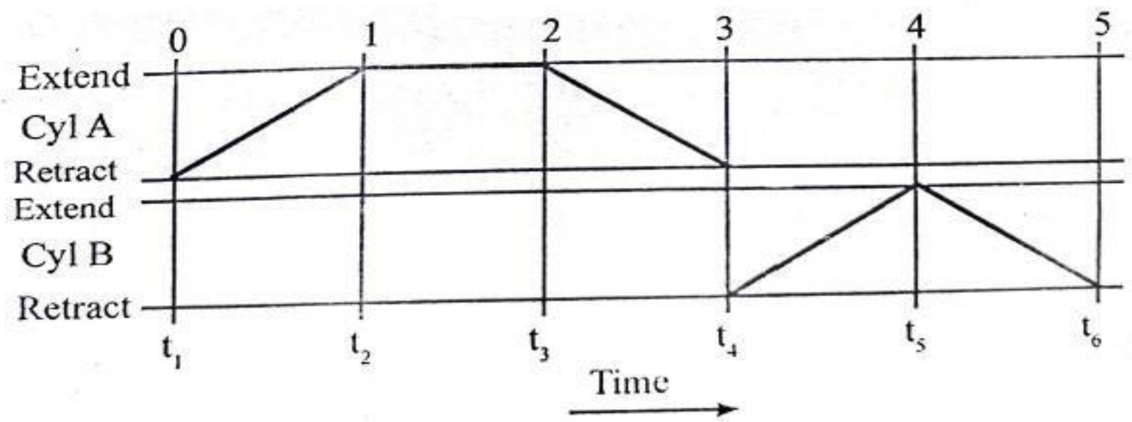


Position step diagram for two cylinder application

Position time diagram

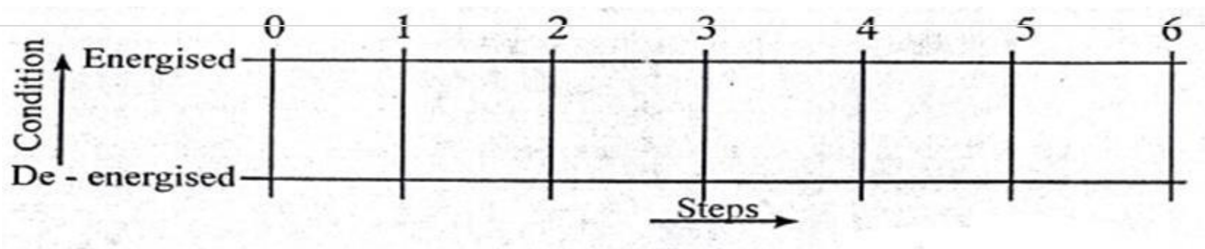
Position time diagram is similar to that of position step diagram. Here cylinder positions are plotted with respect to time. The displacement step diagram is easy to understand and simple to draw on the other hand in case of position time diagram, overlaps and operating speeds can be better shown.

Position time diagram for the above example is shown in figure.



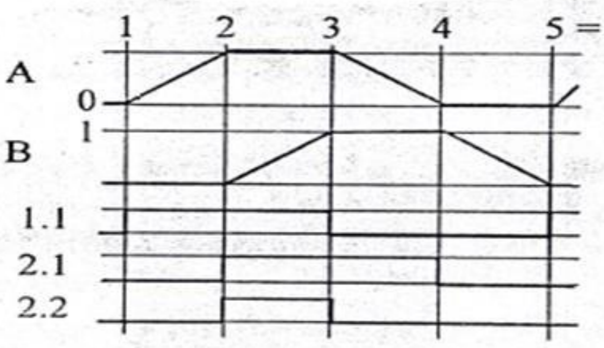
position time diagram

Control diagram



control diagram

Control diagrams are drawn for particular control element. They *simply* display the sequence of actions conducted by a particular control element. It may be called as condition step diagram.



Control diagram for two cylinder application

The control diagram shows the condition of the directional control valves which control the cylinders (A and B) and condition of a limit switch, which is installed at the extended position of cylinder A. As shown in the control diagram as soon as the cylinder A reaches its end of extension the limit switch will be energized to actuate another signal.

Signal Elimination Method

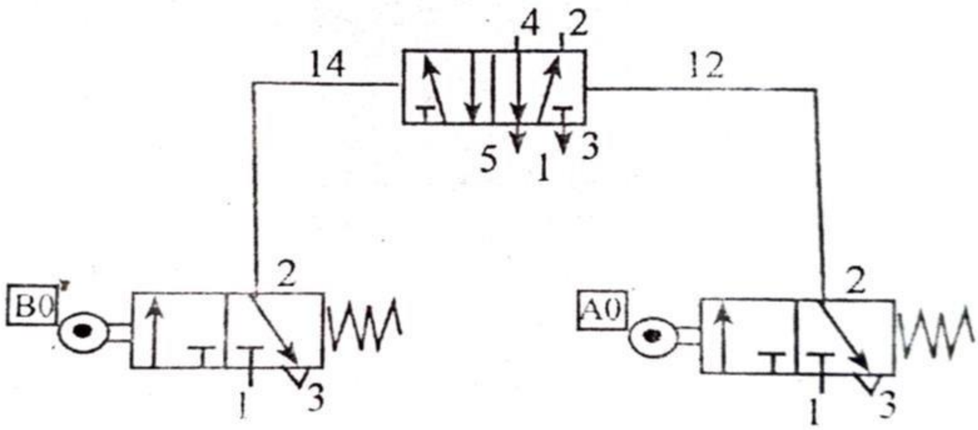


Illustration of signal overlap

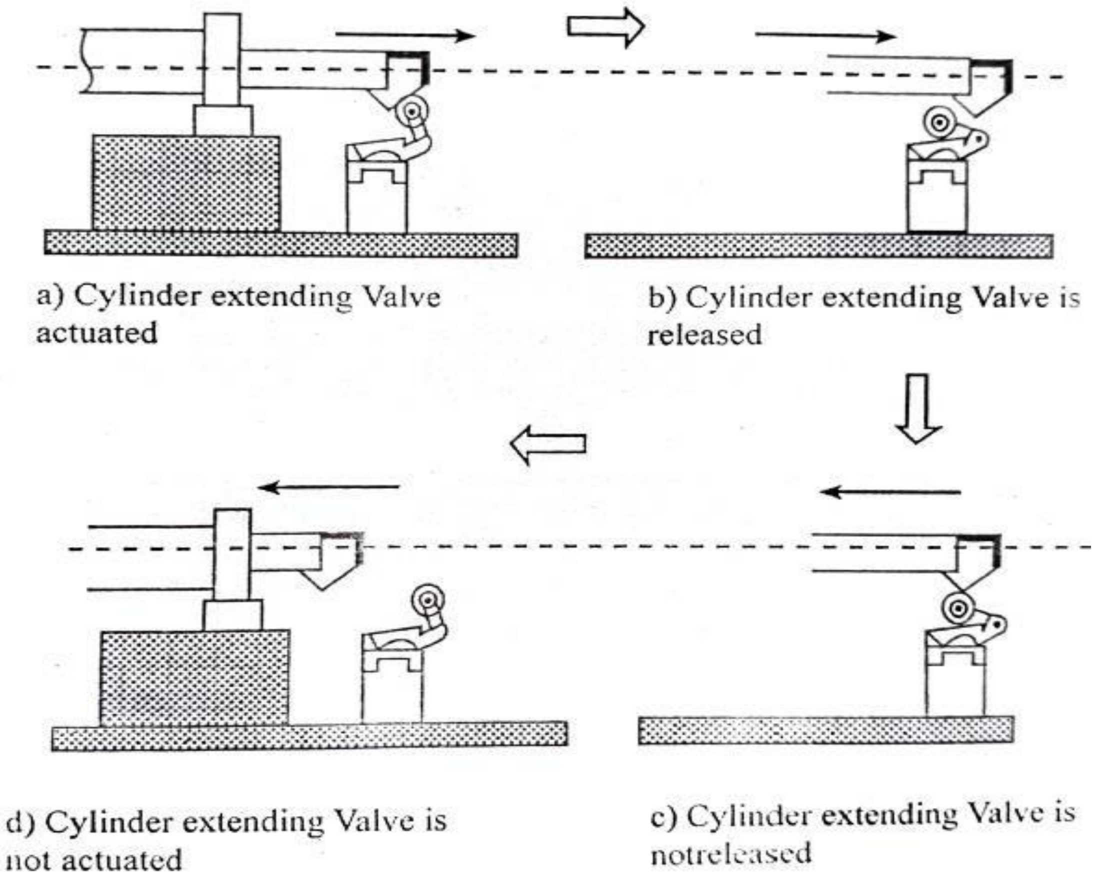
Signal overlap can occur when two active signal appear simultaneously on both set and resetpilot ports of final control valve. This is due to the required sequencing of cylinder. At the start, both signals a0 and b0 appear at same time. This will not result in any change.

Various methods used to solve the problem of signal conflicts in multi cylinder circuits are;

7. Idle return roller
8. Cascading method

Idle return roller

If a signal to be eliminated, a limit switch valve operated by an idle return roller can be used. The action of the idle return roller valve can be understood with the help of figure. The idle return roller may be positioned in the control system so that when the cylinder extends, the piston passes over the idle — roller mechanism of the valve, thus activating the valve, but also permitting the valve to be deactivated immediately when the piston moves to the extreme end position. As a result, the valve generates a short output pulse during the forward motion of the cylinder. The idle return mechanism also allows the cylinder to retract without re-activating the valve. Hence, in the end position or during the return motion of the piston, the valve does not get actuated, and no output signal is produced. For the generation of short output pulse by the idle-return roller valve during the return motion of the cylinder, this valve may be positioned in the opposite direction as compared to the case during the forward motion of the cylinder.



working of idler roller valve

2. Cascading method (Reversing or group changing valves)

Cascading is a methodological approach to the problem of pneumatic circuit design. Cascading Means "in series". In this method the sequence of pneumatic cylinders is controlled by using various type of signaling elements. These signaling elements are of course driven by forward and backward strokes of cylinders but the air supply to pilot linesis delivered through a cascade system. A reversing valve can be used to eliminate signal conflicts. Signal conflict is avoided by allowing the signal to be effective only at times whenthey are needed. In cascade system the forward and backward motions of pneumatic cylinders are classified into groups. Then the particular groups of movements are controlled with components in cascade system. Then those particular groups of movements are controlled with components in cascade system.

The cascade system consists of group selector valves, bus bar lines and pilot lines. Busbar lines are basically pneumatic energy lines; those are spread inside the whole plant. These are used to supply pneumatic energy to pneumatic systems.

To know and learn how the cascade system is drawn for a problem one must be familiar with components of cascade system. In the following paragraphs the method of cascading is explained step by step by taking an example and also various components ofcascade system are explained.

Sign conventions

Certain sign conventions have to be adopted to denote forward and backward motions of cylinders. These are given below:

- Cylinder advance movement designated by +ve sign
- Cylinder backward movement designated by -ve sign
- Cylinder can be named as A, B, C, D... depending upon their numbers
- So we can denote forward motion of cylinder A by the sign A^+, and backward motion by A^-.

Sequencing

Sequencing may be defined as the process to put things in right order. It is the prime step in circuit design depending upon the problem assigned. One can simply apply the mind and can arrange the forward and backward motions of all the cylinders in circuit. Position step diagrams can further show this sequence graphically.

Rest of the procedure is shown step by step taking following examples:

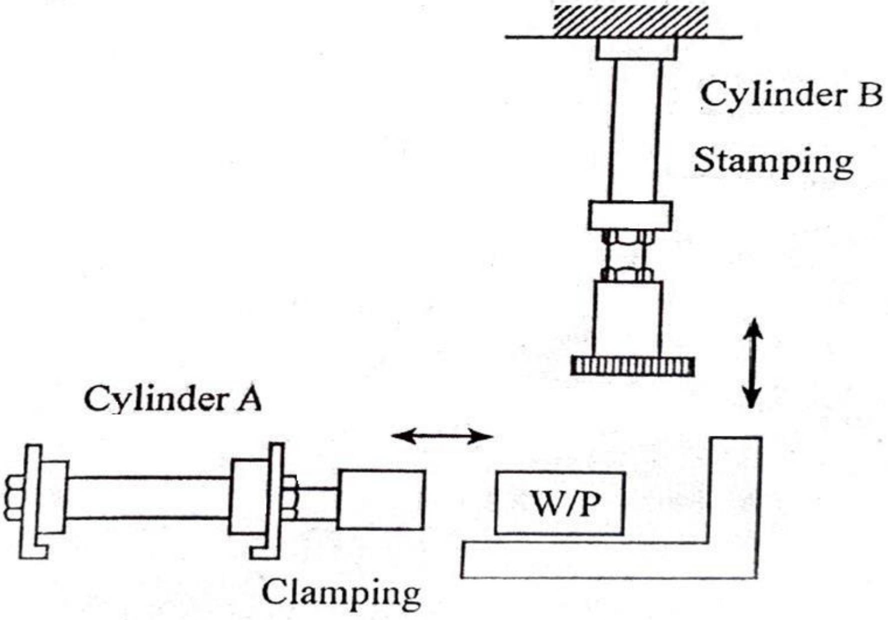
Demonstration of Cascade method

In order to develop control circuitry for multi cylinder applications, it is necessary to draw the motion diagram to understand the sequence of actuation of various signal input switches- limit switches and sensors. Motion diagram represents status of cylinder position whether extended or retracted in a particular step.

Step 1: Write the statement of the problem:

Let A be the first cylinder (clamping) and B be second cylinder (stamping) as shown it the Figure. First cylinder A extends and clamps the workpiece under stamping station where cylinder B is located. Cylinder B then extends and stamps the job. Cylinder A can return back only after cylinder B has retracted fully.

Step 2: Draw the positional layout:



Positional diagram

Step3: Represent the control task using notational form:

Cylinder A advancing step is designated as A+

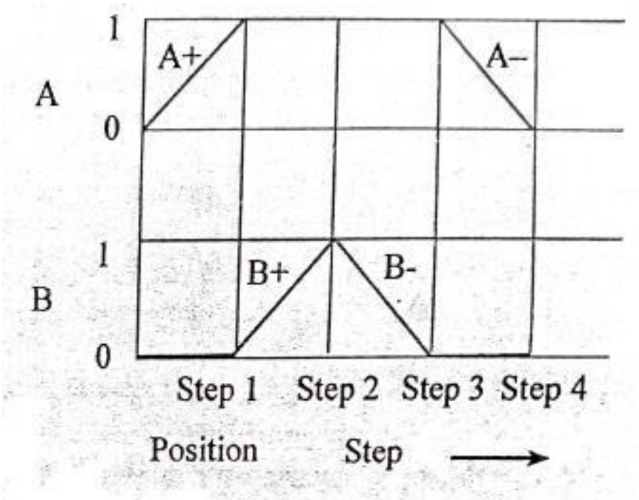
Cylinder A retracting step is designated as A-

Cylinder B advancing step is designated as B+

Cylinder B retracting step is designated as B-

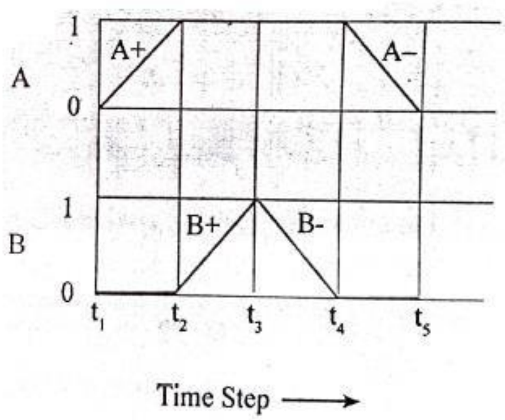
Given sequence for clamping and stamping is A+B+B-A-

Step 4 Draw the Displacement —step diagram:



Displacement step diagram

Step 5:-Draw Displacement time Diagram



Displacement time diagram

Step6:- Analyse and Draw Pneumatic Circuit Step 6.1 Analyse input and output signals: **Input Signals**

Cylinder A - Limit switch at retracted position a0

Limit switch at extended position at a1

Cylinder B - Limit switch at retracted position b0

Limit switch at extended position b1

Output Signal

Forward motion of cylinder A (A+)

Return motion of cylinder A (A-)

Forward motion of cylinder B (B+)

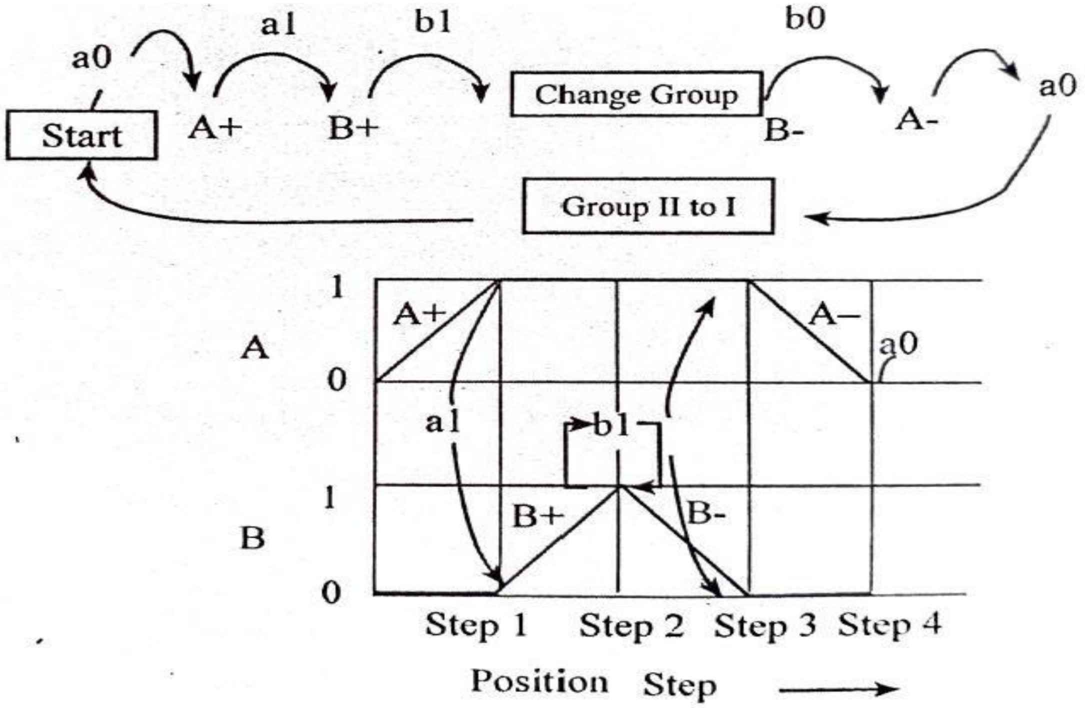
Return motion of cylinder B (B+)

Step 6.2 using the displacement time/step diagram link input signal and output signal:

Usually start signal is also required along with a0 signal for obtaining A+ motion.

1. A+ action generates sensor signal a1, which is used for B+ motion
2. B+ action generates sensor signal b1, which is used for group changing.
3. B- action generates sensor signal b0, which is used for A- motion
4. A- action generates sensor signal a0, which is used for group changing

Above information is shown below graphically.



Displacement time diagram

Step 7 Draw the power circuit:

i) Divide the given circuits into groups. Grouping should be done such that there is no signal conflict. Do not put A+ and A- in the same group. Similarly B+ and B- should not be put in the same group. In other word A+ and A- should belong to different group to avoid signal conflict.

In our example of A+ B+ B- A- we can group as

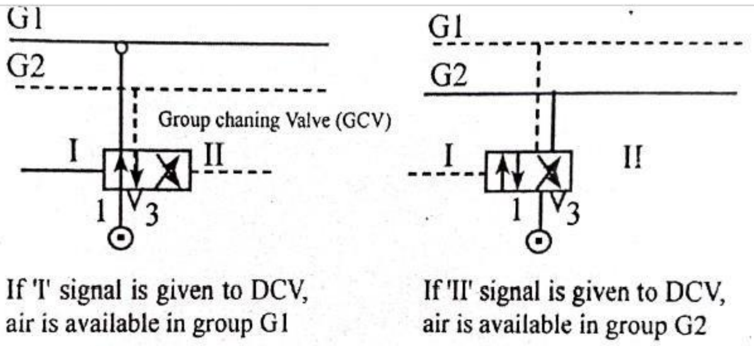
A+ B+	B- A-
Group 1	Group 2

ii) Choose the number of group changing valve = No of groups -1

In our example, we have 2 groups so we need one group changing valve

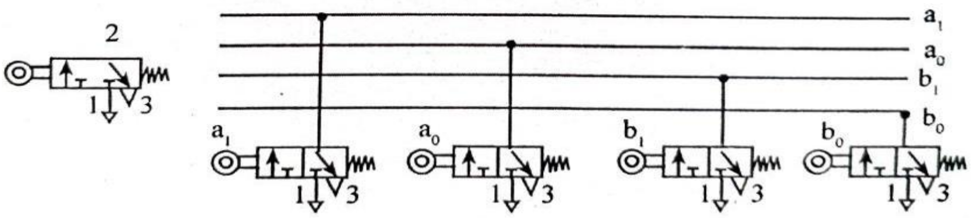
Connect the group changing valve as follows. From the figure it is clear that when the control signals I and II are applied to will, changing valve, the air (power) supply changes from Group l(GI) to Group 2 (G2)

iii) Arrange limit switch and start button as given below



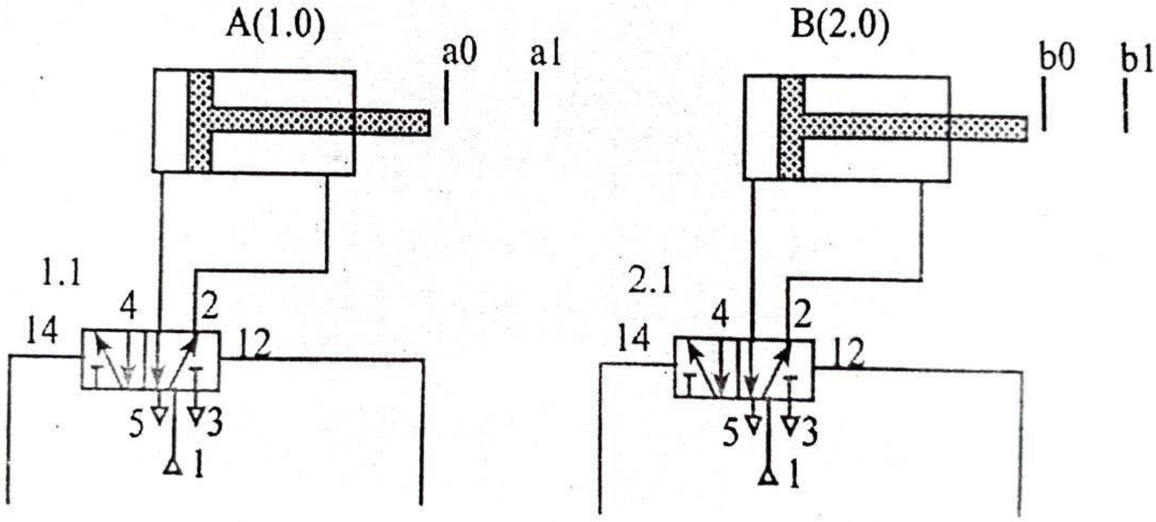
connection of DCV to group changing valve

Figure 5.24 connection of DCV to group changing valve



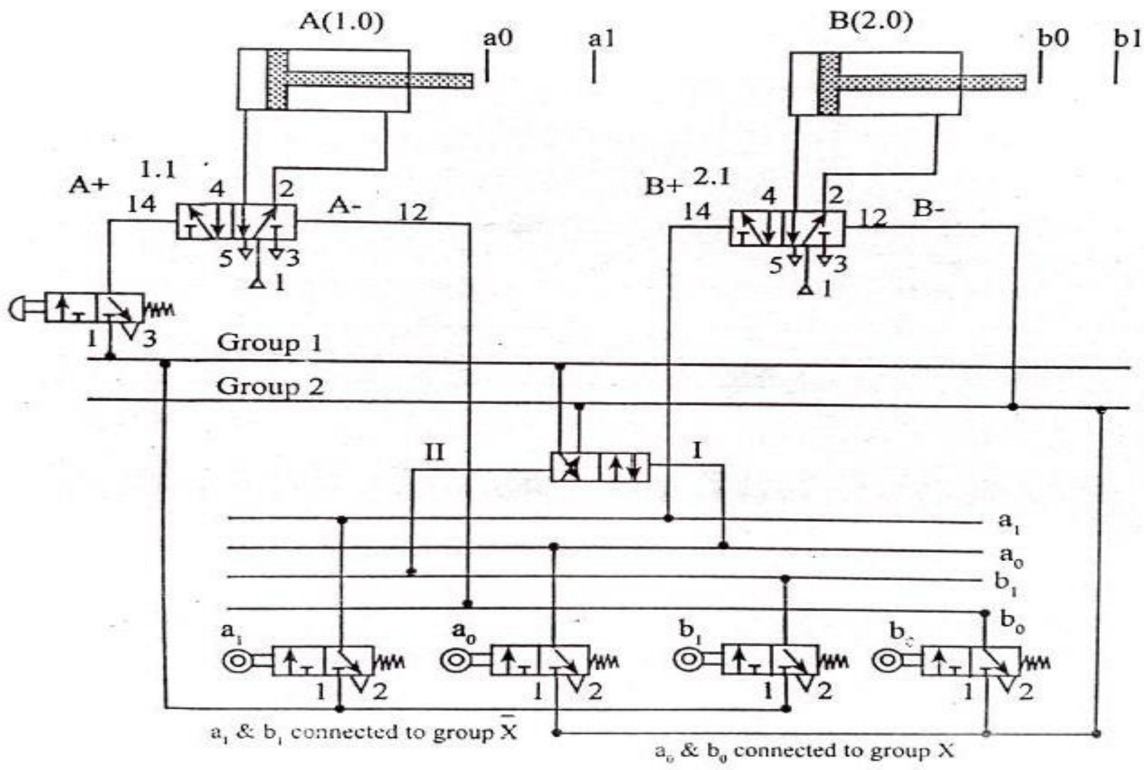
Connection of limit switches and start button

iv) Draw the power circuit



power circuit diagram

Step 8 Draw the control circuit



Pneumatic circuits for A+ B+ B- A-

Step 9 Analysis of pneumatic circuit:

1. Assume that air is available in the line G2 to start with. (Say from previous operation)

2. When the start button is pressed, air supply from Group G2 is directed to line 2 through actuated limit switch a0. Now the air available in line 2 actuates the Group changing valve (GCV) to switch over to position 1. This switching of the GCV causes air supply to change from G2 to G1.

3. Now the air is available in line G1. The air supply from group G1 is directed to port 14 of the valve 1.1. As there is no possibility of signal conflict here. Valve 1.1 switches over causing the A+ action.

4. Sensor a1 is actuated as the result of A+ action, allowing the air supply front the Group G1 to reach to line 1 through a1. Now the air available reaches port 14 of valve 2.1. As there is no possibility of signal conflict here, valve 2. I switches over, causing B+ action automatically.

5. Sensor b1 is actuated as result of B+ action, allowing the air supply in line 3. Air from line 3 allows the air to reach port 12 of Group changing valve (also called reversing valve). As a result, the Group changing valve switches over, causing the group supply to change from GI to G2.

6. Now the air is available in G2. Air from G2 acts on port 12 of the Valve 2.1. As there is no possibility of signal conflict here, valve 2.1 switches over, causing B- action automatically.

7. Sensor b0 is actuated as the result of B- action. Now the air is available in line 4. Air from line 4 reach port 12 of the valve 1.1. As there is no possibility of signal conflict here, valve 2.1 switches over, causing A- action automatically.

The cascade system provides a straightforward method of designing any sequential circuit. Following are the important points to note:

a) Present — the system must be set to the last group for start-up

b) Pressure drop- Because the air supply is cascaded, a large circuit can suffer from more pressure drop.

c) Cost — Costly due to additional reversing valves and other hardware.

Electro Pneumatic Control

Electrical devices have proven to be an important means of improving the overall control flexibility of fluid power systems. In recent years, the trend has been toward electrical control of fluid power systems and away from manual control. One of the reasons for this trend is that more machines are being designed for automatic operation to be controlled with electrical signals from computers.

We are now familiar with several components used in pneumatic circuits. Except for the compressor motor, no other component uses electricity, so, these non-electrical circuits find more applications in mines or where inflammable gases are present. But in industrial applications, use of electrical energy in pneumatic circuits and pneumatic components is more common.

In Electro pneumatic controls, mainly three important steps-are involved:

Signal input devices -Signal generation such as switches and contactor, various types of contact and proximity sensors.

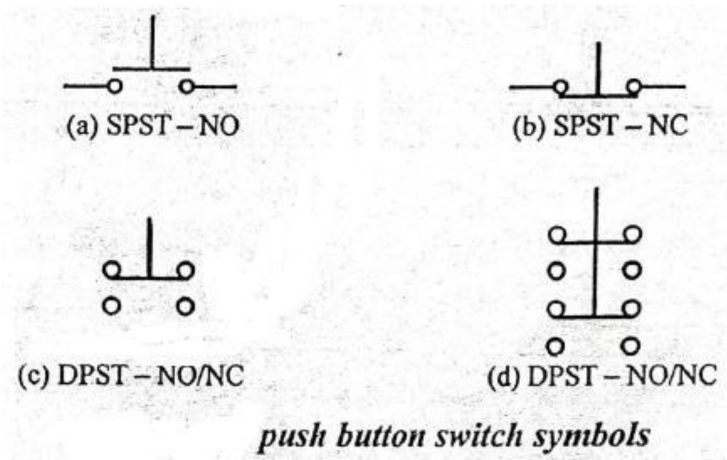
Signal Processing — Use of combination of Contactors of Relay or using Programmable Logic Controllers.

Signal Out puts — out puts obtained after processing are used for activation of solenoids, indicators or audible alarms.

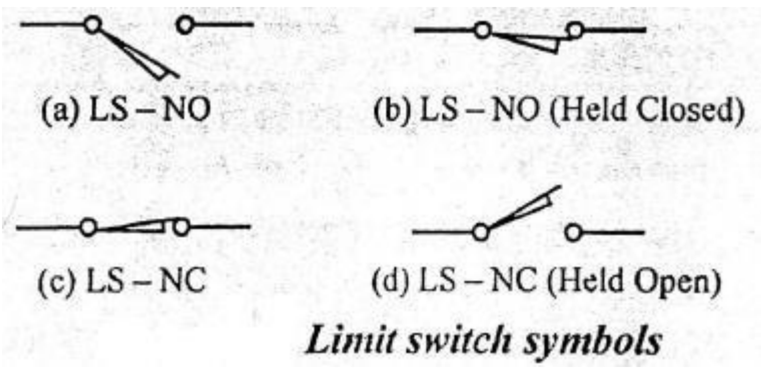
There are seven basic electrical devices commonly used in the control of fluid power systems: manually actuated push-button switches, limit switches, pressure switches, solenoids, relays, timers and temperature switches. Switches can be wired either normally open (NO) or normally closed (NC). A normally open switch is one in which no electric current can flow through the switching element until the switch is actuated. In normally closed switch, electric current can flow through the switching element until the switch is actuated.

1. Push-button switches:

By the use of a simple push-button switch, an operator can cause sophisticated equipment to begin performing complex operations. These push-button switches are used mainly for manual override when an emergency arises. Figure shows four common types of push button switches.



2 Limit switches:



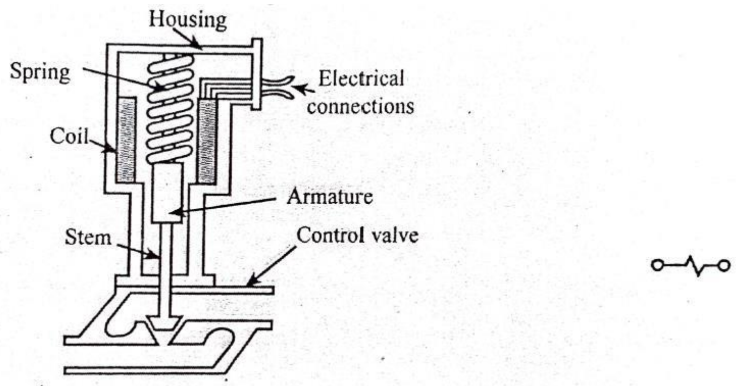
Basically limit switches perform the same function as push-button switches. The difference is that they are mechanically actuated rather than manually actuated. Limit switches open and close circuits when they are actuated either at the end of the extension or retraction strokes of hydraulic or pneumatic cylinders. In figure we see various types of limit switches.

3 Pressure switches:

Pressure switches open or close their contacts based on system pressure. They generally have high pressure setting and a low pressure setting. For example it may be necessary to start or stop a pump to maintain a given pressure. The low pressure setting would start the pump and the high pressure setting would stop it. Figure shows graphical symbol used to represent a pressure switch in fluid power circuits as well as the graphical symbol used in electrical circuits.

pressure switch symbols

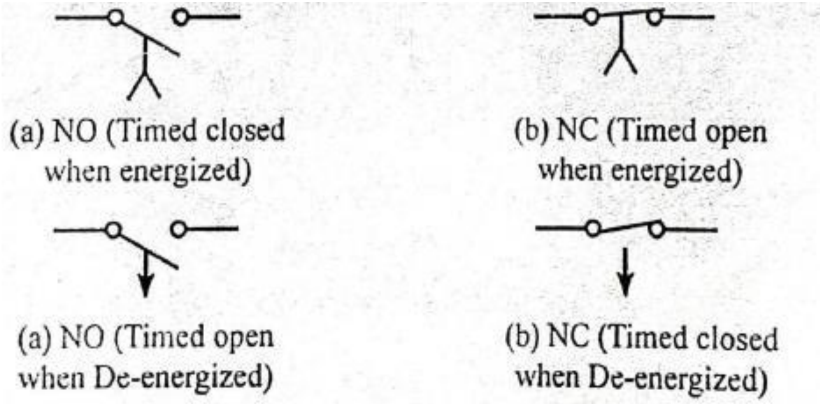
4. Solenoids



working principle of solenoid graphical symbol used in electro-pneumatic circuits

Solenoids are electromagnets that provide a push or pull force to operate fluid power valves remotely. When a solenoid is energized, the magnetic force created causes the armature to shift the spool of the valve containing the solenoid.

5. Timers: Time delay devices are used to control the time duration of a working cycle. In this way a dwell can be provided where needed. For example, a dwell can be applied to a drilling machine operation, which allows the drill to pause for a predetermined time at the end of the stroke to clean out the hole. Most timers can be adjusted to give a specified dwell to accommodate changes in feed rates and other system variables.



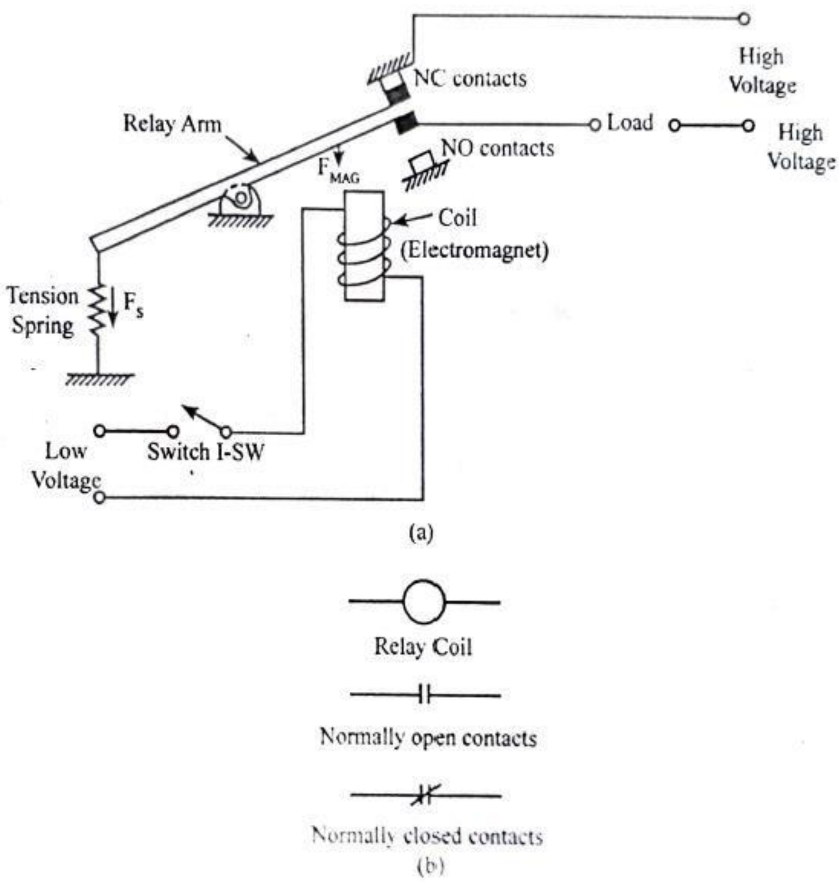
Timer symbols

6. Temperature switches: Temperature switches is an instrument that automatically senses a change in temperature and opens or closes an electrical switch when a predetermined temperature is reached. Temperature switches can be used to protect a fluid power system from serious damage when a component such as a pump or strainer or cooler begins to malfunction. The resulting excessive build up in oil temperature is sensed by the temperature switch, which shuts off the entire system.

temperature switch symbol

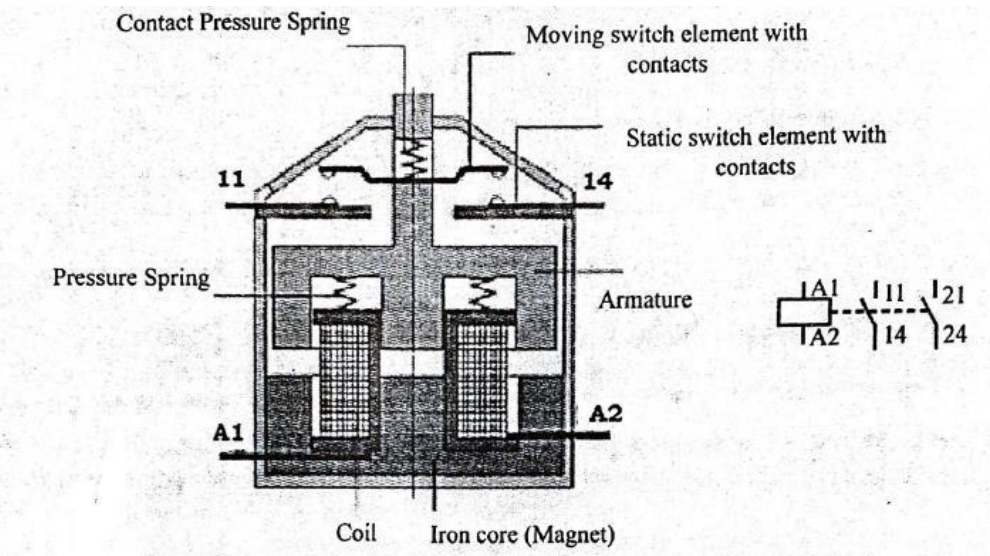
7. Electrical relays and contractors

Relays are switches whose contacts open or close when their corresponding coils are energised. These relays are commonly used for energizing and de-energizing of solenoids because they operate at high current level. In this way a manually actuated switch can be operated at low voltage levels to protect the operator. This low-voltage circuit can be used to open and close circuits containing the solenoids. The use of relays also provides interlock capability, which prevents the accidental energizing of Iwo solenoids at the opposite ends of a valve spool. This safety feature can therefore, prevent the burnout of one or both of these solenoids.



electrical relay and graphical symbol

As shown in schematic diagram, when switch ISW is closed, the coil (electromagnet) is energized. This pulls on the spring-loaded relay arm to open the upper set of normally closed contacts and close the lower set of normally open contacts.

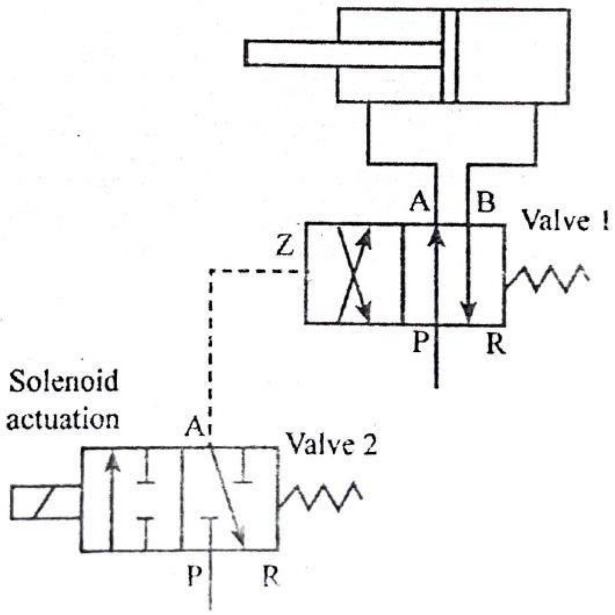


Schematic diagram of contactor and graphical symbol

Contactors operate in the same way as a relay. A contactor has multiple switching elements, normally four to ten contacts. Contactors that only switch auxiliary contacts (control contacts) are called contactor relays. Contactors with main and auxiliary contacts are called main or power contactors. Figure shows the schematic diagram of a contactor used in electro pneumatic system.

Pilot assisted solenoid control of directional control valve

With the large capacity pneumatic power applications the operating force required to move the valve can be large. If the required force is too large for solenoid or manual operation, a two stage process called pilot operation is used. The principle of pilot operated valve is shown in figure. The valve 1 is the main operating valve which is used to move the cylinder. The operating force required to move the valve is too large. Therefore a direction control operation by a solenoid is used. Another valve 2 known as pilot valve has been added to allow the main valve to be operated by system pressure.



Pilot assisted solenoid control of directional control valves

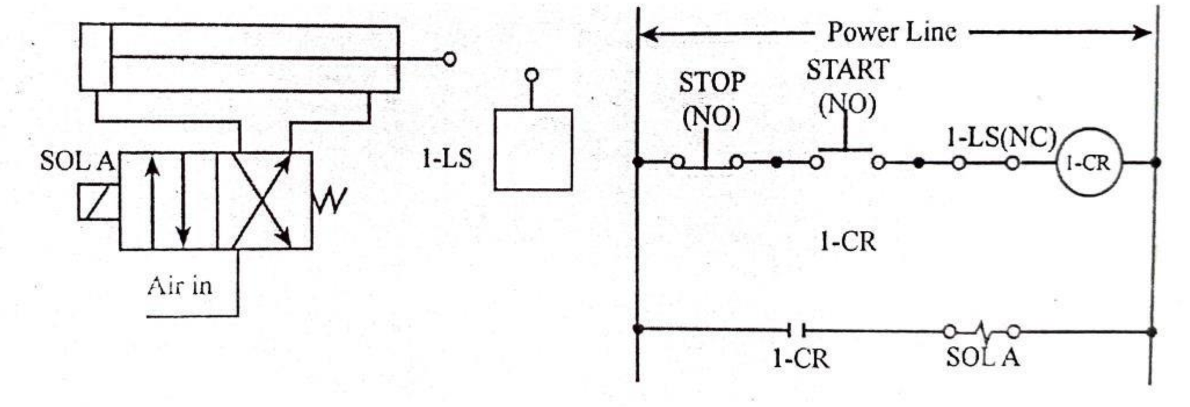
Dotted line in the circuit shows the pilot pressure line and the Z is used to denote the pilot port of the main valve. By energizing the solenoid of the valve 2, flow can be diverted to main valve 1 to change the position of valve 2. As a result the compressed air is allowed to extend the cylinder. To retract the cylinder the electrical signals to the solenoid must be stopped. Note that both the cylinders are spring offset.

Electropneumatic circuits

Control of a cylinder using a single limit switch

A double acting cylinder can be controlled by using a single limit switch and a single solenoid valve as shown in figure gives the pneumatic circuit in which the limit switch is labelled 1-LS and the solenoid is labelled SOL A. this method of labelling is required since many systems require more than one limit switch or solenoid.

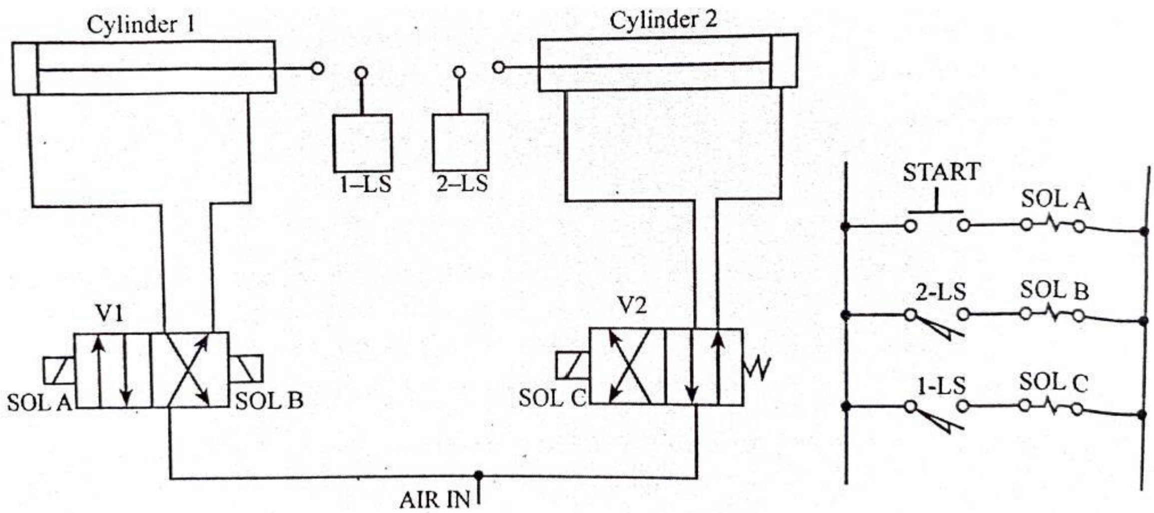
Electrical circuit diagram in figure shows the use of one relay with a coil designated as 1-CR and two separate, normally open sets of contacts with a coil labelled 1-CR (NO). The limit switch is labelled l-LS (NC), and also included are one normally closed and one normally open push button switch labelled STOP and START, respectively. This electrical diagram is called a "ladder diagram" Because of its resemblance to a ladder. The two vertical electric power supply lines are called "rungs".



control of a double acting cylinder using single limit switch.

When the START button is momentarily pressed, the cylinder extends because coil 1-CR is energized, which closes both sets of contacts of 1-CR. Titus, the upper 1-CR set of contacts serves to keep coil 1-CR energized even though the START button is released. The lower set of contacts closes to energize solenoid A to extend the cylinder. When 1-LS is actuated by the piston rod cam, it opens to de-energize coil 1-CR. This re-opens the contacts of 1-CR to de-energize solenoid A. Thus, the valve returns to its spring-offset mode and the cylinder retracts. This closes the contacts of 1-LS, but coil 1-CR is not energized because the contacts of 1-CR and the START button have returned to their normally open position. The cylinder stops at the end of the retraction stroke, but the cycle is repeated each time the START button is momentarily pressed. When the STOP button is momentarily pressed, it will immediately stop the extension stroke and fully retract the cylinder.

Dual-cylinder sequence circuits



dual cylinder sequencing circuits

Fig shows a circuit that provides a cycle sequence of two pneumatic cylinders. When the startbutton is momentarily pressed, SOL A is momentarily energized to shift valve V1, which extends cylinder 1. When 1-LS is actuated, SOL C is energized, which shifts valve V2 into its left flow path mode. This extends, cylinder 2 until it actuates 2-LS. As a result, SOL B is energized to shift valve V1 into its right flow path mode. As cylinder 1 begins to retract, it de-actuates 1-LS, which de-energizes SOL C. this puts valve V2 into its spring-offset mode, and cylinders 1 and 2 retract together. The complete cycle sequence established by the momentary pressing of the start button is as follows:

1. Cylinder 1 extends.
2. Cylinder 2 extends.
3. Both cylinders retract.
4. Cycle is ended.

QUESTIONS FROM PREVIOUS YEAR QUESTION PAPERS:

DEC 2015/JAN 2016

1) Explain a typical pneumatic circuit with OR logic using shuttle valve.
2) With a neat circuit diagram, explain Electro pneumatic control of a double acting cylinder using a 4/2 solenoid actuated spring return cylinder.
3) Explain the cylinder pneumatic circuit and its motion control diagram.

JUNE/JULY 2016

1) Explain the principle of cascade control system.
2) List advantages of solenoid controlled pilot operated direction control valve.
3) What are flow control valves? Draw graphical symbols for FCV

DEC 2016/JAN 2017

1) Briefly explain the following: i) OR gate ii) AND gate iii) Solenoids iv) Motion Diagrams

JUNE/JULY 2017

1) With a neat sketch explain how OR functions are generated in pneumatic systems.
2) Explain control circuitry for single acting cylinders with circuit diagram.
3) Explain signal elimination using reversing valves.

DEC 2017/JAN 2018

1) Explain with neat sketch of circuit of sequencing of two pneumatic cylinder that can be done by using solenoids, limit switches and valves.
2) Explain with a neat circuit diagram, the working of two step speed control system.

JUNE/JULY 2018

1) Explain the different methods employed for controlling the speed of pneumatic cylinders with neat sketches.

CRASH COURSE – MAY 2017

1) Explain with a neat pneumatic circuit for cylinder sequencing.
2) Explain with a neat sketch solenoid controlled pilot operated direction control valve.

ONE TIME EXIT SCHEME – APRIL 2018

1) Explain OR and AND gates used in pneumatic system.
2) Write a short notes on cascading method.