SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – I - Fluid Power Systems – SME1302

UNIT 1: GENERAL INTRODUCTION TO CONTROL SYSTEM COMPONENTS AND ACCESSORIES

INTRODUCTION

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 flow rate.

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.
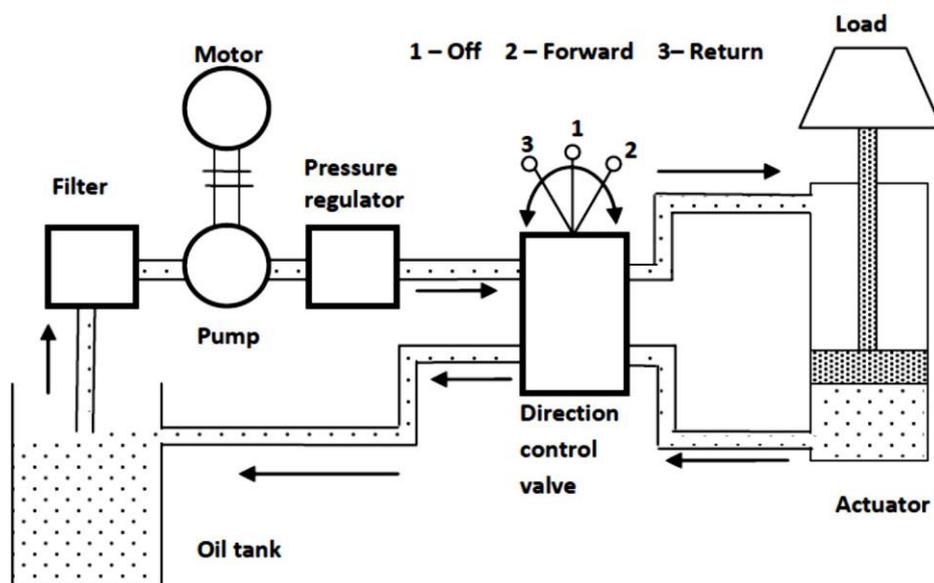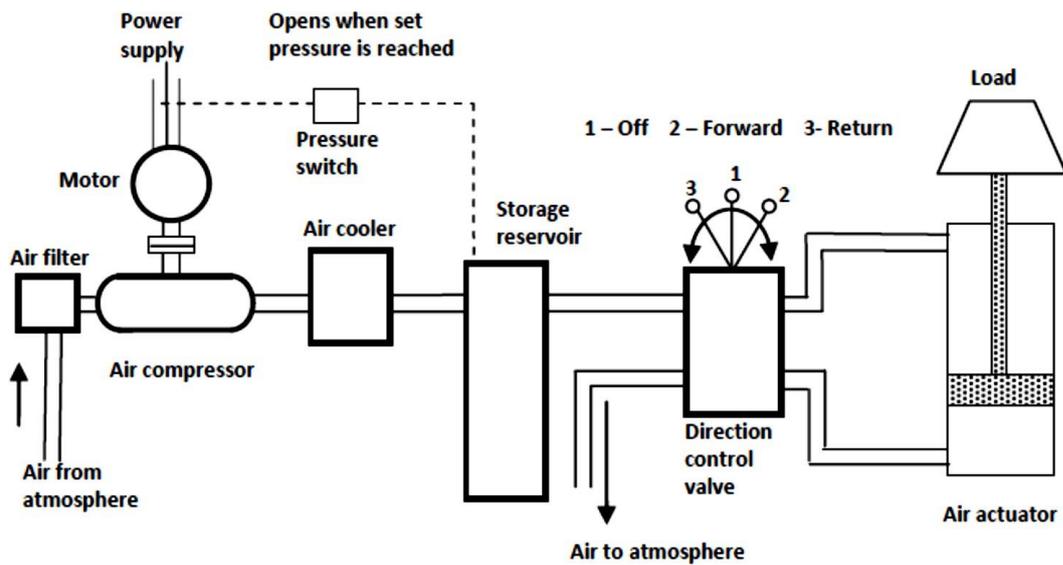
Figure:1: Hydraulic Systems

Figure:2: Pneumatic Systems

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 flow rate.

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.

3

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

TYPES OF FLUID POWER SYSTEM

The Fluid power system is divided in to two types. They are hydraulic and pneumatic system depends upon the fluid medium used to transmit force.

- The hydraulic fluid power system employs liquid (like as water, petroleum oils and synthetic oils) as fluid medium.
- The pneumatic fluid power system employs gas (Compressed Air) as the fluid medium.

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.
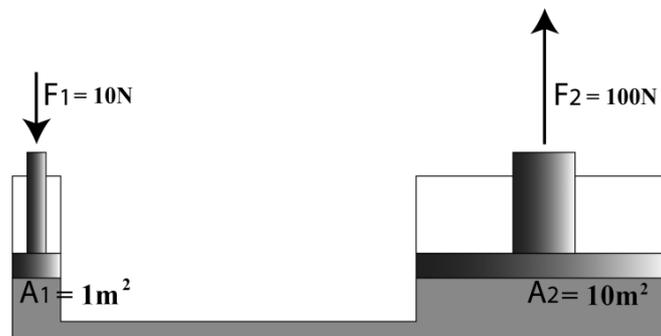

Figure:3: Pascal`s Law

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, $P_1 = P_2$ i.e., $\dfrac{F_1}{A_1} = \dfrac{F_2}{A_2}$

$$\frac{10}{1} = \frac{F_2}{10} \qquad \therefore F_2 = 100N$$

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 high-pressure 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.
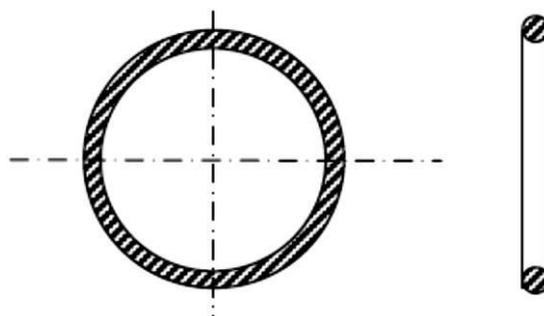
Figure:4: O-rings

2. **V seal and U-ring seal:** V- and U-ring seals are compression-type seals used in virtually all types of reciprocating motion -ring 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.
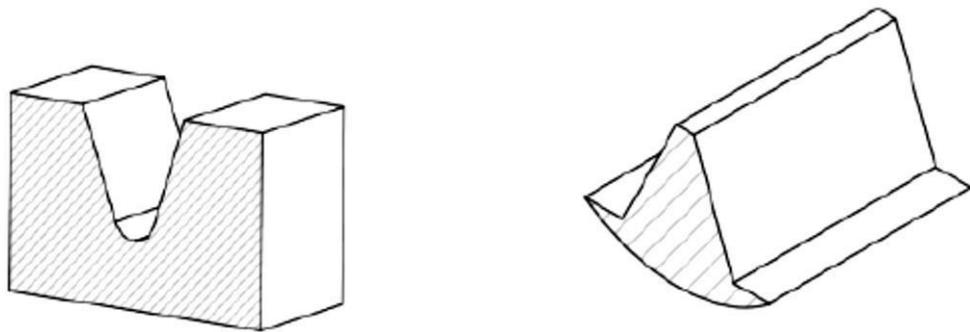

Figure:5: V-Seal and U-ring

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.
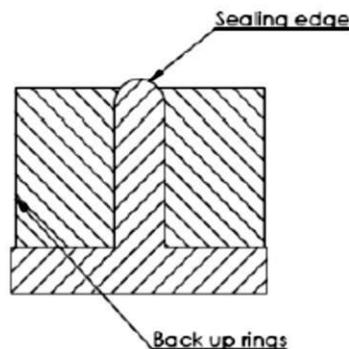

Figure:6: T-Ring Seal

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 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

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 Power Symbols:

Table.1.ISO Designation

ISO Designation	Symbol	Picture Representation

Basic Information
Lines
Continuous
  Non-Flowing — Black
  Pump Flow — Red
  Tank Flow — Blue
  Suction Flow — Green
  Metered Flow — Yellow
  Reduced Pressure — Orange
  Intensified Fluid — Purple
		Represents a working fluid line. This fluid comes from a prime mover and goes to the actuator to perform work. May be a 1/8" plastic air line or any size pipe or tube in a hydraulic system.
		
		COLOR CODING FOR OVERHEADS

Long Dashes — Orange		Represents pilot lines that supply a small amount fluid to another valve or device making it operate. The length of these dashes should be at least ten times their thickness.
Short Dashes — Green		Represents drain lines for hydraulic circuits. Many hydraulic valves have internal leakage that can get trapped and cause a malfunction. A drain line is a small line giving trapped fluid a free flow path to tank. The length of these dashes is five times their thickness.
Double Lines		Represents a mechanical connection Between components, A pump motor shaft, feedback connections between valves and actuators, etc. The outside dimension of these lines should be at least five times the line thickness.
Center Line		Represents an enclosure outline that indicates the parts inside it are a unit. This unit may be a casting with the parts machined in it or it might be a several components assembly.
Electric Line		Denotes a line carrying electrical power or signal.

ISO Designation	Symbol	Picture Representation
Flexible Line		Shows hose or other flexible line. Could be whole length or only a portion of the conduit.
Pipe Junction		Denotes a tee or cross where lines connect to one another. The connecting Dot is always used with the Jumper below. Preferred way.
Pipe Junction		Denotes pipes connecting at a tee or cross Optional way.
		Denotes pipes crossing. Preferred way
Pipes Crossing		Denotes pipes crossing. Optional way
Plug		
Air Bleed		Shows a connection for bleeding trapped air
Pressure Takeoff		A connection for taking power from a line or for pressure testing. Shown plugged.
		With takeoff line connected.
Energy Triangle	Pneumatic / Hydraulic	Shows direction of flow and type of fluid.
Power Source	General / Pneumatic / Hydraulic	Denotes a power source from another part of the schematic or a another source
Arrows		Indicates direction of rotation of a pump or motor shaft, valve actuator or other actuator.
		Indicates direction of movement of a component.
		Arrows used for flow direction in valves. Arrows with a perpendicular line opposite the arrow head Arrows with a perpendicular line at the head end indicates the path stays connected to its outlet when it moves.
Sloping Arrow		A sloping arrow through a pump, valve, spring, cushion plunger, solenoid or other device indicates it is adjustable or variable.

ISO Designation	Symbol	Picture Representation
Directional Control Valves (Cont'd.) Poppet Type Valve		
Sliding Plate Valve		
Spool Type Valve		
4-Way 2 Position Valve Spring Return Direct Acting Solenoid		
4-Way 2 Position Valve Detented Direct acting Solenoid		
4-Way 2 Position Valve Spring Return and Detented Solenoid Pilot Operated		
2 Position Valve Typical Transition or Crossover Condition	Open Crossover	Closed Crossover
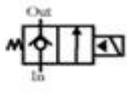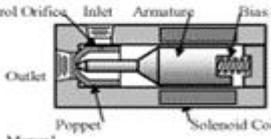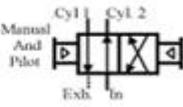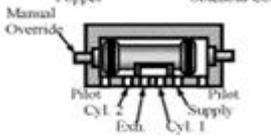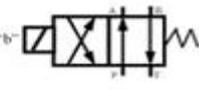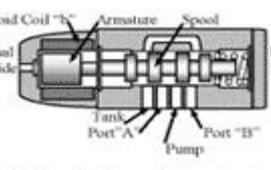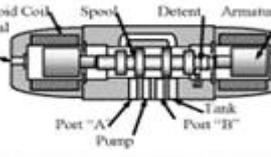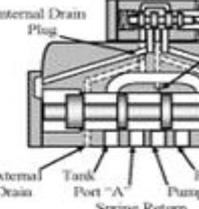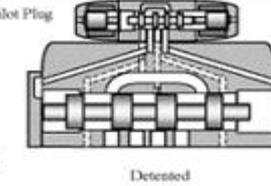
ISO Designation	Symbol	Pre 1966 ANSI Symbol

Laminar flow or streamline flow in pipes (or tubes) occurs when a fluid flows in parallel layers, with no disruption between the layers. At low velocities, the fluid tends to flow without lateral mixing, and adjacent layers slide past one another like playing cards. There are no cross-currents perpendicular to the direction of flow, nor eddies or swirls of fluids. In laminar flow, the motion of the particles of the fluid is very orderly with all particles moving in straight lines parallel to the pipe walls.   Any lateral mixing (mixing at right angles to the flow direction) occurs by the action of diffusion between layers of the liquid. Diffusion mixing can be slow however if the diameter of the pipe of tube is small then this diffusive mixing can be very significant.
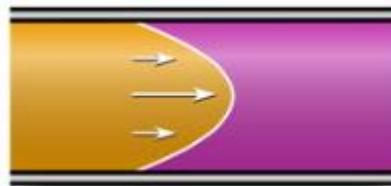
Figure:7: Laminar Flow

Turbulent flow is a flow regime characterized by chaotic property changes. This includes rapid variation of pressure and flow velocity in space and time. In contrast to laminar flow the fluid no longer travels in layers and mixing across the tube is highly efficient. Flows at Reynolds numbers larger than 4000 are typically (but not necessarily) turbulent, while those at low Reynolds numbers below 2300 usually remain laminar. Flow in the range of Reynolds numbers 2300 to 4000 and known as transition.


Figure:8: Turbulent Flow

Laminar and turbulent flows can exist in the same tube network when operated at different flow rates. The Reynolds number for a Vapourtec 1mm bore tubular reactor flowing water at 10 ml/min is only slightly above 200. We can safely assume that under normal operational conditions the flow through to tubing reactors of our flow chemistry systems can be described as Laminar Flow.

Reynolds Number:

The Reynolds number is the ratio of inertial forces to viscous forces within a fluid which is subjected to relative internal movement due to different fluid velocities. A region where these forces change behavior is known as a boundary layer, such as the bounding surface in the interior of a pipe.

Darcy Weisbach Equation:
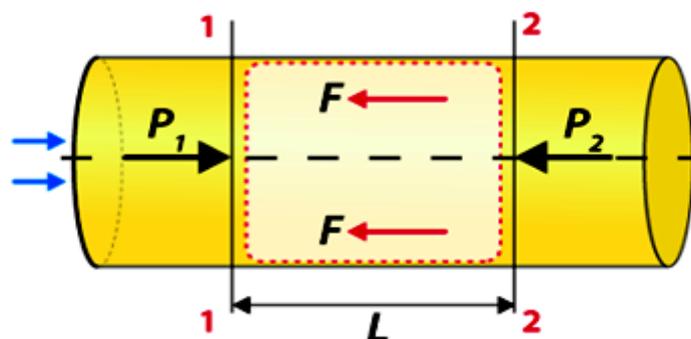
Uniform horizontal pipe with a steady flow of fluid.

Step 1: Terms and Assumptions

Consider a uniform horizontal pipe with fixed diameter d and area A, which allow a steady flow of incompressible fluid.

For simplicity consider two sections; S1 and S2 of the pipe separated by the distance L.

At all the point of S1, The pressure is P_1, velocity is V_1.

At all the point of S2, the pressure is P_2 and velocity is V_2.

Consider the fluid flow as shown in the figure(1) Thus, the pressure at S1 is greater than the pressure at S2 i.e., (P₁>P₂) This pressure difference makes the fluid flow along the pipe.

When fluid flows there will be the loss of energy due to friction. Thus we can apply Bernoulli's principle.

Bernoulli's principle

Bernoulli's principle states that a decrease in the pressure or potential energy of the fluid increases the velocity/speed of the fluid flow or in other words, "For incompressible fluid, the sum of its potential energy, pressure, and velocity remains constant."

Step 2: Applying Bernoulli's principle

On applying Bernoulli's equation at section; S1 and S2 we get-

$$P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g h_2 + H_F \;\text{---(1)}$$

Where,

H_F is the head loss due to friction

On dividing above equation (1) by ρg we get-

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + h_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + h_2 + H_F \;\text{---(2)}$$

For horizontal pipe (That is, the inlet of pipe and the outlet of the pipe are at the same level from the reference plane)

$h_1 = h_2$.

Here, the diameter is uniform, for uniform diameter-

$v_1 = v_2$

On substituting them, the equation(2) becomes-

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + h_1 = \frac{P_2}{\rho g} + \frac{v_1^2}{2g} + h_1 + H_F \Rightarrow \frac{P_1}{\rho g} = \frac{P_2}{\rho g} + H_F \;\text{---(3)}$$

Thus, on rearranging equation (3) for the head loss we get-

$$H_F = \frac{P_1}{\rho g} - \frac{P_2}{\rho g} \Rightarrow H_F = \frac{P_1 - P_2}{\rho g} \Rightarrow H_F \rho g = P_1 - P_2 \;\text{---(4)}$$

Step 3: Find frictional resistance

Due to the combined effect of wet surface and surface roughness, the resistance is offered to the flow of fluid due to friction. As a result, speed is reduced. The Froude was the first person to observe the dependency of frictional resistance with surface roughness.

The frictional resistance is well expressed through Froude's formula.

Let f' be the frictional resistance per unit area(wet) per unit velocity.

Frictional resistance F = f' × wet area × (velocity)²

= f' × 2πrL × v²

= f' × πdL × v²

F = f' × PL × v² ---(5)

[here, diameter; d=2r and perimeter; P=πd]

Step 4: Net force acting on the fluid at section S1 and S2

The net force is the sum of Force due to pressure at S1, S2, and Fluid friction.

- At S1, pressure is given by-

$$P_1 = \frac{F_1}{A}$$

Which implies, The net force $F_1 = P_1 A$

For our convenience consider the direction of the force due to pressure as +ve.

- At S2, the pressure is given by-

$$P_2 = \frac{F_2}{A}$$

Which implies, The net force $F_2 = P_2 A$

here, the direction of the force due to pressure as -ve.

- Fluid Frictional force(F): It is a resistive force, thus the direction as -ve.

Thus, resolving all the forces along horizontal direction we get-

P₁A – P₂A – F = 0

P₁A – P₂A = F

(P₁– P₂)A = F

$$\Rightarrow P_1 - P_2 = \frac{F}{A} \quad\text{---(6)}$$

Substitute the values for F and (P₁– P₂) from equation (5) and (4) respectively.

$$\Rightarrow \rho g H_F = \frac{f' P L v^2}{A}$$

On rearranging the terms we get-

$$H_F = \frac{f' P L v^2}{A \rho g} \quad H_F = \frac{f'}{\rho g} \times L v^2 \times \frac{P}{A} \quad\text{--(7)}$$

But, $\frac{P}{A} = \frac{Wetted\ perimeter}{Area} = \frac{\pi d}{\frac{\pi}{4} d^2} = \frac{4}{d}$

Substituting $\frac{P}{A} = \frac{4}{d}$ in equation(7),

$$(7) \Rightarrow H_F = \frac{f'}{\rho g} \times \frac{4 L v^2}{d} \quad\text{---(8)}$$

Now substitute $\frac{f'}{\rho} = \frac{f}{2}$

Where,

f' is a frictional resistance

ρ is the density of the fluid.

f is the coefficient of friction

Because the fluid is incompressible, which means that with the application of the external force there will not be any change in the density.

$$(8) \Rightarrow H_F = \frac{f}{2g} \times \frac{4 L v^2}{d}$$

Thus, On rearranging, we finally arrive at Darcy Weisbach Equation

$$H_F = \frac{4 f L v^2}{2 g d}$$

Fluid Power Actuators:

Fluid power actuators receive fluid from a pump (typically driven by an electric motor). After the fluid has been pressure, flow, and directionally controlled, the actuator converts its energy into rotary or linear motion to do useful work. Cylinders account for more than 90% of the actuators used in fluid power systems for work output. Of the approximately 10% of actuators that produce rotary output, more than 90% are hydraulic motors, while the rest are some form of rotary actuator.

Single Acting Ram Cylinders

The symbols and cutaway views in single-acting ram cylinders in push and pull types. Rams can be as small and simple as a service station lift operated by air over oil, or as big and complex as a 100,000-ton extrusion press. Single-acting rams often are mounted vertically up and are weight returned. When a ram cylinder is mounted vertically down or horizontally, it must have some method of retracting it to the home position. Small single-acting pull rams mounted alongside the large working ram -- raise and hold it in the up position with a counterbalance valve (not shown). A directional valve or a bi-directional pump directs fluid to the push or pull rams to make them cycle. Another retraction method uses single-acting push rams that oppose the platen movement from the opposite side. (For a circuit that uses a large-diameter vertical down acting ram cylinder) Small ram cylinders may be returned manually or via a spring.
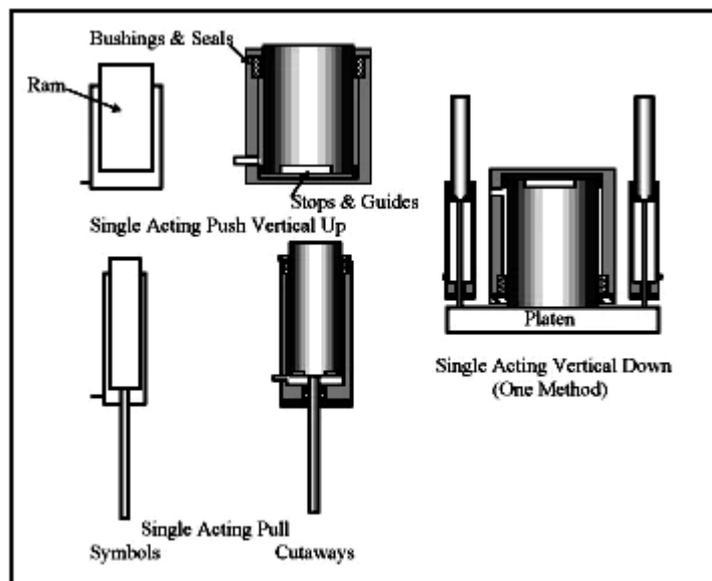

Figure:9: Single Acting Ram Cylinders

Ram cylinders only have seals where the ram passes through the body. Anytime a ram cylinder drifts from its stopped position, the cause is valve or pipe leakage if no fluid is coming out around the ram seal.

As the ram moves, stops and guide protrusions on it keep it aligned and indicate maximum stroke. Usually on large-area rams, the stops tear off the packing gland and bushing retainers if the ram is not stopped some other way. Most machines using rams have other methods to keep them from over stroking. (Some only have warning placards about problems if the ram is powered beyond certain limits.) The guide protrusions and bushing align the ram in its housing so it runs true.

When there is a need for a long-stroke actuator with a short retracted length, one option is a telescoping cylinder. Although the majority of telescoping cylinders are single acting, double-acting models are available. Most telescoping cylinders stroke slowly and cycle infrequently because their construction is not robust enough for high production applications.
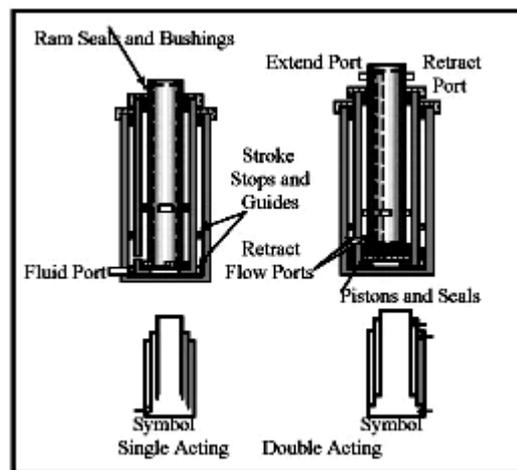

Figure:10: Single and Double Acting Telescoping Cylinders

Telescoping Ram Cylinders

The cutaway views and symbols in Figure depict typical multi-stage telescoping cylinders. The one on the left is single acting; the one on the right is double acting. Single-acting telescoping cylinders are usually mounted vertically with the small ram up. The cylinder then can be weight returned. This arrangement leaves the large ram with its ports attached to a stationary machine member.

Double-acting telescoping cylinders can be mounted vertically with the small ram down or horizontally when required. The best mounting position for any double-acting telescoping cylinder is with the small ram attached to a stationery machine member so the ports do not move. Long-stroke double-acting telescoping mounted horizontally need some sort of carrier to support the center section during extension so they will not sag and wear out seals and bushings prematurely. Also note: the return area may only be only 10% of the extend area, so the return force is not capable of doing much work. This small area also requires very little fluid to give maximum retraction speed without excessive backpressure at the extend port. Another possible problem with double-acting telescoping cylinders occurs if the retract port is blocked while the cylinder is trying

to extend. Up to a 10:1 intensification can result and the high pressure may damage the housing or rams. Installing a safety relief valve at the retract port may be necessary if this port can be blocked or restricted for any reason.

For all telescoping cylinders, make sure the small ram can do the work required. As a telescoping cylinder starts to extend, the large ram always moves first at a lower pressure. When the first and subsequent rams bottom out, pressure and speed increase due to the decreased ram area. If the small ram produces insufficient force, the unit stops before making a full stroke.

Several suppliers build double-acting pneumatic telescoping cylinders in small sizes, with up to three stages. One manufacturer makes a single-acting telescoping cylinder with internal porting and matching areas that cause all rams to move in unison as they extend and retract. These cylinders come in a maximum of three stages because the area staging would make any more rams into a vastly oversized package. An integral combination check and relief valve allows the rams to be filled and bled and to stroke fully in case of bypass at the seals. This design's main advantage is smooth extension and retraction without the bumps of a typical telescoping unit.

Piston and Rod Cylinders

The cutaway view and symbol in Figure is for a typical industrial-grade tie-rod cylinder. This cylinder includes all the standard features available from most manufacturers. The names of the parts are what most fluid power glossaries propose, while the names in brackets may be in common use. The cap end and head end seal off the tube ends with tube-end seals. Tie rods hold the assembly together. The tie rods are tightened to a torque that will resist as much as five times the cylinder's rated pressure. Tie-rod construction gives the package some flexibility or stretch without permanent deflection or damage. The piston provides the area for fluid to work against. The piston seals stop bypass that would waste energy. The piston rod transmits the force on the piston to the outside of the envelope and is attached to the work mechanism. The rod bushing and rod seal keep the rod aligned and stop fluid leaks to atmosphere. Cap end and rod end cushion plungers block high fluid flow near the end of stroke to allow smooth, no-shock stopping. Cushion-adjusting screws make it possible to adjust stopping speed, while cushion-bypass checks let the piston move rapidly as the cushion plungers are leaving their chambers.
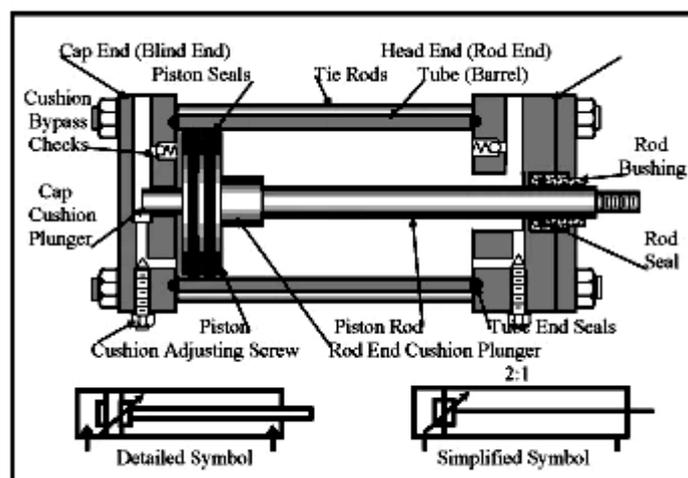

Figure:11: Typical industrial-grade single-rod end tie-rod cylinder

The symbol on the left is the detailed symbol for a hydraulic cylinder with adjustable cushions on both ends. This cylinder also could be as shown as: non-cushioned, cushioned rod end only, or cushioned cap-end only. (When the energy triangles at the ports are blackened, the cylinder is pneumatic.) The simplified symbol shows less detail but represents the same unit. The 2:1 information over a single rod end cylinder indicates that the rod area is half that of the piston. (Cylinders with 2:1 area ratio will be discussed later in this chapter.)
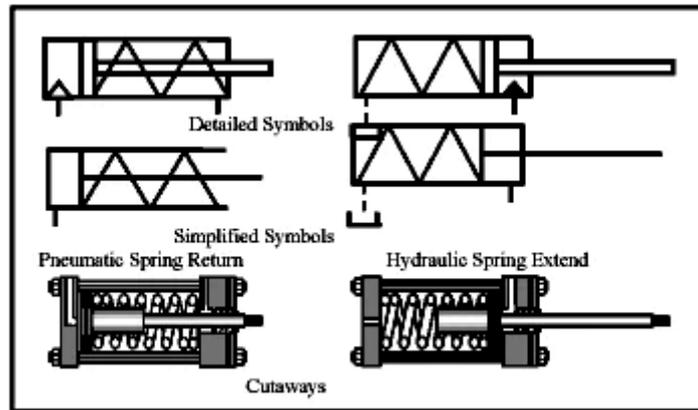
Figure:12: Single-acting spring-return and extend cylinders

The spring return and extend cylinders in Figure illustrate another method of moving cylinder pistons and rods for some applications. The cutaway views show typical construction (using a tie-rod cylinder as the basic unit). Many other designs are available but essentially use similar parts. Notice that the pistons have mechanical stops to keep the spring from compressing enough to bottom out. Breather ports for air operation or connections for tank drains for hydraulic cylinders are commonly found at the spring end. Most manufacturers indicate that the spring is only capable of returning the piston and rod. It may not be capable of returning the external load. Springs can be less than reliable and difficult to monitor especially when they are internal. Because there usually is little savings in hook up or operation, use these cylinders with care.

Tandem Cylinder:

The tandem cylinder in Figure can produce almost twice the force from the same diameter, but it is a little over twice the length. The two cylinders can be independently piped or drained to give extra force in one direction only or both directions. The center heads have guide bushings and seals for both sections so a different fluid can also be used in either end. (See Chapter 17 to learn how tandem cylinders allow oil to control speed and air as the power source. Circuits for matched and unmatched tandem cylinders can be found in the author's upcoming e-book Fluid Power Circuits Explained.)
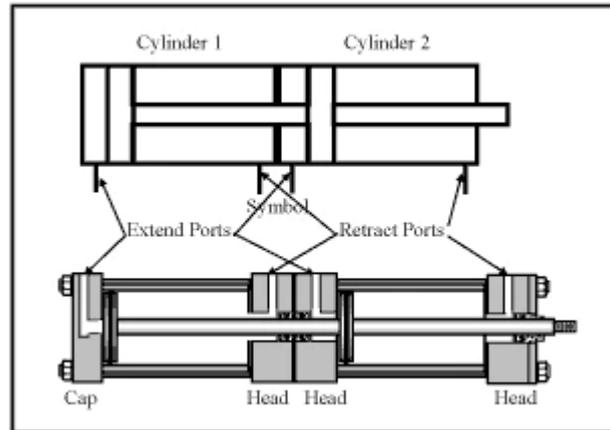
Figure:13: Tandem cylinders with attached rod

The tandem cylinder in Figure has a common rod for both pistons. The tandem cylinder in Figure has two separate pistons and rods and two different stroke lengths. This combination can be used to get three positive stops from an air or hydraulic cylinder with no special valves or controls. The stops are mechanically fixed, so the stop positions are in the same place every time. However, the stop positions only work for one situation. A four- or five-way directional valve at each cylinder plus flow controls are all that is normally required to operate this circuit.

Special consideration must be used in circuit design for the unattached tandem cylinder in Figure. If the long-stroke cylinder is not restrained while the short-stroke cylinder extends, it can over travel and miss the exact position. This problem is exaggerated with horizontal or vertical rod-down applications. Meter-out flow controls or counterbalance valves can eliminate the problem, but could increase cycle time in some cases.
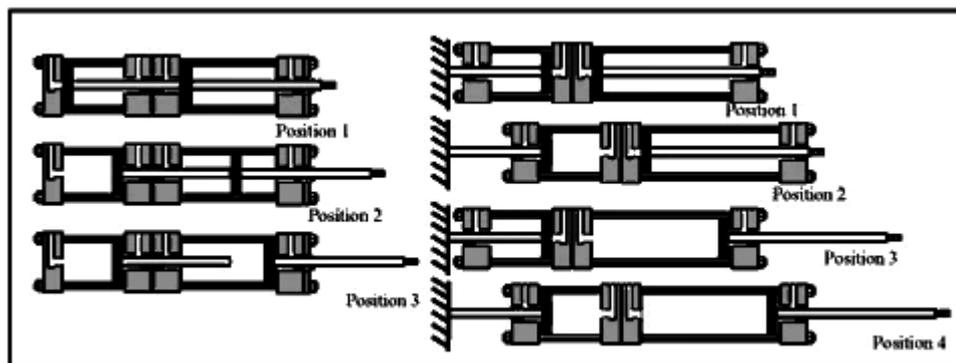

Figure:14: Tandem cylinders with attached rod for three positive stop positions (left) and cap-to-cap cylinders for four positive positions (right)

Double Rod End Cylinder:

The cap-to-cap mounted cylinders in Figure depict another way to use pneumatic or hydraulic cylinders to obtain positive positioning without special valves or equipment. Two four- or five-way valves and flow controls usually make this circuit operate smoothly. Some designers specify double-rod end cylinders such as those shown in Figure. These cylinders cost about twice as much

as single-rod cylinders and the design has a second place for fluid to leak. In most cases the reason for using them can be accomplished by other methods with equal or better results. If you must use a double-rod end cylinder, remember to allow space for the extra rod and the safety hazard it can cause. Also, the rod reduces the area on the working side of the piston, so a larger bore or higher pressure is necessary in many cases.
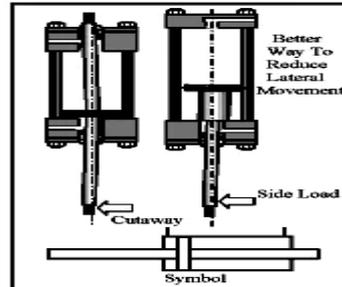

Figure:15: Double-rod end cylinders

A double-rod end cylinder might be specified so that the force and speed in both directions is the same when flow and pressure are equal. This may be true, but flow controls and a reducing valve can accomplish the same result at a reduced cost and in less space. Another alternative is a regeneration circuit, used when producing the exact speed and force in both directions is not critical. (Regeneration circuits are covered extensively in the author's upcoming e-book Fluid Power Circuits Explained.)

It may appear that double-rod end cylinders reduce rod flexure when the cylinder is fully extended. The rods in their bushings and the piston in its bore provide snug bearing points -- but allow some play. As the piston nears the end of stroke, two of the bearing points get closer together, so lateral movement at the extended end of the rod can increase. It is supposed that the opposite rod will reduce lateral movement and hold the attached load closer to a centered position. However, from the cutaway it is obvious the distance between the piston bearing and the opposite rod bushing almost eliminates any centering effect of the piston. A better way to reduce lateral movement of the extended rod is to stop the piston short of full stroke – either by an internal stop tube or externally by machine members. This arrangement requires a longer cylinder but gives the desired results at a lower cost.

A main reason for using double-rod end cylinders is to mount limit switches to show cylinder position. A special bracket opposite the attachment end holds the limit switches and a doughnut-shaped protrusion on the rod contacts them as the piston strokes. For the same price (and consuming a lot less space), most cylinder manufacturers offer limit switches that attach to the head and/or cap and are activated by cushion plungers. Another signal indicator especially for pneumatics – is a Hall-effect switch and a magnetic piston to activate it.

All of the above cylinder-position indicators have one potential major flaw. If the part attached to the rod end gets disconnected for any reason, the machine still will cycle when the cylinder moves even though the disconnected load may be in the way. If at all possible, mount limit switches on the machine member so its position is never misinterpreted.

Rodless Cylinder:

The cylinders in Figure take up less space on long-stroke applications because they only need mounting space slightly longer than their stroke length. Conventional piston-and-rod cylinders require space more than twice their stroke length -- and can be difficult to conveniently place on many machines.

The earliest long-stroke design is the cable cylinder – shown at top left in Figure. A coated cable fitted with a work piece attachment, wrapped around two pulleys, and attached to a piston in a bore produces reciprocating motion as fluid -- usually air -- enters and exhausts through the ports. These cylinders are usually 4-in. bore or less, and may have strokes up to 30 ft (or more in certain configurations). Cushions may be specified when required. The cable is coated with nylon or Teflon so it can slide through seals with minimal damage to them. However, the coatings are prone to cracking and eventually will cut the seals until they leak. (The symbol for the cable cylinder is adapted from a manufacturer's catalog because ISO does not show one.)
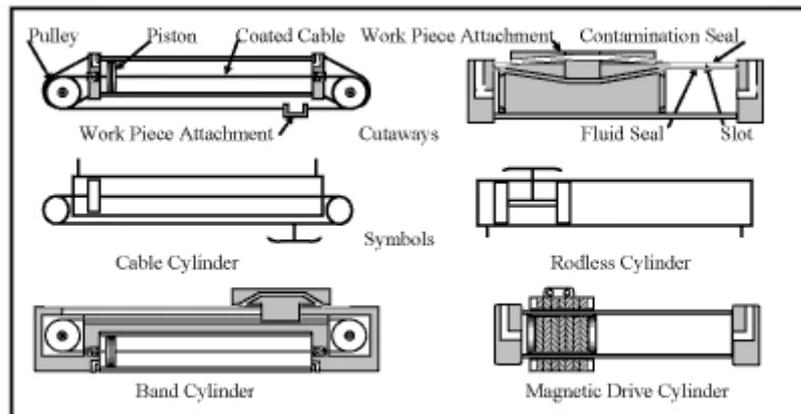

Figure:16: Types of Cylinder

The rodless cylinder, top right in the figure, was introduced in the late 1970s. It is even more compact than a cable cylinder and avoids the coating wear problem. It consists of a piston in a bore that has a slot open to atmosphere along its whole length. A seal blocks air from escaping through the slot while the piston is not present. A second contamination seal keeps debris from filling the slot. The fluid seal and contamination seal pass through slots in the piston in slots as it reciprocates. The work piece attachment (connected to the piston) reciprocates to move machine members as fluid enters and exhausts the cylinder. Bores up to 2 12 in. and strokes as long as 33 ft are available from several manufacturers. Cushions may be specified when required.

The band cylinder is an alternative to the cable cylinder. Its smooth steel band passes through seals instead of a coated cable. The magnetic-drive cylinder uses magnetic attraction to keep the piston and work piece attachment connected. It operates at pressures up to 120 psi and will maintain connection up to 180 psi.

One manufacturer has a modified rodless cylinder with a toothed belt and pulley arrangement to drive the work piece attachment. It offers the option of an external output shaft to which a brake can

be fitted to stop and hold position. This output shaft can also drive an encoder to show work piece position or can connect to another unit for synchronization. It also could act as a low power rotary actuator. It is available in 1- or 1 12-in. bores and up to 177-in. stroke.

Linear Actuators

The actuators in Figure depict other ways of producing linear force. The rolling diaphragm, diaphragm, and bellows actuators are single acting. The rolling diaphragm is capable of long strokes but not long life at high cycles. The diaphragm is designed only for short-stroke applications only but can have high force due to large areas. All these single-acting devices use some internal or external method to retract them. Using vacuum and weight are two of the methods used for retracting bellows. The double-acting rolling diaphragm operates like a double-acting piston cylinder but is not designed for long life at high cycles.
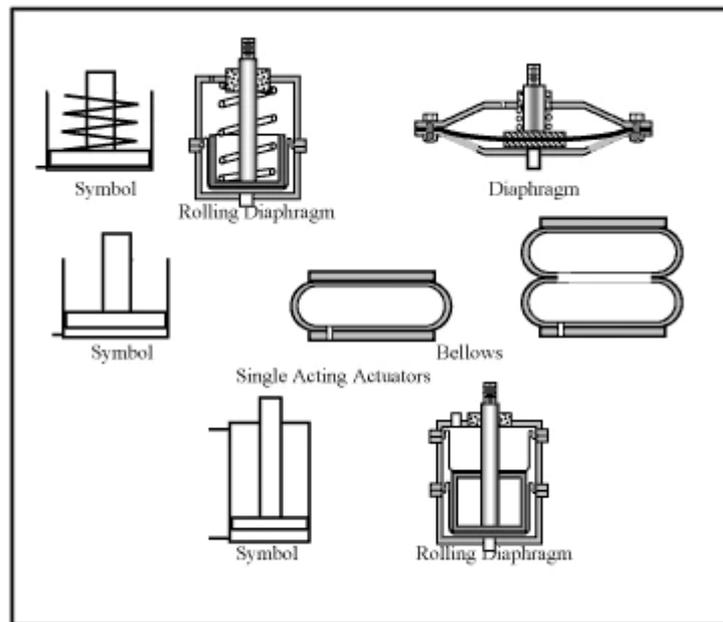

Figure:17: Double Acting Actuators

Cushioning Mechanism:

Cylinders that move at high speed need some sort of deceleration method to keep them from slamming when they reach end of stroke. Some applications with high speed and heavy loads may need valves and limit switches to give enough time to bring the load to a smooth stop. For most cases standard cylinder cushions work well. They are 3/4- to 11/16-in. long and can be in the head or cap end or both. Cushions add cost on most cylinders so should not be specified when unnecessary.

The cutaway in Figure shows a cylinder with an oversize rod and standard cushions on both ends. The cushion-adjusting screw and cushion bypass check valve can only be installed in the cap end

because the cushion plunger on the rod end is so large there is no room for them. The necessity of oversize rods is a problem for most manufacturers. It is possible to taper the cushion and get a smooth stop but it also slows the stroke as the cushion plunger leaves its chamber. The best option to control deceleration of oversize rod cylinders' extend stroke is with external valves or proportional directional controls.
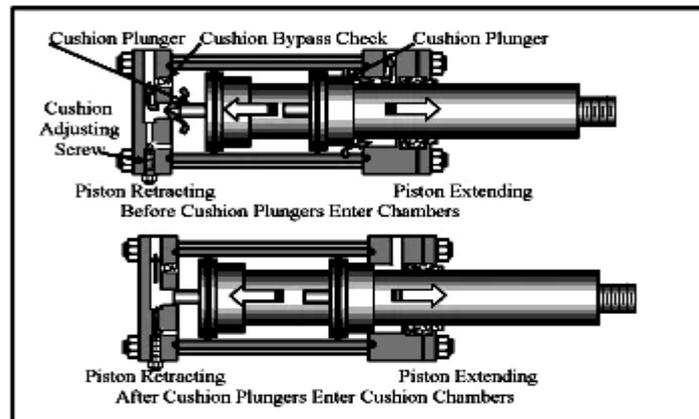

Figure:18: Cushioning

The other problem with oversize rods and rod-end cushions is the high intensification pressure present when working pressure is high and/or there is a heavy overrunning load. Pressure in the rod end can easily reach two-to-four times rated pressure each time the cylinder extends. High pressure can damage tube end seals and piston seals, and stretch the cylinder tube past its tensile limits.

The top cutaway in Figure shows the cylinder piston moving to end of stroke with full flow exiting through the cushion chambers almost unrestricted. This means the cylinder can travel fast until the cushion plungers enter their chambers. The bottom cutaway is what happens after the cushion plungers have entered the cushion chambers. Trapped fluid decelerates the piston quickly to a speed set by the cushion-adjusting screws. Deceleration is sudden on the straight cushion plungers shown here because hydraulic fluid is almost non-compressible. The piston continues to end-of-stroke at a preset controlled speed without damage to itself or the machine.

On cylinders with standard and some oversize rod sizes, the rod-end cushion would function the same as one on the cap end. There is always some pressure intensification on the rod end but this is normally not a problem. When the cylinder starts to extend again, the cushion bypass check valve opens to allow fluid to the full piston area so it can extend quickly at full force. Without the bypass valves, takeoff speed would be as slow as deceleration on retract.

The cutaways in Figure show a way of making cushions work. In actual cylinder design, cushions are built in many ways but the general function is the same. One company offers a self compensating non-adjustable cushion option without adjusting screws or bypass checks. Another supplier offers tapered or tapered slots in the plungers that give smooth deceleration instead of the sudden slowdown. Tapered cushions only work for a given pressure, load, and mounting position. They must be figured from information collected prior to building the cylinder.

Pneumatic Cylinder Cushioning

Pneumatic cylinder cushions have similar designs but operate differently because the fluid is compressible. When the cushion plunger enters a cushion chamber, the trapped air starts compressing according to Boyles' Law discussed in Chapter 1. When the load is light and the starting trapped pressure is high enough, the cylinder stops smoothly without slamming. When the load is heavy and/or starting trapped pressure is low, the cylinder slows but still may bang the end of stroke. This situation requires the addition of external deceleration in the form of valves and/or shock absorbers. Often the rod cushion is ineffective due to less area for the trapped fluid to work against. As with hydraulic cylinders, oversize rods exaggerate the problem.

Most suppliers offer standard cushions on both air and hydraulic cylinders. This option could smooth the operation of certain heavy loads that need extra deceleration distance. These longer cushions only work well for a fixed load and speed condition. If the machine has changing loads and/or speeds a cushion is not the way to go. Using external shock absorbers or proportional valves makes control easy to setup.

Cylinder Mounting

The mounting styles shown in Figure depict the standard NFPA-approved ways to mount cylinders. Up to 25 different companies make cylinders that match these styles in every dimension. This means no supplier has to be the sole source for any cylinder on a machine. Starting at top left are the least expensive mounting styles. Tie-rod mounts are extensions of the tie-rod threaded section. These extensions go through a machine member with nuts installed and tightened to hold the cylinder in place.

Rotary Actuators:

A rotary actuator is an actuator that produces a rotary motion or torque. The simplest actuator is purely mechanical, where linear motion in one direction gives rise to rotation. The most common actuators are electrically powered; others may be powered pneumatically or hydraulically, or use energy stored in springs. A rotary actuator is a pneumatic cylinder used to provide a turning or angular movement, allowing a stroke in an oscillating motion through a defined angle. They are durable and give a relatively high force (torque) for size. Rotary actuators simplify a design and can reduce maintenance issues.

Manual Rotary Actuator

Often a manual rotary actuator will employ a worm drive to increase the torque that a worker can physically apply to close a valve. Such actuators are common on quarter-turn butterfly and ball valves where the self-locking capabilities of many worm drives help to keep the valve shut. These actuators will often use large hand wheels to further increase a worker's available torque. These devices are sometimes referred to as "gear operators" or "manual overrides" in the valve industry.

Electric Rotary Actuators

Electric rotary actuators typically drive through a worm-gear reducer as well. They use reversible motors to move the valves between open and closed positions. Models are available that will return the valve to a safe position upon power loss using either stored spring energy or battery

or capacitor backup. Generally, the stored spring design requires a more complex transmission to wind the spring. Electric rotary actuators are easily adapted to distributed control systems. Hand wheels are generally provided for manual override, usually with a declutching feature.

Fluid Powered Rotary Actuators

Fluid power – be it air or hydraulic oil – is applied to cylinders to move rack-and-pinion assemblies and scotch yokes, or to vaned rotors for direct shaft actuation. These actuators generally move between stops of 90° to 360°, depending on the rotational requirements of a given valve or component.

Rack-and-pinion styles use at least one, and sometimes two or four, cylinders to drive the rack(s) past the pinion. The pinion rotates in response, driving the output shaft. A rack-and-pinion actuator will continue to revolve the pinion until it reaches the end of the stroke, although modulation is possible both with air and hydraulic systems. Hydraulic systems are better at holding a valve partway open because of the incompressibility of oil. In many instances, the pistons in the cylinders will work against large coil springs which provide the valve with the capacity to return to a safe position during a power interruption.

Scotch-yoke actuators also use cylinders, generally single-acting with spring return. This style is usually limited to 90° of rotation and sees applications in quarter-turn valves.

Hydraulic and pneumatic vane actuators use one or two vanes attached to a hub within a circular chamber, a kind of cylinder-in-the-round. Air or oil pressure is used to revolve the hub between stops and produce motion at the output stem.

Another rotary-actuator style is used mainly with hydraulic pressure. It employs a cylinder and set of helical gears to convert a linear input to a rotary, oscillatory output. In theory, the limits of rotation for such a device is only bounded by the length of the piston stroke.

Electro hydraulic actuators combine electrical hydraulic pumps with traditional hydraulic actuators to take advantage of the benefits of each. Such devices require only electrical inputs, produce significant torque, and are fail-safe—their downside being cost. In many instances, several hydraulic actuators could be served less expensively from a single hydraulic power pack.

Gear Motor

Gear motors are mechanisms that adjust the speed of electric motors, leading them to operate at a certain speed. They are composed of a series of gears that make up a kinematic chain, working on a set of rotary parts. A gear motor is an all-in-one combination of an electric motor and a gearbox. This makes it a simple, cost-effective solution for high-torque, low-speed applications because it combines a motor with a gear reducer system.
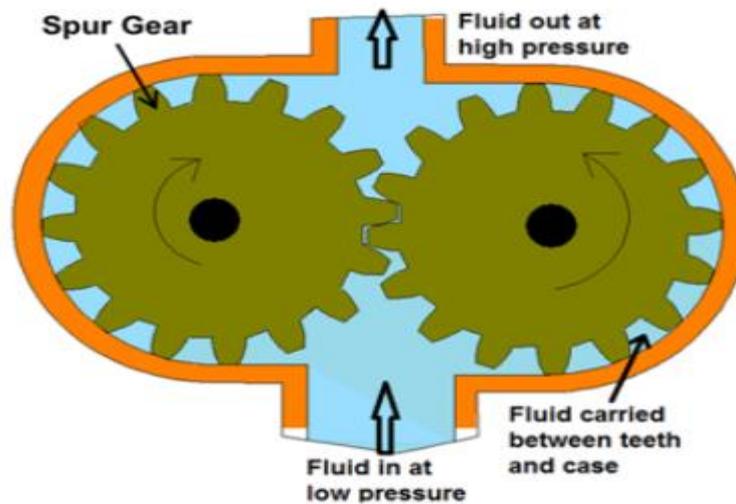
Figur:19:Gear Motor

- It consists of two inter meshing gears inside a housing with one gear attached to the drive shaft. Figure shows a schematic diagram of Gear motor.
- The air enters from the inlet, causes the rotation of the meshing gear due to difference in the pressure and produces the torque.
- The air exists from the exhaust port. Gear motors tend to leak at low speed, hence are generally used for medium speed applications.

Vane Motor

A vane motor consists of housing with an eccentric bore, in which runs a rotor with vanes in it that slide in and out. The force differential created by the unbalanced force of the pressurized fluid on the vanes causes the rotor to spin in one direction. A vane motor consists of a housing with an eccentric bore, in which runs a rotor with vanes in it that slide in and out. The force differential created by the unbalanced force of the pressurized fluid on the vanes causes the rotor to spin in one direction.
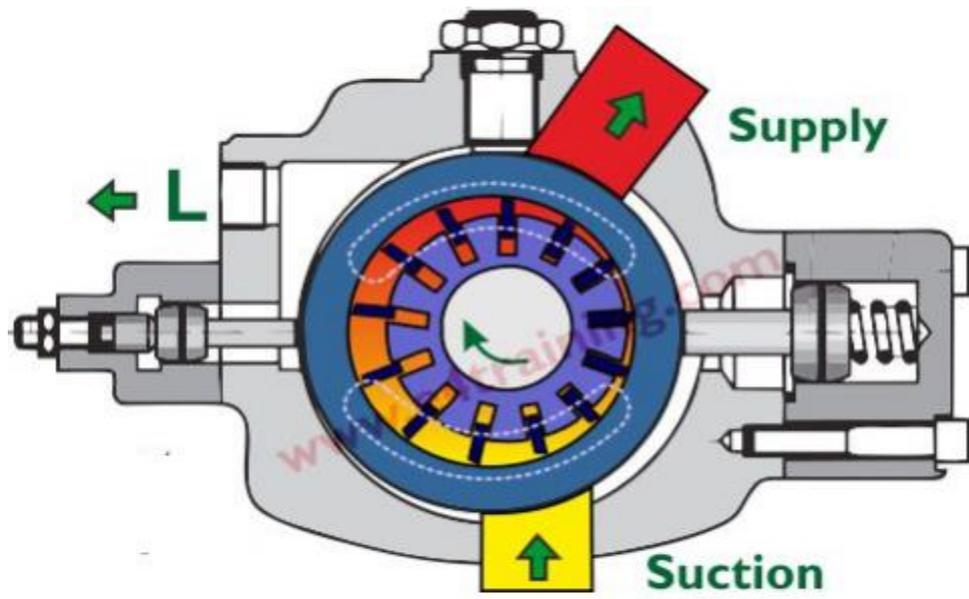
Figure:20: Vane Motor

Vane motors have a slotted rotor mounted on a driveshaft that is driven by the rotor *(Fig. 5)*. Vanes, closely fitted into the rotor slots, move radially to seal against the cam ring. The ring has two major and two minor radial sections joined by transitional sections or ramps. These contours and the pressures introduced to them are balanced diametrically.

In some designs, light springs force the vanes radially against the cam contour to ensure a seal at zero speed so the motor can develop starting torque. The springs are assisted by centrifugal force at higher speeds. Radial grooves and holes through the vanes equalize radial hydraulic forces on the vanes at all times.

Pressure fluid enters and leaves the motor housing through openings in the side plates at the ramps. Pressure fluid entering at the inlet ports moves the rotor counterclockwise. The rotor transports the fluid to the ramp openings at the outlet ports to return to tank. If pressure were introduced at the outlet ports, it would turn the motor clockwise.

The rotor is separated axially from the side plate surfaces by the fluid film. The front side plate is clamped against the cam ring by pressure and maintains optimum clearances as temperature and pressure change dimensions.

Vane motors provide good operating efficiencies, but not as high as those of piston motors. However, vane motors generally cost less than piston motors of corresponding horsepower ratings. The service life of a vane motor usually is shorter than that of a piston motor, though. Vane motors are available with displacements of 20 in.3/rev. Some low-speed/high-torque models come with displacements to 756 in.3/rev. Except for the high-displacement, low-speed models, vane motors have limited low-speed capability.

Piston Motor:

Radial-piston motors have a cylinder barrel attached to a driven shaft *(Figure)*. The barrel contains a number of pistons that reciprocate in radial bores. The outer piston ends bear against a thrust ring. Pressure fluid flows through a pintle in the center of the cylinder barrel to drive the pistons outward. The pistons push against the thrust ring and the reaction forces rotate the barrel.

Shifting the slide block laterally to change the piston stroke varies motor displacement. When the centerlines of the cylinder barrel and housing coincide, there is no fluid flow and therefore the cylinder barrel stops. Moving the slide past center reverses the direction of motor rotation.

Radial piston motors are very efficient. Although the high degree of precision required in the manufacture of radial piston motors raises initial costs, they generally have a long life. They provide high torque at relatively low shaft speeds and excellent low-speed operation with high efficiency. Also, they have limited high-speed capabilities. Radial piston motors have displacements to 1,000 in.3/rev. *Axial-piston motors* also use the reciprocating piston motion principle to rotate the output shaft, but motion is axial, rather than radial. Their efficiency characteristics are similar to those of radial-piston motors. Initially, axial-piston motors cost more than vane or gear motors of comparable horsepower. Like radial piston motors, they also have a long operating life. Consequently, their higher initial cost may not truly reflect the expected overall costs during the life of a piece of equipment. In general, axial piston motors have excellent high-speed capabilities. Unlike radial piston motors, though, they are limited at low operating speeds. The inline type will operate smoothly down to 100 rpm, and the bent-axis type will provide smooth output down to the 4-rpm range. Axial piston motors are available with displacements from a fraction to 65 in.3/rev.
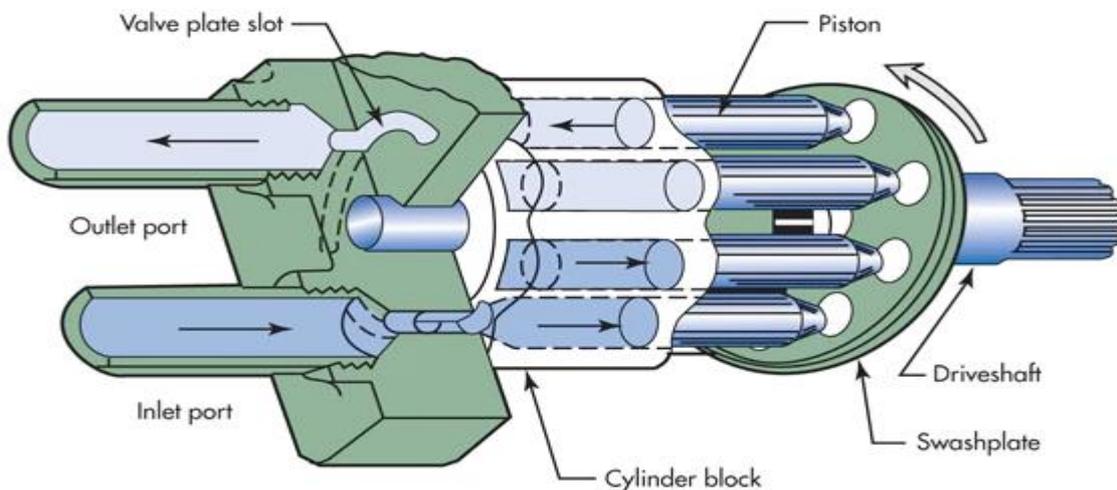

Figure:21: Piston Motor

Inline-piston motors generate torque through pressure exerted on the ends of pistons that reciprocate in a cylinder block *(Figure)*. In the inline design, the motor driveshaft and cylinder block are centered on the same axis. Pressure at the ends of the pistons causes a reaction against a tilted swash plate and rotates the cylinder block and motor shaft. Torque is proportional to the area of the pistons and is a function of the angle at which the swash plate is positioned.

These motors are built in fixed- and variable-displacement models. The swash plate angle determines motor displacement. In the variable model, the swash plate is mounted in a swinging yoke, and the angle can be changed by various means, ranging from a simple lever or hand-wheel to sophisticated servo controls. Increasing the swash plate angle increases the torque capacity but reduces driveshaft speed. Conversely, reducing the angle reduces the torque capacity but increases driveshaft speeds (unless fluid pressure decreases). Angle stops are included so torque and speed stay within operating limits.

A compensator varies motor displacement in response to changes in the workload. A spring-loaded piston is connected to the yoke and moves it in response to variations in operating pressure. Any load increase is accompanied by a corresponding pressure increase as a result of the additional torque requirements. The control then automatically adjusts the yoke so torque increases when the load is light. Ideally, the compensator regulates displacement for maximum performance under all load conditions up to the relief valve setting.
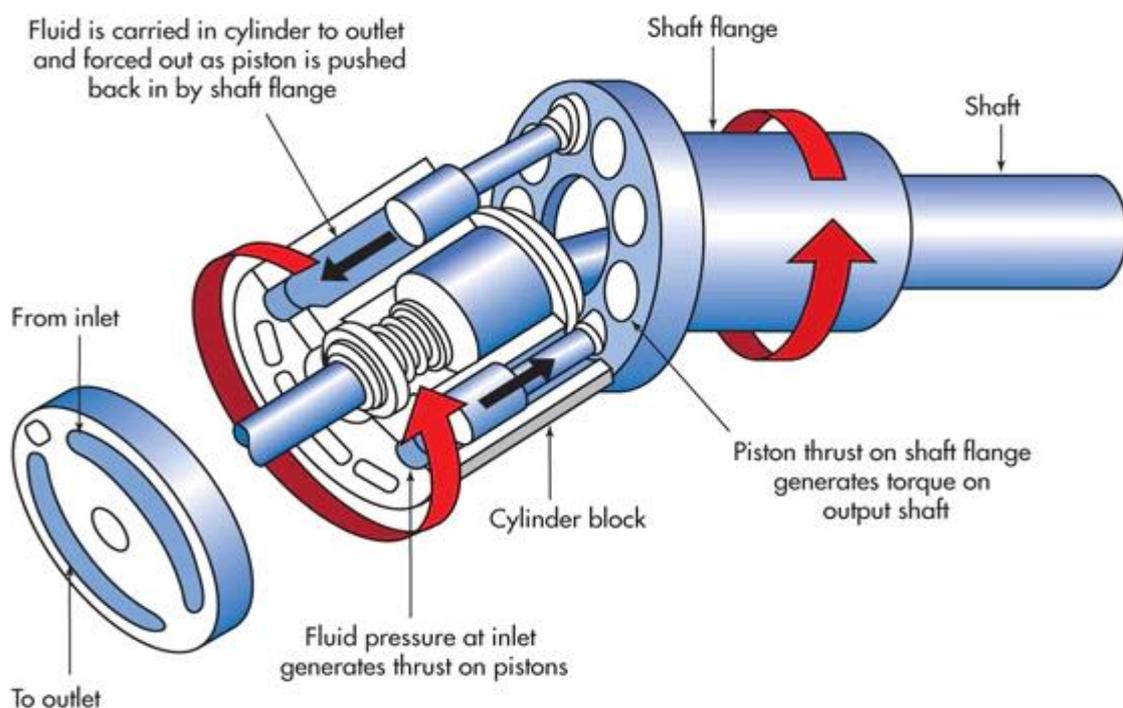

Figure: 22: Variable displacement Model - Piston Type

Bent-axis piston motors develop torque through a reaction to pressure on reciprocating pistons *(Figure)*. In this design, the cylinder block and driveshaft are mounted at an angle to each other. The reaction is against the drive-shaft flange.

Speed and torque change with changes in the angle, from a predetermined minimum speed with a maximum displacement and torque at an angle of approximately 30Ëš to a maximum speed with minimum displacement and torque at about 7.5Ëš. Both fixed- and variable-displacement models are available.

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – II - Hydraulic Circuits – SME1302

UNIT - II HYDRAULIC CIRCUITS

Hydraulic power, also called Fluid Power, power transmitted by the controlled circulation of pressurized fluid, usually a water-soluble oil or water–glycol mixture, to a motor that converts it into a mechanical output capable of doing work on a load.

PUMP CLASSIFICATION

All pumps are classified as either positive-displacement or non-positive-displacement. Most pumps which are used in hydraulic systems are positive-displacements. Non-positive-displacement pumps produce a continuous flow. Both propeller pumps and centrifugal pumps are typical examples of a non-positive design.

Three different types of hydraulic pumps exist: gear pumps, piston pumps and vane pumps.

GEAR PUMP

A **gear pump** uses the meshing of gears to pump fluid by displacement. They are one of the most common types of pumps for hydraulic fluid power applications. The gear pump was invented around 1600 by Johannes Kepler.

Gear pumps are also widely used in chemical installations to pump high viscosity fluids. There are two main variations: external gear pumps which use two external spur gears, and internal gear pumps which use an external and an internal spur gears (internal spur gear teeth face inwards, see below). Gear pumps are positive displacement (or fixed displacement), meaning they pump a constant amount of fluid for each revolution. Some gear pumps are designed to function as either a motor or a pump.

As the gears rotate they separate on the intake side of the pump, creating a void and suction which is filled by fluid. The fluid is carried by the gears to the discharge side of the pump, where the meshing of the gears displaces the fluid. The mechanical clearances are small— in the order of 10 μm. The tight clearances, along with the speed of rotation, effectively prevent the fluid from leaking backwards. The rigid design of the gears and houses allow for very high pressures and the ability to pump highly viscous fluids.

Many variations exist, including helical and herringbone gear sets (instead of spur gears), lobe shaped rotors similar to Roots blowers (commonly used as superchargers), and mechanical designs that allow the stacking of pumps. The most common variations are shown below (the drive gear is shown blue and the idler is shown purple).

An external precision gear pump is usually limited to a maximum working pressure of 210 bars (21,000 kPa) and a maximum speed of 3,000 rpm. Some manufacturers produce gear pumps with higher working pressures and speeds but these types of pumps tend to be noisy and special precautions may have to be made.

Suction and pressure ports need to interface where the gears mesh (shown as dim gray lines in the internal pump images). Some internal gear pumps have an additional, crescent-shaped seal (shown above, right). This crescent functions to keep the gears separated and also reduces eddy currents.

TYPES OF GEAR PUMP

There are two basic types: **external** and internal. An **external** gear pump consists of two identical, interlocking gears supported by separate shafts. An internal gear pump has two interlocking gears of different sizes with one rotating inside the other.

External

An external gear pump uses two external gears (Figure 1, below) that displace non-lubricating fluids (gears are oil lubricated). The mechanism is usually driven by one of the toothed gears, which in turn drives the other. Three factors are involved in the regulation of flow: volume of cavity between the teeth, speed of gears, and the amount of fluid that slips back to the inlet (tolerance dependant) via the mechanism. There are three main types of external gears: spur, helical and herringbone. Helical and herringbone deliver more flow at higher pressure while also being quieter, but may require a greater inlet pressure than spur (EPW, 2012)
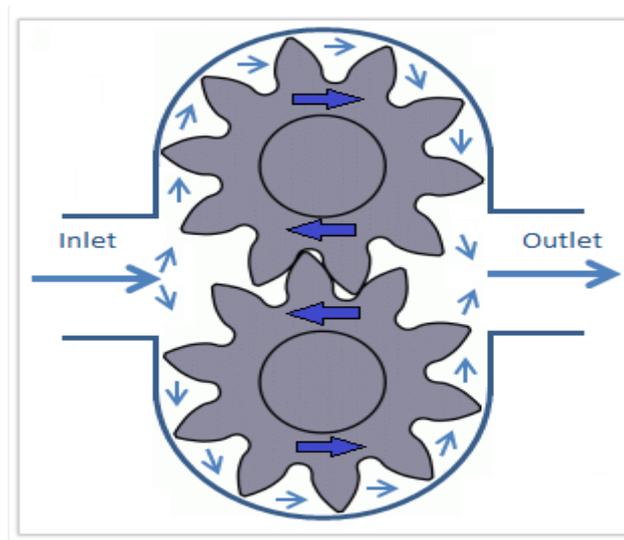
Figure:1: External Gear Pump

Internal

An internal gear pump uses internal and external gears (Figure 2, below). The gears themselves are lubricated by the fluid, which is of a lubricating nature. The internal design is seen as being reliable, easy to operate and maintain – due to only two moving parts being present. Only one drive gear is required for the mechanism to function but it is possible to use two. The pump will usually contain at least one bushing (EPW, 2012). The design can also be modified to include a crescent shaped portion that improves performance when pumping high viscosity fluids (Figure 2). Internal gear pumps have relatively low speed and inlet pressure requirements.
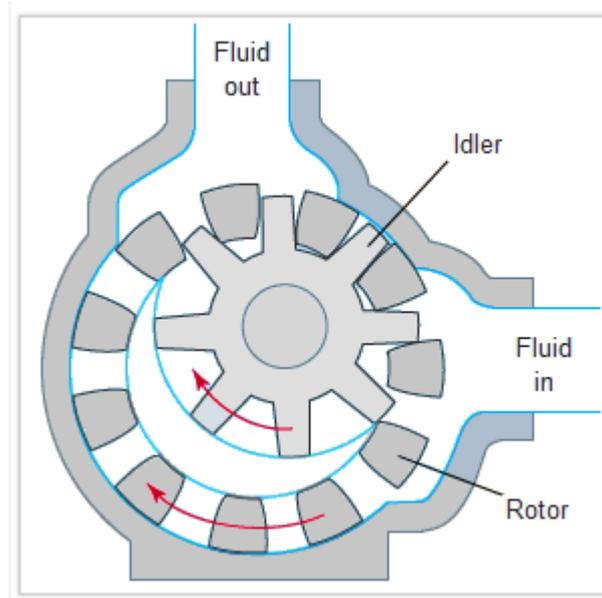
Figure:2: Internal Gear Pump

Vane Pump:

Vanes are allowed to slide into and out of the rotor and seal on all edges, creating vane chambers that do the pumping work. On the intake side of the pump, the vane chambers are increasing in volume. These increasing-volume vane chambers are filled with fluid forced in by the inlet pressure.

A rotary vane pump is a positive-displacement pump that consists of vanes mounted to a rotor that rotates inside a cavity. In some cases these vanes can have variable length and/or be tensioned to maintain contact with the walls as the pump rotates.

The rotor is sealed into the cam by two side plates. Vanes or blades fit within the slots of the impeller. As the rotor rotates (yellow arrow) and fluid enters the pump, centrifugal force, hydraulic pressure, and/or pushrods push the vanes to the walls of the housing.

Vane pumps are available in a number of vane configurations including sliding vane (left), flexible vane, swinging vane, rolling vane, and external vane. Vane pumps are noted for their dry priming, ease of maintenance, and good suction characteristics over the life of the pump.

The simplest vane pump consists of a circular rotor rotating inside of a larger circular cavity. The center's of the two circles are offset, causing eccentricity. Vanes are allowed to slide into and out of the rotor and seal on all edges, creating vane chambers that do the pumping work. On the intake side of the pump, the vane chambers are increasing in volume. These increasing volume vane chambers are filled with fluid forced in by the inlet pressure. Inlet pressure is actually the pressure from the system being pumped, often just the atmosphere. On the discharge side of the pump, the vane chambers are decreasing in volume, forcing fluid out of the pump. The action of the vane drives out the same volume of fluid with each rotation.

Usually, the pump mechanism comprises of a cylindrically shaped rotor rotating inside an asymmetrically shaped casing or cavity. The cylindrical rotor often has a number of rectangle

shaped slots running linearly along the outside of the cylinder. As the rotor turns, centrifugal force causes the vanes to move outward, such that the outer edge of the vane stays in touch with the inside surface of the asymmetrically shaped casing. In some cases the vanes can be tensioned. The asymmetrical shape of the casing causes the vanes to move in and out of the slots as the rotor turns. As the vanes move past the suction port of the pump, a vacuum is created. This vacuum is what draws fluid into the pumping chamber. The fluid then moves between the vanes, and is eventually forced out the discharge port of the pump. Like many rotary pumps, the direction of the fluid flow can be reversed by reversing the direction of rotation of the pump.

Typical Applications for Vane Pumps

Vane pumps can be used in many different positive displacement applications. They can handle thin and low viscosity liquids, like water and petrol. They don't work particularly well with highly viscous fluids, as the higher viscosity prevents the vanes from moving freely in the slots.

Due to the fact that they can handle a wide range of viscosities, Vane pumps are often widely used for fuel loading terminals, fuel transport vehicles, solvents, alcohol and even soft drinks and syrups.

Vane pumps are available in many different configurations and can also handle fluids with a wide range of temperatures and pressures. Since they often are used for pumping clean hydrocarbons including gas and light oils, vane pumps are normally constructed with ductile iron casings and metal rotors. The vanes are often made of carbon, which exhibits a good lubricity to keep the vanes sliding inside the slots and against the inside surface of the casing.

The type of fluid being handled plays a large part in whether this pump is right for a specific application. High-viscosity or thicker fluids will obviously greatly reduce the speed of the pump — and a therefore vane pump might not be the best choice. In some cases *vane pumps* present a good alternative to gear pumps for pumping relatively low viscosity oils.

Vane pumps generally work within the following ranges:

- Flow rate ranges between 20 to 9500 lpm
- Total head (pressure) ranges between 1 to 14 Bar
- Horsepower ranges between 1 to 300 hp

Figure:3: Vane Pump

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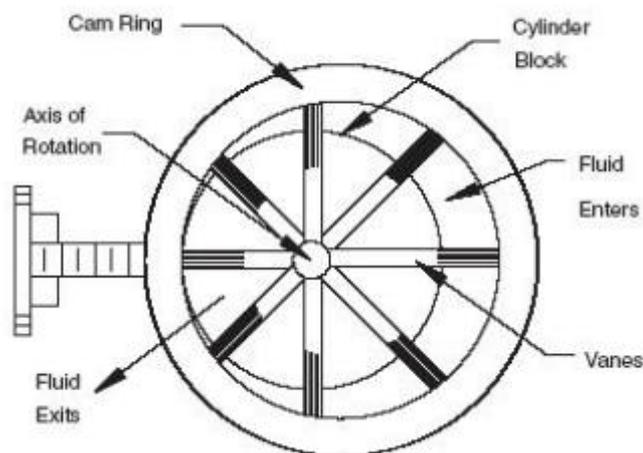
Piston Pump

A piston pump is a type of positive displacement pump where the high-pressure seal reciprocates with the piston. Piston pumps can be used to move liquids or compress gases. They can operate over a wide range of pressures. High pressure operation can be achieved without a strong effect on flow rate.

Piston pumps and plunger pumps use a mechanism (typically rotational) to create a reciprocating motion along an axis, which then builds pressure in a cylinder or working barrel to force gas or fluid through the pump. The pressure in the chamber actuates the valves at both the suction and discharge points.

The piston pump is strong, as well as simple devices. These pumps are made with a chamber, a piston, and a couple of control devices. These pumps function by flowing downward into the chamber, thus reducing the media within a hand pump. When the air pressure surpasses from the opening valve spring, then the reduced media can be sent throughout the open exit valve. As the piston is drawn back-up, then it releases the inlet valve & shuts the outlet valve, thus suction can be used to draw in extra media for compression. This article discusses an overview of piston-pump, working, types, etc.

Working:

The piston pump working is similar to PD pumps. Because they work with the help of the pumping mechanism force to increase the volume of the liquid. These pumps can use the power from power sources.

These pumps include more than one piston with a set of control devices. The duplex pump includes two pistons as well as two controlling devices. Similarly, a triplex pump includes three pistons as well as three controlling devices. It is very important to check the controlling devices on both sides to ensure that the flow of liquid direction at both sides is flowing or not.

These pumps are single otherwise double acting pumps. Double acting pumps involve two sets of controlling devices & liquid on both ends. This lets the pump to complete a pumping cycle by flowing in one direction to other. When the piston is taking in one direction, then it will exhaust at another side. This pump needs solo action versions for flowing in both directions for completing a cycle.

Types of Piston Pumps

These pumps are classified into different types namely lift pump, a force pump, axial pump, and radial piston-pump. From these pumps, lift and force pumps can operate manually otherwise with the help of an engine.
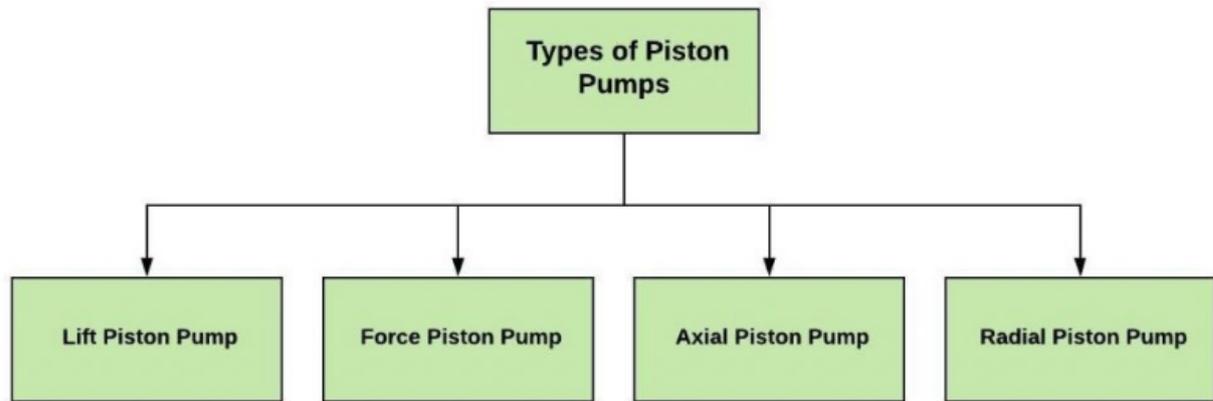
Figure:4: Types of Piston Pumps

Lift Piston Pump:

In this type of pump, the piston above stroke can draw fluid with the help of a control device which is named as valve into the below portion of the cylinder. On the below stroke, fluid flows through control devices which are arranged in the piston into the higher portion of the cylinder. After that on the upstroke, fluid can be released from the higher portion of the cylinder through a spout.

Force Piston Pump

In this type of pump, the piston pumps upstroke can draw fluid throughout an inlet valve to the cylinder (tube). On top of the downstroke, the fluid level can be discharged via an exit valve into the outlet tube.

Axial Piston Pump

This is pump is a PD (positive displacement) pump and it has several pistons within a circular array of a tube block. This block can be driven to turn its symmetry axis with an important shaft which is associated with the pumping pistons. These pumps can be used like an automotive air conditioning compressor, a separate pump, otherwise a hydraulic motor.

Radial Piston Pump

This pump is one kind of hydraulic pump, and the working pistons expand within a radial track symmetrically in the region of the drive shaft, in disparity in the direction of the axial piston pump.

Specifications

The main specifications while choosing these pumps mainly include the rate of flow, head of the pump, volume stroke, pressure, outlet diameter, power rating, horsepower, and finally operating temperature.

Materials

The materials used to design the piston-pump mainly depend on the application of a pump. The casing and cylinder materials must have sufficient strength as well as they have to hold up adjacent to the operating environment conditions. Materials to get in touch with the pumped media require to resistant for any rust-induced with the liquid. Some type of materials used in this pump is discussed below.

- Cast iron offers high tensile power, robustness, and scratch resistance equivalent to high force ratings.
- Plastic materials are cheap as well as offer a wide resistance toward rust as well as chemical attack.
- Stainless steel alloys and steel give safety against rust and chemical and they have superior tensile powers compare with plastics, equivalent to superior pressure ratings.
- Other types of materials used to design the pump mainly include aluminum, brass, bronze, ceramics, and nickel-alloy.

Advantages

The advantages of a piston pump mainly include the following.

- The range of pressure is wide
- Force can be managed without moving flow rate.
- The rate of flow and Pressure changes has a small outcome on the act.
- Skilled in moving of thick fluids, slurries, as well as abrasives with good control device design.

Disadvantages

The disadvantages of piston pump mainly include the following.

- Maintenance cost, & operating is high usually bulky and heavy
- They handle only lesser flow rates
- Flow is Pulsating

Thus, this is all about piston pumps which are used like hydraulic pumps for powering heavy machines as well as small machines. Piston pump applications mainly include transferring paint, pastry, chocolate, etc. The size of these pipes has increased for utilizing in industries. All types of piston-pumps in the form of radial and axial are also used in advanced industrial applications, which include numerous pistons arranged within a round cylinder block.
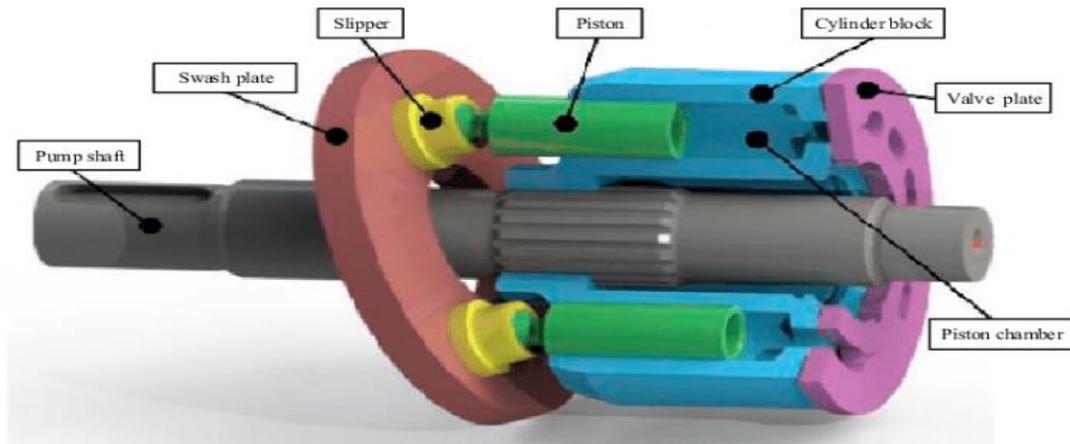
Figure:5:Piston Pumps

Pump Performances:

A hydraulic pump is a mechanical device that converts mechanical power into hydraulic energy. It generates flow with enough power to overcome pressure induced by the load. Second, its mechanical action delivers this liquid to the pump outlet and forces it into the hydraulic system.

Variable Displacement Pumps:

Variable-Displacement Pump. In this pump, pumping-chamber sizes can be changed. The GPM delivery can be changed by moving the displacement control, changing the drive speed, or doing both. The pump can be used in a closed-center system—a pump continues to operate against a load in the neutral condition.

Directional control valve:

Directional control valves (DCVs) are one of the most fundamental parts of hydraulic and pneumatic systems. DCVs allow fluid flow (hydraulic oil, water or air) into different paths from one or more sources. ... The position of the spool restricts or permits flow, thus it controls the fluid flow.

Directional control valves may be classified in several ways. The most common method is by the type of valving element used in the construction of the valve. The most common types of valving elements are the ball, cone, sleeve, poppet, rotary spool, and sliding spool.

Four-way, directional-control valves are used to control the direction of fluid flow in a hydraulic circuit, which controls the direction of movement of a work cylinder or the rotation of a fluid motor. Four-way valves consist of a rectangular cast body, a sliding spool, and a way to position a spool.

Solenoid operated directional valves are used in circuits where 2-way, 3-way, and 4-way functions are required. Sun offers both direct acting and pilot operated, and are available in poppet and spool configurations.

The 4-Way Directional Valve block represents a directional control valve with four ports and three positions, or flow paths. The ports connect to what in a typical model are a hydraulic pump (port P), a storage tank (port T), and a double-acting actuator (ports A and B).

Three-way valves have three pipe connection s and two orifices. When one orifice is open, the other is closed, and vice versa. They are commonly used to alternately apply pressure to and exhaust pressure from a valve actuator or a single-acting cylinder.

A 2-way valve stops flow or allows flow. A 4-way valve pressurizes and exhausts two ports interdependently. A 3-position, 4-way valve stops an actuator or allows it to float. The 4-way function is a common type of directional control valve for both air and hydraulic circuits.

5/3 or 4/3 air valves, like the 5/2 or 4/2 air valves, are used to power double acting air actuators. The 5/3 and 4/3 body design allow compressed air to flow to one port of a double acting air actuator while simultaneously allowing air to exhaust from the other port on the same air actuator at the same time.

Shuttle Valve:

A shuttle valve is a type of valve which allows fluid to flow through it from one of two sources. Generally a shuttle valve is used in pneumatic systems, although sometimes it will be found in hydraulic systems.

The basic structure of a shuttle valve is like a tube with three openings; one on each end, and one in the middle. A ball or other blocking valve element moves freely within the tube. When pressure from a fluid is exerted through an opening on one end it pushes the ball towards the opposite end. This prevents the fluid from traveling through that opening, but allows it to flow through the middle opening. In this way two different sources can provide pressure without the threat of back flow from one source to the other.

The shuttle valve is a pneumatic OR valve and is also called as a double check valve. The valve consists of a valve body and a synthetic ball or cuboid valving element moving inside the bore in the valve housing. With its design based on a mechanical iris, the Shutter Valve controls flow by moving the petals into any position needed. At full open, the Shutter Valve has 0% pressure drop (P1=P2) and because there is no obstruction in the flow path when open, cavitation, noise, water hammer, wear and tear are lowered.
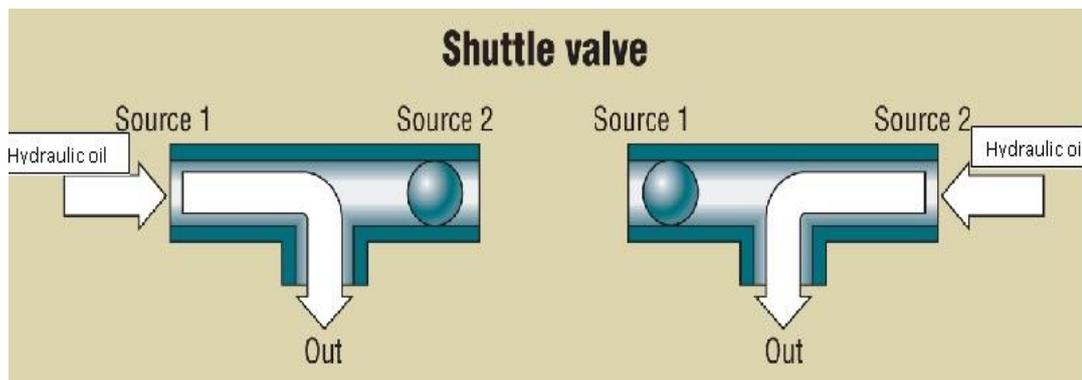

Shuttle valve

Figure:6: Shuttle Valve

A shuttle valve has several applications including:

1. The use of more switches on one machine: by using the shuttle valve, more than one switch can be operated on a single machine for safety, and each switch can be placed at any suitable location. This application is normally used with heavy industrial machinery.
2. Winch brake circuit: a shuttle valve provides brake control in pneumatic winch applications. When the compressor is operated the shuttle valves direct air to open the brake shoes. When the control valve is centered, the brake cylinder is vented through the shuttle valve, and the brake shoes are allowed to close.
3. Air pilot control: converting from air to oil results in locking of the cylinder. Shifting the four-way valve to either extreme position applies the air pilot through the shuttle valve, holding the two air-operated valves open and applying oil under air pressure to the corresponding side of the cylinder. Positioning a manual valve to neutral exhausts the air pilot pressure, closing the two-way valves, and trapping oil on both sides of the cylinder to lock it in position.
4. Standby and emergency systems: compressor systems requiring standby or purge gases capability are pressure controlled by the shuttle valve. This is used for instrumentation, pressure cables, or any system requiring continuous pneumatic input. If the compressor fails, the standby tank—regulated to slightly under the compressor supply—will shift the shuttle valve and take over the function. When the compressor pressure is re-established, the shuttle valve shifts back and seals off the standby system until needed again.

Check Valve:

A check valve, clack valve, non-return valve, reflux valve, retention valve or one-way valve is a valve that normally allows fluid (liquid or gas) to flow through it in only one direction. Check valves are two-port valves, meaning they have two openings in the body, one for fluid to enter and the other for fluid to leave. There are various types of check valves used in a wide variety of applications. Check valves are often part of common household items. Although they are available in a wide range of sizes and costs, check valves generally are very small, simple, or inexpensive. Check valves work automatically and most are not controlled by a person or any external control; accordingly, most do not have any valve handle or stem. The bodies (external shells) of most check valves are made of plastic or metal.

An important concept in check valves is the cracking pressure which is the minimum differential upstream pressure between inlet and outlet at which the valve will operate. Typically the check valve is designed for and can therefore be specified for a specific cracking pressure. Heart valves are essentially inlet and outlet check valves for the heart ventricles, since the ventricles act as pumps.
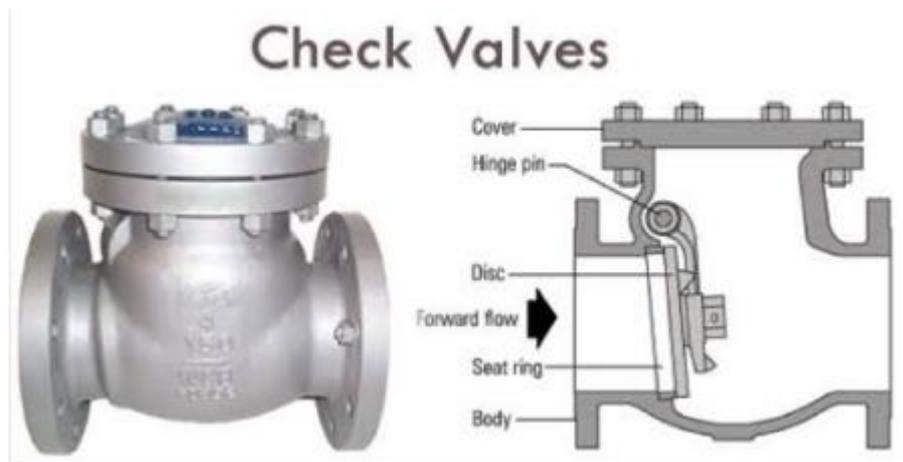
Figure:7 : Check Valve

Types of Check Valve

A ball check valve is a check valve in which the closing member, the movable part to block the flow, is a ball. In some ball check valves, the ball is spring-loaded to help keep it shut. For those designs without a spring, reverse flow is required to move the ball toward the seat and create a seal. The interior surface of the main seats of ball check valves are more or less conically-tapered to guide the ball into the seat and form a positive seal when stopping reverse flow.

Ball check valves are often very small, simple, and cheap. They are commonly used in liquid or gel mini pump dispenser spigots, spray devices, some rubber bulbs for pumping air, etc., manual air pumps and some other pumps, and refillable dispensing syringes. Although the balls are most often made of metal, they can be made of other materials; in some specialized cases out of highly durable or inert materials, such as sapphire. High pressure HPLC pumps and similar applications commonly use small inlet and outlet ball check valves with balls of (artificial) ruby and seats made of sapphire or both ball and seat of ruby, for both hardness and chemical resistance. After prolonged use, such check valves can eventually wear out or the seat can develop a crack, requiring replacement. Therefore, such valves are made to be replaceable, sometimes placed in a small plastic body tightly-fitted inside a metal fitting which can withstand high pressure and which is screwed into the pump head.

There are similar check valves where the disc is not a ball, but some other shape, such as a poppet energized by a spring. Ball check valves should not be confused with ball valves, which is a different type of valve in which a ball acts as a controllable rotor to stop or direct flow.

A diaphragm check valve uses a flexing rubber diaphragm positioned to create a normally-closed valve. Pressure on the upstream side must be greater than the pressure on the downstream side by a certain amount, known as the pressure differential, for the check valve to open allowing flow. Once positive pressure stops, the diaphragm automatically flexes back to its original closed position.

Swing check valve opening and closing

A swing check valve or tilting disc check valve is a check valve in which the disc, the movable part to block the flow, swings on a hinge or trunnion, either onto the seat to block reverse flow or off the seat to allow forward flow. The seat opening cross-section may be perpendicular to the centerline between the two ports or at an angle. Although swing check valves can come in various sizes, large check valves are often swing check valves. A common issue caused by swing check valves is known as water hammer. This can occur when the swing check closes and the flow abruptly stops,

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causing a surge of pressure resulting in high velocity shock waves that act against the piping and valves, placing large stress on the metals and vibrations in the system. Undetected, water hammer can rupture pumps, valves, and pipes within the system.

The flapper valve in a flush-toilet mechanism is an example of this type of valve. Tank pressure holding it closed is overcome by manual lift of the flapper. It then remains open until the tank drains and the flapper falls due to gravity. Another variation of this mechanism is the clapper valve, used in applications such fire fighting and fire life safety systems. A hinged gate only remains open in the inflowing direction. The clapper valve often also has a spring that keeps the gate shut when there is no forward pressure. Another example is the backwater valve (for sanitary drainage system) that protects against flooding caused by return flow of sewage waters. Such risk occurs most often in sanitary drainage systems connected to combined sewerage systems and in rainwater drainage systems. It may be caused by intense rainfall, thaw or flood.

A stop-check valve is a check valve with override control to stop flow regardless of flow direction or pressure. In addition to closing in response to backflow or insufficient forward pressure (normal check-valve behavior), it can also be deliberately shut by an external mechanism, thereby preventing any flow regardless of forward pressure.

A lift-check valve is a check valve in which the disc, sometimes called a *lift*, can be lifted up off its seat by higher pressure of inlet or upstream fluid to allow flow to the outlet or downstream side. A guide keeps motion of the disc on a vertical line, so the valve can later reseat properly. When the pressure is no longer higher, gravity or higher downstream pressure will cause the disc to lower onto its seat, shutting the valve to stop reverse flow.

An in-line check valve is a check valve similar to the lift check valve. However, this valve generally has a spring that will 'lift' when there is pressure on the upstream side of the valve. The pressure needed on the upstream side of the valve to overcome the spring tension is called the 'cracking pressure'. When the pressure going through the valve goes below the cracking pressure, the spring will close the valve to prevent back-flow in the process.

A duckbill valve is a check valve in which flow proceeds through a soft tube that protrudes into the downstream side. Back-pressure collapses this tube, cutting off flow.

A pneumatic non-return valve:

Multiple check valves can be connected in series. For example, a double check valve is often used as a backflow prevention device to keep potentially contaminated water from siphoning back into municipal water supply lines. There are also *double ball check valves* in which there are two ball/seat combinations sequentially in the same body to ensure positive leak-tight shutoff when blocking reverse flow; and piston check valves, wafer check valves, and ball-and-cone check valves.

Pressure Control Valve:

Pressure valves are hydraulic valves that gradually (control) or suddenly (switch) change in position. The most common types of pressure control valves are the pressure relief valve and the pressure reducing valve. Pressure relief valves control the system pressure by relieving part, or all, of the flow to tank.

It is often referred to as a pressure regulator. The valve simply uses spring pressure against a diaphragm to open the valve. When the outlet pressure drops below the set point of the valve, the spring pressure overcomes the outlet pressure and forces the valve stem downward, opening the valve.

The most common types of pressure control valves are the pressure relief valve and the pressure reducing valve. Pressure relief valves control the system pressure by relieving part, or all, of the flow to tank. Pressure reducing valves reduce the pressure supplied to a sub-system of a hydraulic system. Sequence valves are used to direct the flow to a secondary circuit. Unloading valves are used to direct flow to tank at pre-set system pressure.

Every pressure control valve switches (or controls) at a predetermined pressure setting. The switching pressure is generally a variable setting on the valve itself. A change in position of the pressure control valve (i.e. open or closed) occurs either gradually (by control) or suddenly (by switch). Pressure shut-off valves and pressure sequence valves are hydraulic valves with a fixed throttle whereas relief and reducing valves are hydraulic valves with a variable throttle.

Pressure reducing valve with a wrench and back it off by unscrewing it. Fit a socket wrench over the adjustment nut on the top of the valve. Turn the nut counter clockwise to reduce the pressure downstream from the valve and clockwise to increase it.
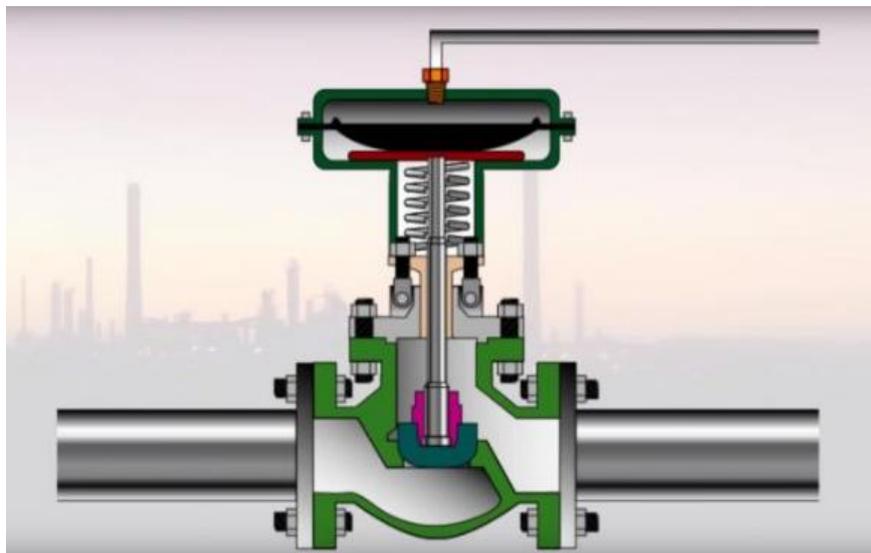
Figure:8: Pressure Control Valve

Pressure Reducing Valve:

A common way of lowering pressure is by throttling down the size of the steam passageway. For the most basic pressure reduction, it is possible to simply use a conventional globe valve in a fixed partly-open position, or by inserting an orifice plate into the flow of steam. However, any fluctuation in flow rate would be accompanied by a corresponding fluctuation in pressure. To avoid such circumstances, pressure reducing valves (PRVs) can be used to provide precise control of downstream pressure. They automatically adjust the amount of valve opening to allow the pressure to remain unchanged even when the flow rate fluctuates.

Types of Pressure Reducing Valve:

In pressure reducing valves, the mechanism that automatically adjusts the downstream pressure typically uses the balance of forces between the steam pressure and an adjustment spring. At present, this is a universal concept on almost all manufactured pressure reducing valves. However, there are two different ways in which this mechanism is implemented to control the amount of valve opening:

Non-piloted, Direct Acting Valve: Adjustment spring places downward pressure setting force directly on the main valve.

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Pilot-Operated Valve: Adjustment spring places downward pressure setting force directly on a pilot valve, which is smaller and different from the main valve.

The following is an overview of the features of each type of PRV.

Direct Acting (Non-piloted)

Used for small loads where extremely close pressure control is not needed.
Pros: Compact size, low price, easy to install.
Cons: Higher droop (variation from set pressure) than Pilot-operated PRV.
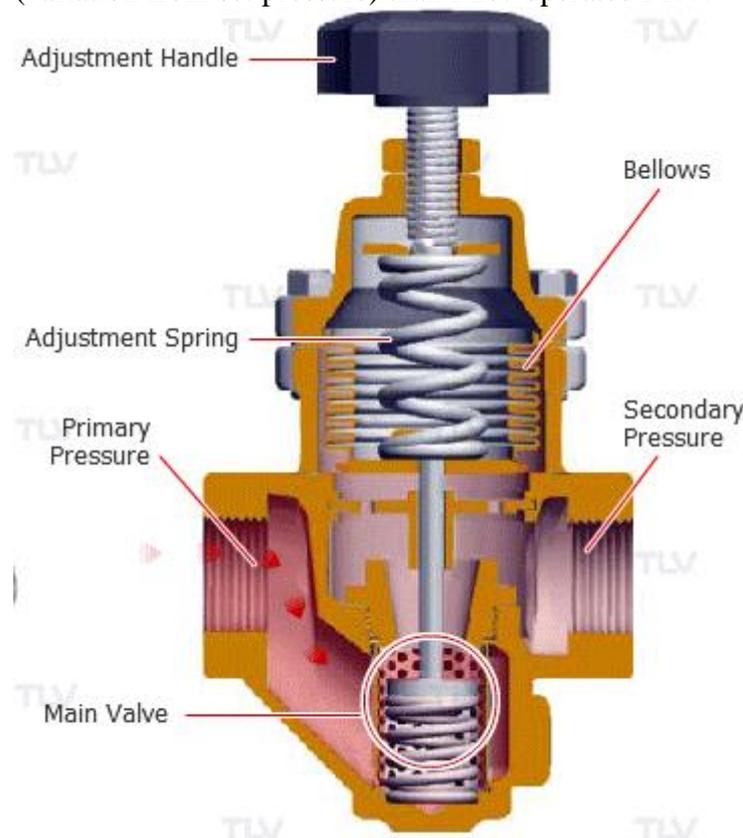
Figure:9: Direct Acting Pressure Reducing Valve

In direct acting pressure reducing valves, the amount of valve opening is determined directly by the movement of the adjustment spring. If the spring is compressed, it creates an opening force on the valve which increases flow. As pressure builds downstream, equalizing occurs by feeding the downstream pressure to the underside of the adjustment spring (usually against a bellows or diaphragm) where its upward force counter-balances against the spring compression. Spring compressive force which opens the valve is limited to allow sufficient spring sensitivity to equalize with downstream pressure changes. The net result is simple pressure control through a valve orifice where high flow rates can cause pressure droop.

Pilot-Operated

Used for larger loads where close pressure control is required
Pros: Close pressure control, fast response to load variation, may be used across a broader range of flow rates than the direct acting types.
Cons: Larger size, higher price.
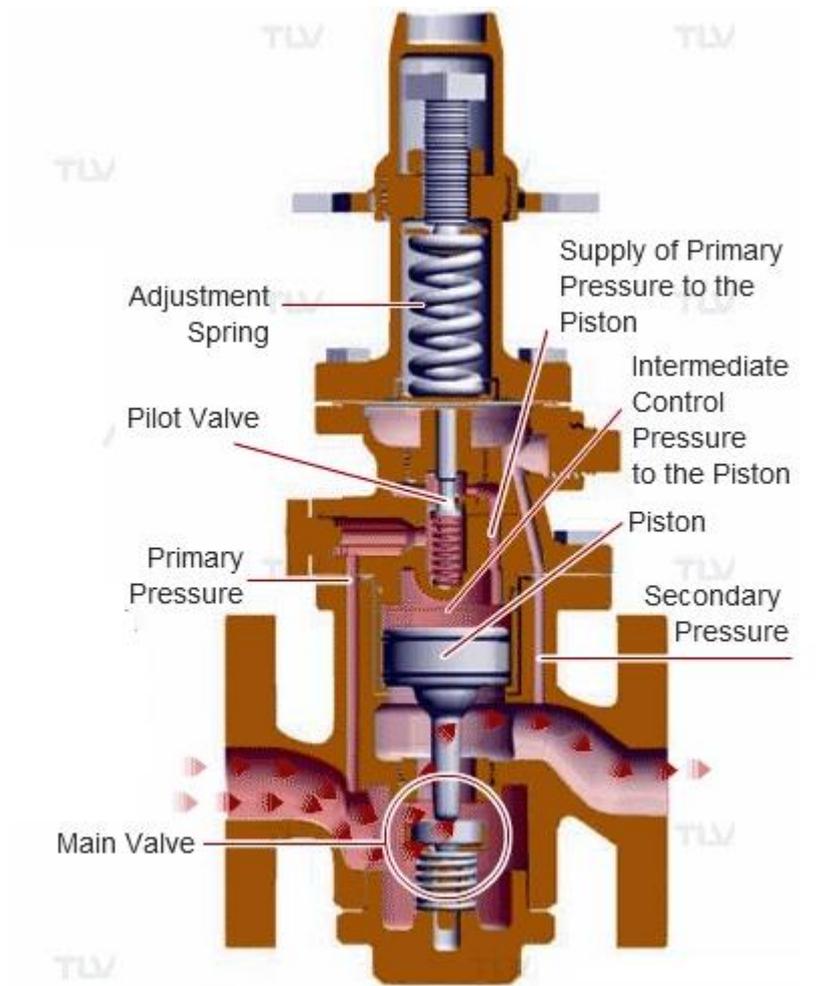
Figure:10: Pilot Operated Pressure Reducing Valve

In pilot-operated pressure reducing valves, a pilot valve is used to load a piston or diaphragm that increases the downward force used to open a larger main valve. This enables larger flow capacity with a lower pressure offset (droop). The opening and closing of the pilot valve is controlled by the balance of force between the adjustment spring and the secondary pressure in the same manner that a direct-acting valve operates. However, in a pilot-operated PRV, this opening and closing of the pilot valve purposely delivers pressure to the main valve piston or diaphragm. This pilot flow pressure then causes a downward force that is amplified by the area of the piston or diaphragm to enable opening of a much larger main valve, which in turn provides the ability for very high flow rates.

Because the downward force is amplified through the use of a piston or diaphragm, a small change in the opening on the pilot valve can result in a large change in flow and downstream pressure through the main valve. As a result, there is little change needed in adjustment spring force on the pilot to accomplish quick response over a wide range of steam flow rates. Quick response and tight delivered pressure control represent the main advantages of this type of valve over the direct-acting type.

Sequencing Valve:

A sequence valve is a pressure valve designed to open when its set pressure is reached, providing a path of flow alternate and sequential to the primary circuit. In some ways, a sequence valve is a

directional valve, allowing flow to occur. However, it's just a relief valve with some added features. A sequence valve is somewhat similar to a relief valve except that, after the set pressure has been reached, the sequence valve diverts the fluid to a second actuator or motor to do work in another part of the system. Fluid is free to flow into cylinder A. The simplest way to make two or more cylinders stroke in a planned sequence is by using a single directional valve. However, when two or more cylinders are piped in parallel, the cylinder with the lowest resistance will stroke first. If this is the intent, the circuit runs smoothly without other valves. However, in most cases, loads change, so if you want cylinders to stroke in a specific order regardless of the load on each, you'll need more than just a single directional valve.

The only positive way to do this is with separate directional control valves and limit switches or limit valves. This setup ensures the first actuator has reached a specific location before the next operation commences. However, the first cylinder may lose holding power when the second directional valve shifts. If there is no safety concern or possibility of product damage if the first actuator does not complete its cycle before the second starts, a sequence valve can be a simple way to control the actuators' actions. Sequence valves are normally closed, and they usually incorporate an integral bypass check valve to allow bidirectional flow. Sequence valves always have an external drain connected directly to tank. On the other hand, one great feature of a sequence-operated circuit is that it does not matter how far the first cylinder moves before the next operation takes place. Thick or thin parts are clamped at the same force before the next operation starts because pressure must build to the same level to trigger the next sequence.
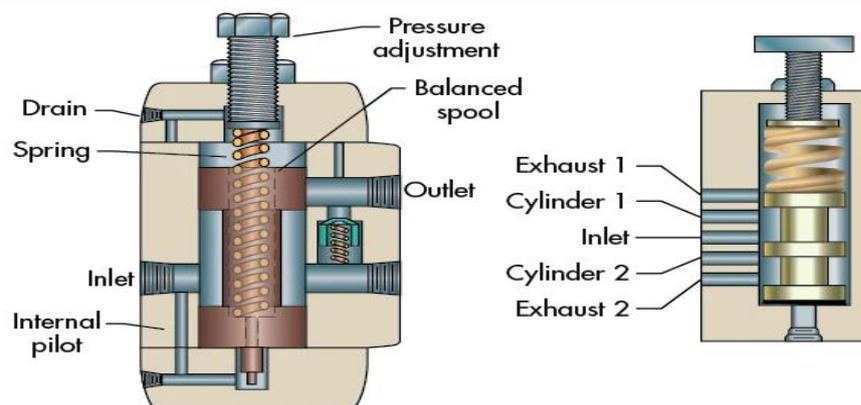
Figure:11: Sequence Valve

Flow Control Valve:

The purpose of flow control in a hydraulic system is to regulate speed. All the devices discussed here control the speed of an actuator by regulating the flow rate. Flow rate also determines rate of energy transfer at any given pressure. The two are related in that the actuator force multiplied by the distance through which it moves (stroke) equals the work done on the load. The energy transferred must also equal the work done. Actuator speed determines the rate of energy transfer (power), and speed is thus a function of flow rate.

Eight different types of flow-control valves are commonly used in hydraulic systems.

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Orifices—A simple orifice in a hydraulic line, *Fig.* is the most elementary method for controlling flow and can also be used as a pressure-control device. When used to control flow, the orifice is placed in series with the pump. An orifice can be a drilled hole in a fitting, in which case it is fixed; or it may be a calibrated needle valve, in which case it functions as a variable orifice.

Flow regulators—These devices, *Fig.* are slightly more sophisticated than a fixed orifice and consist of an orifice that senses flow rate as a pressure drop (ΔP) across the orifice. Also, a compensating piston adjusts to variations of inlet and outlet pressures. This compensating ability provides closer control of flow rate under varying pressure conditions. Control accuracy may be 5%, possibly less with specially calibrated valves that operate around a given flow-rate point.

Bypass flow regulators—In this flow regulator, flow in excess of set flow rate returns to reservoir through a bypass port, *Fig.* Flow rate is controlled by throttling fluid across a variable orifice regulated by the compensator piston. The bypass flow regulator is more efficient than a standard flow regulator.

Demand-compensated flow controls—Flow controls can also bypass excess system flow to a secondary circuit, *Fig.* Fluid is routed at a controlled flow rate to the primary circuit, and bypass fluid can be used for work functions in secondary circuits without affecting the primary one. There must be flow to the primary circuit for this type of valve to function—if the primary circuit is blocked, the valve will cut off flow to the secondary circuit.

Pressure-compensated, variable flow valves—This flow control is equipped with an adjustable variable orifice placed in series with a compensator. The compensator automatically adjusts to varying inlet and load pressures, maintaining an essentially constant flow rate under these operating conditions to accuracies of 3% to 5%, *Fig.* Pressure-compensated, variable flow-control valves are available with integral reverse-flow check valves (which give fluid unrestricted flow in the opposite direction) and integral overload relief valves (which route fluid to tank when a maximum pressure is exceeded).

Pressure- and temperature-compensated, variable flow valves—Because the viscosity of hydraulic oil varies with temperature (as do the clearances between a valve's moving parts), output of a flow-control valve may tend to drift with temperature changes. To offset the effects of such temperature variations, temperature compensators adjust the control orifice openings to correct the effects of viscosity changes caused by temperature fluctuations of the fluid, *Fig.* This is done in combination with adjustments to the control orifice for pressure changes as well.

Priority valves—A priority valve, *Fig.* , is essentially a flow-control valve that supplies fluid at a set flow rate to the primary circuit, thus functioning as a pressure-compensated flow-control valve. Flow in excess of that required by the primary circuit bypasses to a secondary circuit at a pressure somewhat below that of the primary circuit. Should inlet or load pressure (or both) vary, the primary circuit has priority over the secondary — as far as supplying the design flow rate is concerned.
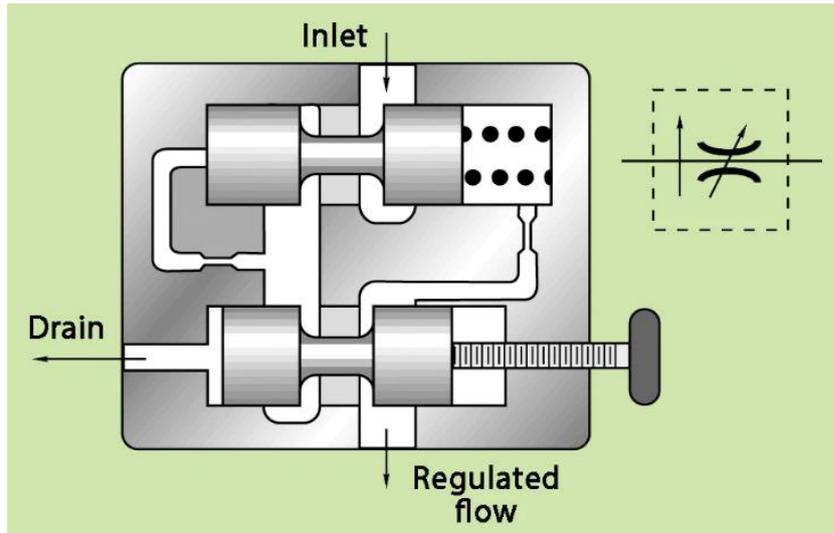
Figure:12: Flow Control Valve

Relief Valve:

A **relief valve** or **pressure relief valve** (**PRV**) is a type of safety valve used to control or limit the pressure in a system; pressure might otherwise build up and create a process upset, instrument or equipment failure, or fire. The pressure is relieved by allowing the pressurized fluid to flow from an auxiliary passage out of the system. The relief valve is designed or set to open at a predetermined set pressure to protect pressure vessels and other equipment from being subjected to pressures that exceed their design limits. When the set pressure is exceeded, the relief valve becomes the "path of least resistance" as the valve is forced open and a portion of the fluid is diverted through the auxiliary route. The diverted fluid (liquid, gas or liquid-gas mixture) is usually routed through a piping system known as a *flare header* or *relief header* to a central, elevated gas flare where it is usually burned and the resulting combustion gases are released to the atmosphere. As the fluid is diverted, the pressure inside the vessel will stop rising. Once it reaches the valve's reseating pressure, the valve will close. The *blowdown* is usually stated as a percentage of set pressure and refers to how much the pressure needs to drop before the valve reseats. The blowdown can vary from roughly 2–20%, and some valves have adjustable blowdowns.

In high-pressure gas systems, it is recommended that the outlet of the relief valve is in the open air. In systems where the outlet is connected to piping, the opening of a relief valve will give a pressure build-up in the piping system downstream of the relief valve. This often means that the relief valve will not re-seat once the set pressure is reached. For these systems often so-called "differential" relief valves are used. This means that the pressure is only working on an area that is much smaller than the area of the opening of the valve. If the valve is opened the pressure has to decrease enormously before the valve closes and also the outlet pressure of the valve can easily keep the valve open. Another consideration is that if other relief valves are connected to the outlet pipe system, they may open as the pressure in the exhaust pipe system increases. This may cause undesired operation.

In some cases, a so-called bypass valve acts as a relief valve by being used to return all or part of the fluid discharged by a pump or gas compressor back to either a storage reservoir or the inlet of the pump or gas compressor. This is done to protect the pump or gas compressor and any associated

equipment from excessive pressure. The bypass valve and bypass path can be internal (an integral part of the pump or compressor) or external (installed as a component in the fluid path). Many fire engines have such relief valves to prevent the over pressurization of fire hoses.

In other cases, equipment must be protected against being subjected to an internal vacuum (i.e., low pressure) that is lower than the equipment can withstand. In such cases, vacuum relief valves are used to open at a predetermined low-pressure limit and to admit air or an inert gas into the equipment to control the amount of vacuum.

1 - Inlet nozzle   6 - Cap
2 - Valve seat   7 - Spring
3 - Seat holder   8 - Bonnet
4 - Valve body   9 - Seal
5 - Set pressure
    adjusting screw
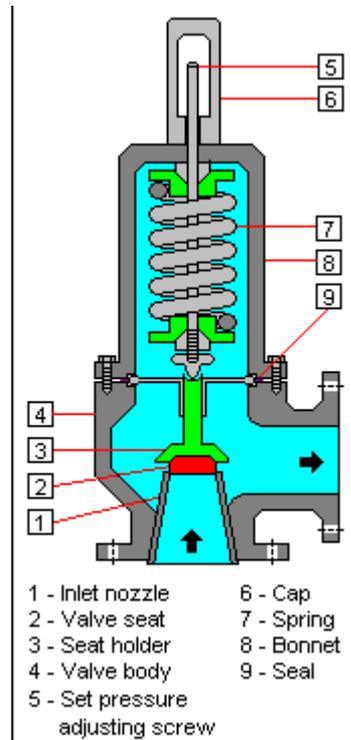
Figure:13: Relief Valve

Break Valve:

A brake valve performs the same function as a counterbalance valve, but it is designed to overcome a key disadvantage. An example will illustrate this point. Suppose a direct-operated counterbalance valve is used in a motor circuit. There are times when the motor load can overrun, and braking is needed for those times. This valve is set at 350 psi, and the pressure drop across the motor to supply required torque is 350 psi. The pump must develop $350 + 350 = 700$ psi. The pressure drop across the counterbalance valve is converted to heat; consequently, half the hydraulic power is wasted. A brake valve overcomes this disadvantage.

As shown in the functional diagram in Fig, a brake valve has an internal pilot passage and a remote pilot passage. Suppose the spring is set for 1000 psi. When pressure at the internal pilot reaches 1000 psi, the piston pushes the spool upward to open the valve.
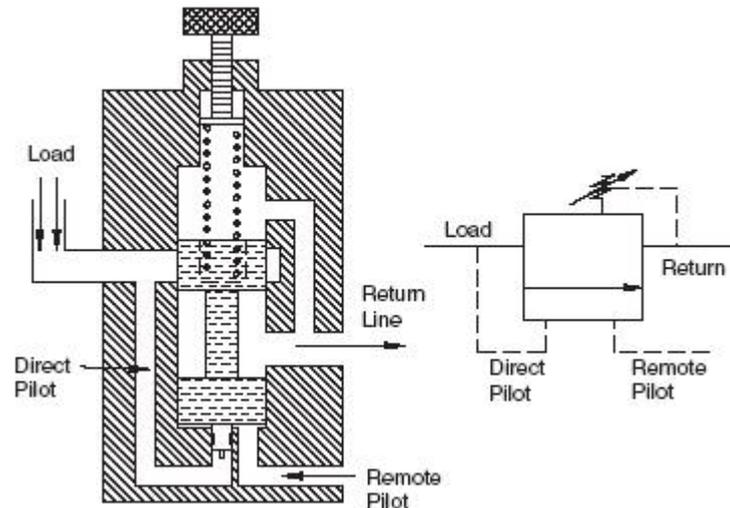
Figure:14: Break Valve

The area of the piston is much less than the area of the bottom of the spool. A typical area ratio might be 10:1. The remote pilot applies pressure directly to the bottom of the spool; consequently, only 100 psi is required to compress the spring and open the valve. Pressure required to open the valve is 1000 psi at the internal pilot and 100 psi at the remote pilot.

Counter Balance Valve:

Counterbalance valves are also known as load holding valves because of its ability to safely hold heavy loads. The load holding capacity is achieved by allowing free flow into the cylinder/actuator and by blocking the reverse flow until a pilot pressure inversely proportional to the load is applied. In short, the counterbalance valve permits flow in one direction and block the flow opposite to it. Vertical presses, lift trucks, loaders and other machine tools that positions or hold suspended loads are some counterbalance valve applications. Some important benefits of the counterbalance valve are listed below.

- Prevent unintended or uncontrolled movement of static or dynamic loads
- Protect the equipment from damages by handling induced pressure
- Offers greater stability to the machinery
- Control the load speed in case of hydraulic hose failure
- Stabilize the system when it experiences high or variable backpressure.
- Suitable for safe and stable load handling

Counterbalance valves are well suited for clamping applications and it avoids falling of negative loads when any failures occur. These valves can be used with paired cylinders. In a paired cylinder, the pilot pressure will open the valve of the heavily loaded cylinder and this load will be transferred to the next cylinder and its corresponding closed valve and will open. The counterbalance valve is either flange mounted or connected with a metallic pipe and is fitted next to the actuator to offer safety.

The counterbalance valve functions are similar to that of flow control valves and are used for high-speed safe lowering/elevation of loads. Load holding, load control and load safety are the three important counterbalance valve functions. The counterbalance valve prevents unintended motion of actuators/cylinders holding heavy loads. These valves will help to stabilize the load, avoid damage of equipment and eliminate dangers caused as a result of the hose failures. For aerial work platforms, it is necessary to prevent sudden or unwanted downward drifts. Even under the inoperable conditions, these valves will hold the load firmly against the gravitational force by applying a back pressure against the load. Under operating conditions, the load can be elevated by passing fluid through the check valve. Also, this valve will prevent uncontrolled or unsafe motion of loads as a result of line breaks or overloads.
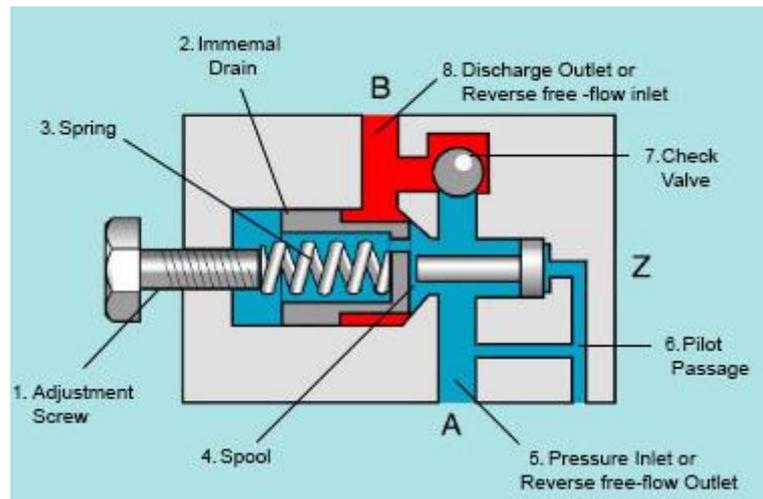
Figure:15: Counter Balance Valve

Ladder Diagram

A ladder diagram is a type of schematic diagram used in industrial automation that represents logic control circuits. Ladder diagrams are composed of two vertical power rails and horizontal logic rungs to form what looks like a ladder. The control logic in a ladder diagram is contained within the rungs.

There are two differences between an electrical schematic and a ladder diagram. The first difference is the control logic in an electrical schematic is represented using components whereas in a ladder diagram symbols are used. The second difference is the control logic execution in an electrical schematic is as per the operation of an electrical circuit whereas in a ladder diagram it relies on the methodical nature of the PLC scan.

The reason why ladder diagrams are used for PLC programming is because the early control system designers were accustomed to relay logic control circuits and ladder diagrams closely mimic these. They preferred to use ladder diagrams instead using text based programming languages of the day like C, BASIC, Pascal and FORTRON. The other reason ladder diagrams are used is because factory maintenance staff already understand how to read relay control circuits so using ladder diagrams for programming a PLC meant they were easily able to troubleshooting control system problems.

Ladder diagrams help you to formulate the logic expressions in graphical form that are required to program a PLC. They represent conditional, input and output expressions as symbols. So writing a PLC program using ladder diagrams is similar to drawing a relay control circuit.

Ladder logic is a programming language that is used to program a PLC (Programmable Logic Controller). It is a graphical PLC programming language which expresses logic operations with symbolic notation using ladder diagrams, much like the rails and rungs of a traditional relay logic circuit. It is used by engineers and electricians to execute logical, sequential, counting, timing and arithmetic tasks in order to carry industrial automation applications.

Because ladder logic was originally designed to replace the use of hard wired relay logic circuits for machine control the ladder logic programming code actual looks like an electrical schematic drawing. You might be thinking that ladder logic sounds like an old programming language. So, with the advancements in software that the world has recently made, is ladder logic still used?

Ladder logic is definitely still being used in PLC programming. It is the most common method for programming a PLC. Ladder logic programming is still used today because the core fundamental logic principles for machine and process control are still the same.

In PLC programming, ladder logic is a programming language that is used for developing logic expressions in order to automate tasks. Recent advancements in software technology means that PLC programming using ladder logic has been extended into counting, timing, arithmetic, sequencers, PID control, data manipulation functions and more.

Ladder logic is used extensively for programming PLCs in a multitude of industrial automation applications. Some examples include.

- Material Handling Conveyor System.
- Pallet Packing and Strapping.
- Ball Mill Lubrication System.
- Logistics Package Conveying and Sorting.
- Cement Batching.
- Beverage Bottling and Labelling.
- Hopper and Tank Level Control.
- Air and Liquid Flow and Pressure Control.

How to Draw a Ladder Diagram:

The simple way to describe a ladder diagram is a graphic programming language that uses a series of rails and rungs containing logic symbols that are combined to form decision making expressions. Ladder diagrams actually look like a ladder and are more commonly known as ladder logic programming. The rails in a ladder diagram represent the supply wires of a relay logic control circuit. There is a positive voltage supply rail on the left hand side and a zero voltage rail on the right hand side. In a ladder diagram the logic flow is from the left hand rail to the right hand rail.

The rungs in a ladder diagram represent the wires that connect the components of a relay control circuit. In a ladder diagram symbols are used to represent the relay components. The symbols are placed in the rung to form a network of logic expressions.

When implementing a ladder logic program in a PLC there are **seven basic parts of a ladder diagram** that critical to know. They are rails, rungs, inputs, outputs, logic expressions, address notation/tag names and comments. Some of these elements are essential and others are optional.

To help understand **how to draw ladder logic diagrams** the seven basic parts of a ladder diagram are detailed below…..

1. **Rails** – There are two rails in a ladder diagram which are drawn as vertical lines running down the far most ends of the page. If they were in a relay logic circuit they would represent the active and zero volt connections of the power supply where the power flow goes from the left hand side to the right hand side.

2. **Rungs** – The rungs are drawn as horizontal lines and connect the rails to the logic expressions. If they were in a relay logic circuit they would represent the wires that connect the power supply to the switching and relay components.

3. **Inputs** – The inputs are external control actions such as a push button being pressed or a limit switch being triggered. The inputs are actually hardwired to the PLC terminals and represented in the ladder diagram by a normally open (NO) or normally closed (NC) contact symbol.

4. **Outputs** – The outputs are external devices that being are turned on and off such as an electric motor or a solenoid valve. The outputs are also hardwired to the PLC terminals and are represented in the ladder diagram by a relay coil symbol.

5. **Logic Expressions** – The logic expressions are used in combination with the inputs and outputs to formulate the desired control operations.

6. Address Notation & Tag Names – The address notation describes the input, output and logic expression memory addressing structure of the PLC. The tag names are the descriptions allocated to the addresses.

7. **Comments** – Last but by not least, the comments are an extremely important part of a ladder diagram. Comments are displayed at the start of each rung and are used to describe the logical expressions and control operations that the rung, or groups of rungs, are executing. Understanding ladder diagrams is made a lot easier by using comments.
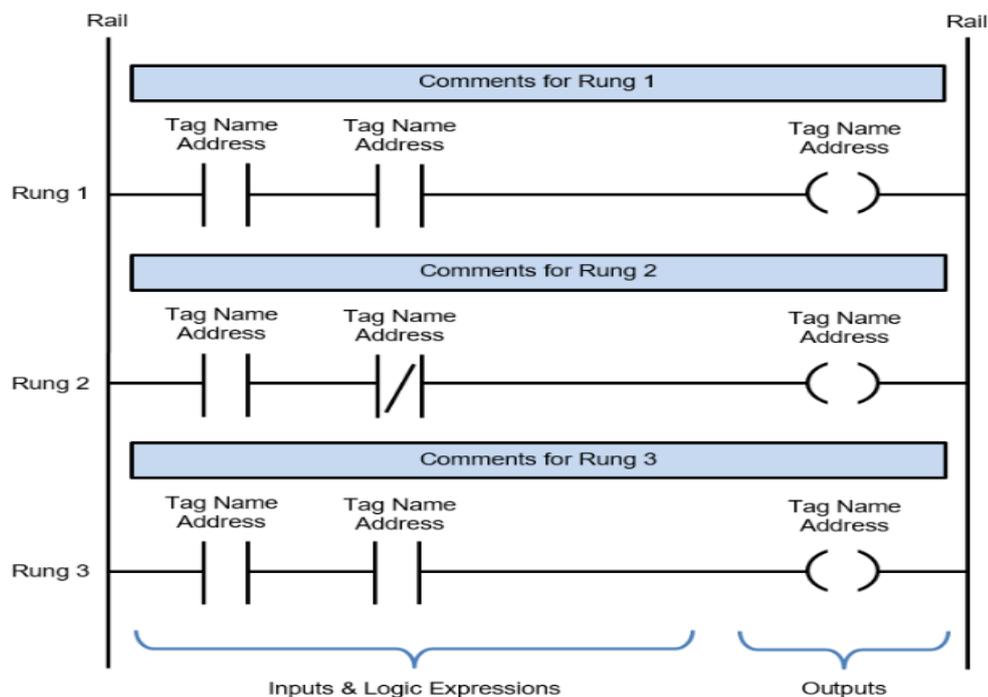
Pressure Switch:

A pressure switch is a form of switch that operates an electrical contact when a certain set fluid pressure has been reached on its input. The switch may be designed to make contact either on pressure rise or on pressure fall. A pressure switch is a mechanical device that relies on air pressure to control the operation of an electric air compressor. This simple mechanism completes the circuit and allows power to the motor as long as system pressure is below a specified setting.

Pressure switches rely on water pressure to do all the work. Open contacts located within the switch, closes when pressure drops. This completes an electrical circuit, which in turn activates the pump. When the set pressure is reached, this allows the contacts to open again which turns off the pump.

A pressure switch for sensing fluid pressure contains a capsule, bellows, Bourdon tube, diaphragm or piston element that deforms or displaces proportionally to the applied pressure. The resulting motion is applied, either directly or through amplifying levers, to a set of switch contacts. Since pressure may be changing slowly and contacts should operate quickly, some kind of over-center mechanism such as a miniature snap-action switch is used to ensure quick operation of the contacts. One sensitive type of pressure switch uses mercury switches mounted on a Bourdon tube; the shifting weight of the mercury provides a useful over-center characteristic.

The pressure switch may be adjustable, by moving the contacts or adjusting tension in a counterbalance spring. Industrial pressure switches may have a calibrated scale and pointer to show the set point of the switch. A pressure switch will have a hysteresis, that is, a differential range around its setpoint, known as the switch's deadband, inside which small changes of pressure do not influence the state of the contacts. Some types allow adjustment of the differential.

The pressure-sensing element of a pressure switch may be arranged to respond to the difference of two pressures. Such switches are useful when the difference is significant, for example, to detect a clogged filter in a water supply system. The switches must be designed to respond only to the difference and not to false-operate for changes in the common mode pressure.

The contacts of the pressure switch may be rated a few tenths of an ampere to around 15 amperes, with smaller ratings found on more sensitive switches. Often a pressure switch will operate a relay or other control device, but some types can directly control small electric motors or other loads.

Since the internal parts of the switch are exposed to the process fluid, they must be chosen to balance strength and life expectancy against compatibility with process fluids. For example, rubber diaphragms are commonly used in contact with water, but would quickly degrade if used in a system containing mineral oil.

Switches designed for use in hazardous areas with flammable gas have enclosure to prevent an arc at the contacts from igniting the surrounding gas. Switch enclosures may also be required to be weatherproof, corrosion resistant, or submersible.

An electronic pressure switch incorporates some variety of pressure transducer (strain gauge, capacitive element, or other) and an internal circuit to compare the measured pressure to a set point. Such devices may provide improved repeatability, accuracy and precision over a mechanical switch.
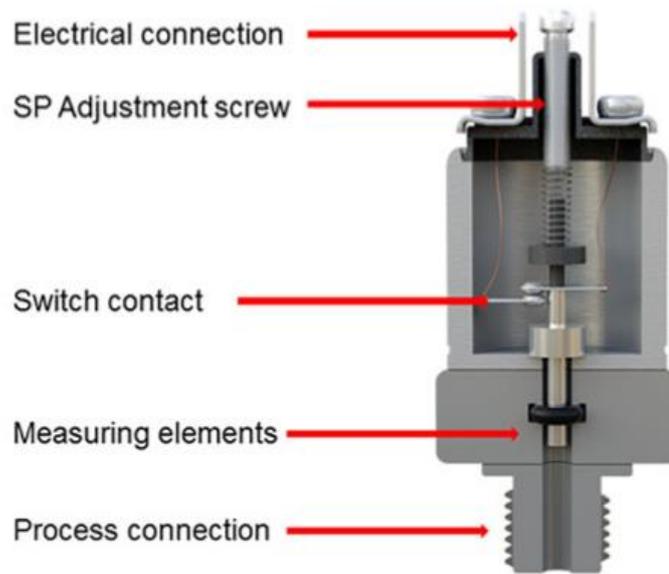
Figure:17:Pressure Switch

Limit Switch

In electrical engineering a **limit switch** is a switch operated by the motion of a machine part or presence of an object. They are used for controlling machinery as part of a control system, as a safety interlocks, or to count objects passing a point. A limit switch is an electromechanical device that consists of an actuator mechanically linked to a set of contacts. When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection.

Limit switches are used in a variety of applications and environments because of their ruggedness, ease of installation, and reliability of operation. They can determine the presence or absence, passing, positioning, and end of travel of an object. They were first used to define the limit of travel of an object; hence the name "Limit Switch".

Standardized limit switches are industrial control components manufactured with a variety of operator types, including lever, roller plunger, and whisker type. Limit switches may be directly mechanically operated by the motion of the operating lever. A reed switch may be used to indicate proximity of a magnet mounted on some moving part. Proximity switches operate by the disturbance of an electromagnetic field, by capacitance, or by sensing a magnetic field.

Rarely, a final operating device such as a lamp or solenoid valve will be directly controlled by the contacts of an industrial limit switch, but more typically the limit switch will be wired through a control relay, a motor contactor control circuit, or as an input to a programmable logic controller.

Miniature snap-action switch may be used for example as components of such devices as photocopiers, computer printers, convertible tops or microwave ovens to ensure internal components are in the correct position for operation and to prevent operation when access doors are opened. A set of adjustable limit switches are installed on a garage door opener to shut off the motor when the door has reached the fully raised or fully lowered position. A numerical

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control machine such as a lathe will have limit switches to identify maximum limits for machine parts or to provide a known reference point for incremental motions.

Figure:18:Limit Switch

Meter in and Meter out Circuit

The difference between the **meter** in circuit and the **meter out** circuit are as follows. 1) In the **meter** in circuit the flow rate goes into the cap end of the cylinder while in the **meter out** circuit the flow rate comes **out** of the rod end of the cylinder. With a meter-out circuit, a flow-control valve is installed on the return side of a cylinder so that it controls a cylinder's actuation by metering its discharge flow. A relief valve is set slightly above the operating pressure that is required by the type of work. Meter-in is a method by which a flow control valve is placed in a hydraulic circuit in such a manner that there is a restriction in the amount of fluid flowing to the actuator. But with an overrunning load over which the actuator has no control, the cylinder begins to cavitate. An essential rule of thumb in Fluid Power is, "when in doubt, meter out." This phrase means that if you do not know the complete application circuit but need to control it, do it by regulating the fluid flow out of the actuator. The metering valve holds back fluid to the front brakes until enough pressure is created to overcome the return springs inside the rear drums. It is also known as a "metering block." The metering valve is plumbed into the system immediately after the Master Cylinder.

Meter Out

In the meter-out operation shown in Figure, the direction of the flow through the circuit is simply changed as can be made out from the diagram. It is the opposite of a meter-in operation as this change in direction will cause the fluid leaving the actuator to be metered. The advantage with the meter-out operation is that unlike in the case of meter-in operation, the cylinder here is prevented from overrunning and consequent cavitating.

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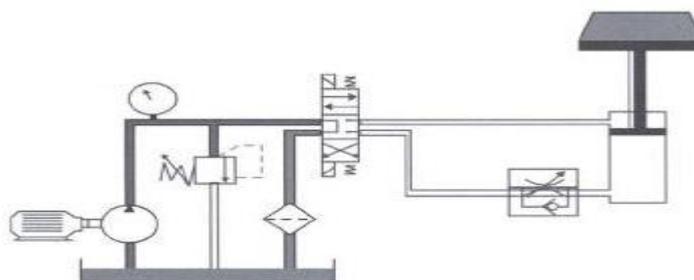
Figure:19: Meter Out

One major problem confronting the meter-out operation is the intensification of pressure in the circuit which can in turn occur on account of a substantial differential area ratio between the piston and the rods. Pressure intensification occurs on the rod side when the meter-out operation is carried out without a load on the rod side of the cylinder and can result in failure of the rod seals. It is therefore seen that both the meter-in and meter-out operations have their relative advantages and disadvantages and only the application determines the type and nature of flow valve placement.

Meter in

With this circuit, a flow-control valve is installed in a pressure line that leads to a work cylinder. All flow entering a work cylinder is first metered through a flow-control valve. Since this metering action involves reducing flow from a pump to a work cylinder, a pump must deliver more fluid than is required to actuate a cylinder at the desired speed. Excess fluid returns to a tank through a relief valve. To conserve power and avoid undue stress on a pump, a relief valve's setting should be only slightly higher than a working pressure's, which a cylinder requires. A meter-in circuit is ideal in applications where a load always offers a positive resistance to flow during a controlled stroke. Examples would be feeding grinder tables, welding machines, milling machines, and rotary hydraulic motor drives. A flow-control-and-check valve used in this type of circuit would allow reverse free flow for the return stroke of a cylinder, but it would not provide control of return stroke speed.
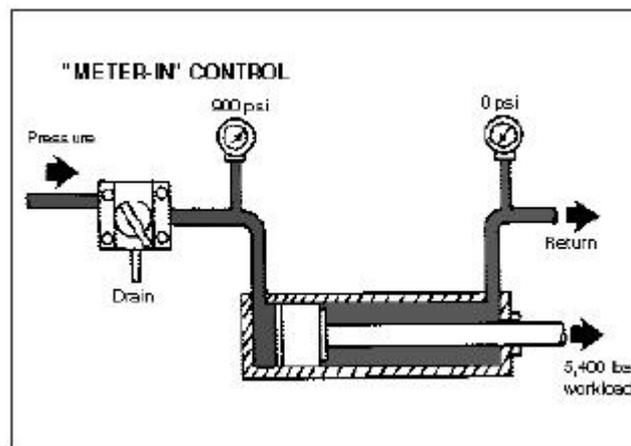
Figure:20: Meter in Circuit

Vehicle Suspension Systems

Suspension is the system that connects a vehicle to its **wheels** and allows relative motion between the two. Suspension includes **springs, shock absorbers, linkages, wheels** and **tires. The main purpose of suspension** is supporting both road holding and ride quality. Suspension system affects on the vehicle handling too. It is very important to keep the road wheel in contact with the road surface, for the suspension.

There are different ways of attaching the wheels of the car so that they can move up and down on their springs and dampers. The design of front suspension and design rear suspension have some differences to the ability of opposite wheels to move independently of each other.

For front-wheel drive cars, rear suspension has few constraints and a variety of beam axles and independent suspensions are used. For rear-wheel drive cars, rear suspension has many constraints and the development of the superior but more expensive independent suspension layout has been difficult.

Four-wheel drive cars often has suspensions that are similar for both the front and rear wheels.The design of independent and dependent suspension have some differences to the ability of opposite wheels to move independently of each other, so suspensions classified in two types:

Type of suspension:

Dependent suspension;

Independent suspension.
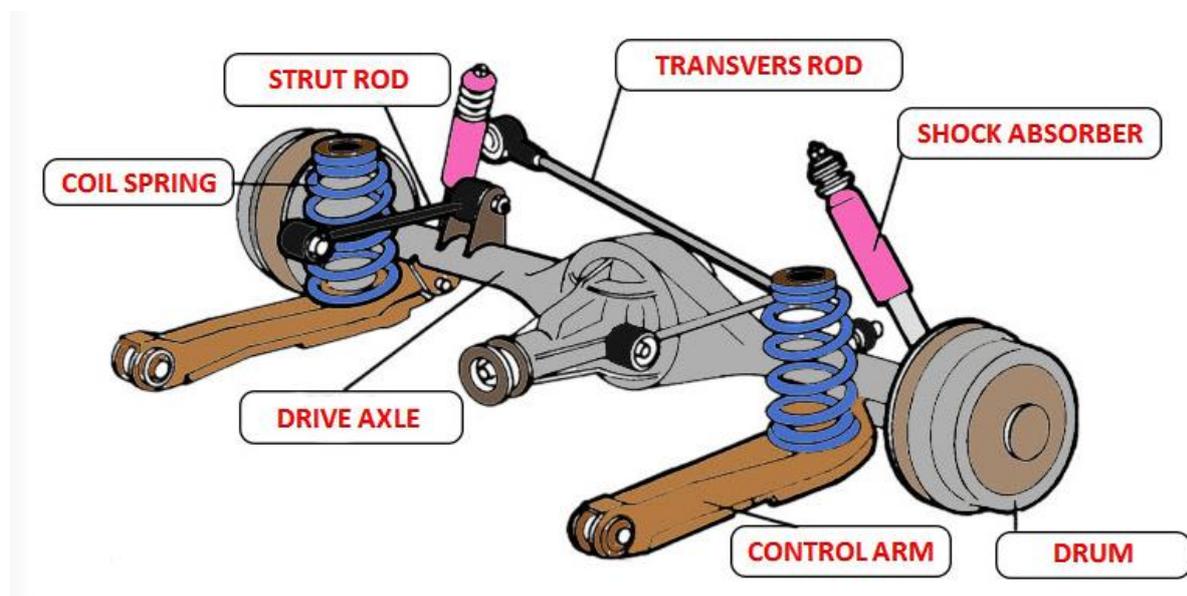
Figure:21:Vehicle Suspension System

Hydraulic Press

Joseph Bramah (13 April 1748 – 9 December 1814), born Stainborough Lane Farm, Stainborough, Barnsley Yorkshire, was an English inventor and locksmith. He is best known for having invented the hydraulic press. Along with William George Armstrong, he can be considered one of the two fathers of hydraulic engineering. Hydraulic presses are commonly used for forging, clinching, moulding, blanking, punching, deep drawing, and metal forming operations. The hydraulic press is advantageous in manufacturing, it gives the ability to create more intricate shapes and can be economical with materials. A hydraulic press works on the principle of Pascal's law, which states that when pressure is applied to a confined fluid, the pressure change occurs throughout the entire fluid. Within the hydraulic press, there is a piston that works as a pump, that provides a modest mechanical force to a small area of the sample.

Hydraulic press are reliable and accurate because they are based on Pascal's law which says that: Pressure on a confined fluid is transmitted undiminished and acts with equal force on equal areas and at 90 degrees to the container wall. A hydraulic press has all of the essential components of a basic hydraulic system. It has a set of cylinders, punches (or pistons), hydraulic pipes that move the fluid, and a die (or anvil). The pistons use liquid under pressure to push on the anvil with a high level of force.
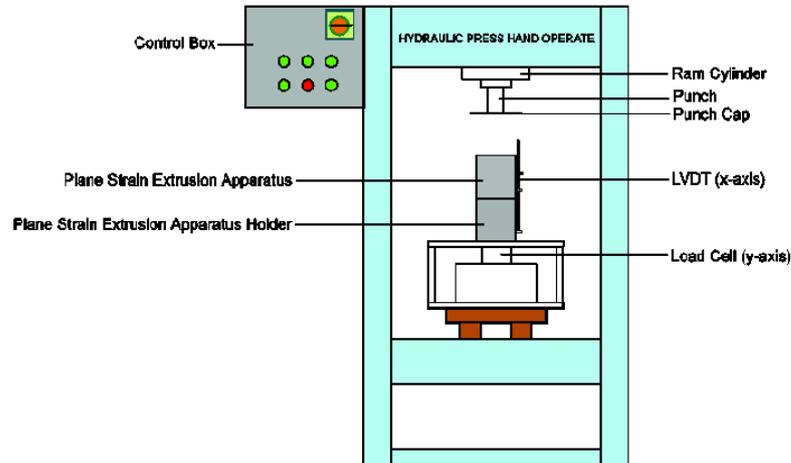
Figure:22: Hydraulic Press

Hydraulic Copying Machine

The introduction of the technique of copying on production lathes and other machine tools represents an important stage in the development of automation of machine tools. There has been a tremendous increase in the saving of labour required for the production of certain components by the copying method.

Everyone knows that the setting and control of machines by means of hydraulic, pneumatic, electric and combined systems of cycle automations are designed for high versatility and a wide range of adjustments. The dynamic features, space and weight reduction, high accuracy, remote control facilities, low price, etc., are added advantages of hydro-copying systems. We get a very high power-to-weight ratio and thus reduced construction and installation costs.

Consequently, the hydraulic control copying machines have conquered the field of small and medium size machines with particularly high rates of feeds. As regards the work, incomparable setting simplicity, higher dimensional stability of products coupled with higher chip flows, better surface finish and, in particular, fidelity of shape are the significant features obtained by the use of hydro-copying machines.

A hydraulic system consists of pumps delivering oil under pressure to operate cylinders, and serves mainly to obtain reciprocating motions. Control devices set up the magnitude and direction of travel of the various units, as well as the sequence of their operations within the working cycle.

As distinct from mechanical systems, hydraulic devices do not have rigid transmission ratios between the driven and driving elements. Mineral lubricating oil is used for the movements of tables in copying units, for self-clamping devices and indexing units. Here we will consider the hydro-copying methods alone.

Hydro-copying units are extensively used in automatic lathes to turn the contours on a work piece to the profiles of a template. The tracer (or stylus) of the copying unit operates a hydraulic valve in a hydraulic system.

In combination with the longitudinal movement of the saddle, effected by mechanical or hydraulic means, the stylus follows the profile of the template and operates the control valve that admits or exhausts oil under pressure on either end of a piston, which transmits its motion to the tool slide. The advantage of these systems over mechanical type includes the magnitude of the force (very small) acting upon the tracing stylus which controls the valve. Inspite of the number of advantages, the hydraulic feeding system has a few drawbacks of its own. Frictional losses in the fluid, internal and external leakages, the variation, in the supply of liquid, and the varying speed of the mechanisms due to fluctuations of temperature, viscosity of the fluid and other factors, like the compressibility of the fluid, leakage of air into the system, heating of the hydraulic fluid, the in-flammability of the oils, etc., are some of the shortcomings. Except for the fluctuation in the feed rates, all other defects can easily be avoided or compensated by a discriminating selection of designs of hydraulic circuits. The fluctuations in feed rates of a hydraulically driven feed device are eliminated by the mechanically controlled piloting system, thus eliminating the defects of instability and irregularity. When turning with copying lathe, the spindle speed and the rate of feed must constantly be adjusted so that both the steadiness of the cutting speed and the constant feed increment per revolution of the chuck are maintained, regardless of the tool position with relation to the centre of rotation of the work piece, i.e. if the hydraulic feed is constant and independent of the spindle speed, the feed per revolution can suffer considerable changes in machining stepped parts and hence it should be adjusted accordingly.
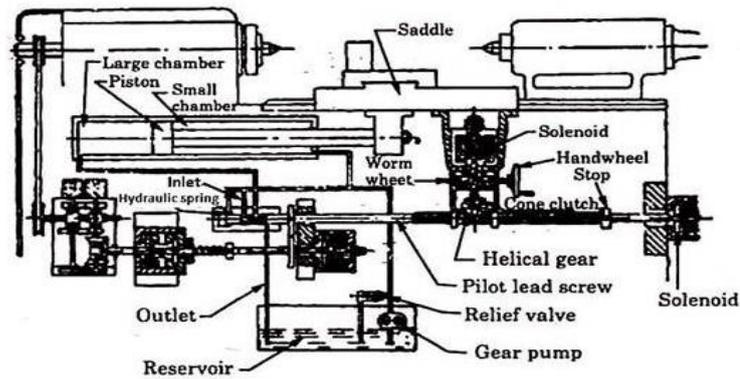
Figure:23: Hydraulic Copying Machine

Hydraulic Cranes:

A hydraulic crane is a type of heavy-duty equipment used for lifting and hoisting. Unlike smaller cranes, which rely on electric or diesel-powered motors, hydraulic cranes include an internal hydraulic system that allows the crane to lift heavier loads.

The pressurized hydraulic fluid pushes the piston in and out of the cylinder, allowing the piston to lift or move a load. With hydraulic systems in cranes, there are typically two different pistons. When one piston is compressed, the displaced oil forces the other piston to extend.

The basic idea of all hydraulic systems is that force applied at one point is transmitted through a fluid to another point. In order for this to work, the fluid (which is usually oil) must be incompressible, meaning its volume should not change when pressure is applied. Piping and cylinders within the system can be structured and altered in many different ways to achieve specific results. The initial force applied can be multiplied in the process, allowing for applications such as the lifting of heavy loads. This is because piping within the system can be any length or shape, and it can fork so that one applied force can drive several cylinders.

Essential components of a hydraulic system

- Reservoir oil tank.
- Piping.
- Hydraulic pump.
- Power source.
- Actuator.
- Valves.
- Filters.

1. Reservoir Oil Tank

The reservoir holds the incompressible fluid, which is usually hydraulic oil. It also protects the fluid from getting contaminated, which is critical to ensure the hydraulic system functions optimally.

2. Piping

Piping is simply, but importantly, the hollow structures that carry the hydraulic fluid from one location to another within the system.

3. Hydraulic Pump

The role of hydraulic pumps is to force the hydraulic fluid from the reservoir to the rest of the circuit. Firstly, the pump creates a vacuum at the pump inlet which forces the fluid from the reservoir into the pump. Next, the pump pushes the fluid to the pump outlet and then forces it into the rest of the hydraulic system.

Figure:24: Hydraulic Cranes

Earth Moving Equipment:

Heavy equipment is essential for construction jobs of almost any size, from home building to large-scale commercial and civil projects. Earth-moving equipment covers a broad range of machines that can excavate and grade soil and rock, along with other jobs. Earth movers and other heavy equipment help to speed not only earth work but also materials handling, demolition, and construction. Many types of heavy construction equipment are designed for multiple functions, making them indispensable on job sites. Earthmoving equipment is heavy equipment, typically heavy-duty vehicles designed for construction operations which involve earthworks. They are used to move large amounts of earth, to dig foundations for landscaping and so on. Most earthmoving equipment uses hydraulic drives as the primary source of motion. Earthwork operations involve processes such as excavating, hauling, dumping, crushing and compacting soil. Activities are typically equipment-driven, and most frequently include excavators, loaders, compactors and hauling trucks.

Figure:25:Earth Movers

Excavators:

Excavators are large construction equipment that can be driven by tracks or wheels, but tracks are more standard. A conventional excavator has a long bucket arm attached to a pivoting cab that can rotate a full 360 degrees. The operator sits in the cab and from there has good visibility of the site. Excavators are highly versatile and can be fitted with special attachments for specialty jobs. The most common uses for an excavator include:

- Material handling
- Excavating trenches, holes, and foundations
- Brush cutting with hydraulic attachments
- Demolition
- Rough grading
- Heavy lifting and pipe installation
- Mining
- River dredging

Backhoe Loader:

Backhoe loaders, often called backhoes, have a body that's similar to a farm tractor and include an adjustable shovel in front and a small bucket in the back for digging. Backhoe loaders are considered medium-sized construction equipment for smaller jobs and are capable of working in limited space to perform various operations. They can move dirt, backfill excavations, dig holes and trenches, and place pipes and other materials. One of the best attributes of backhoe loaders is that they are wheel-driven and can be used in urban areas. They can even be driven to a job site. The bucket in the back can be changed to dig trenches of different widths.

Bulldozers:

Bulldozers are considered one of the strongest and most reliable heavy equipment used in the construction industry. A bulldozer is a powerful and extremely heavy machine used to move dirt along large open tracts of land. Bulldozers have a wide, flat blade in front that can be operated using two hydraulic pistons to move the blade in a limited range of angles and depths. They are

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normally used to push piles of earth and for rough or fine grading, depending on the size of the bulldozer. A bulldozer's considerable weight helps it crush large boulders, among other operations.

Skid –Steer Loaders:

Skid-steer loaders are among the most versatile machines available in the construction industry. They are small and nimble and can turn within their own footprint, just like a tank, making them ideal for work in confined spaces or in areas where construction activity has been finalized. Skid-steer loaders are wheel-driven and offer good traction in snow and mud. The wheels also minimize soil compaction and damage to finished areas. These handy loaders come in a few different sizes and can be outfitted with a variety of attachments to perform digging, drilling, compacting, log grappling, snow blowing, jack-hammering, and other tasks.

Motor Graders:

Motor graders are heavy equipment used for fine grading and for moving small amounts of dirt. They have a long blade that can be adjusted to meet certain angles to create a flat surface. They can also be fitted with a second blade in front of the front axle and in some instances can be used for underground mining. Motor graders are typically used to fine-grade dirt or gravel roads or to prepare the road base course before placing asphalt. Graders can also be used to create sloped surfaces or drainage ditches with shallow V-shaped cross-sections.

Crawler Loader:

A crawler loader is a cross between an excavator and a backhoe or bucket loader. Its tracks give it excellent stability, and its versatile bucket makes it useful for moving soil and debris and for loading material onto trucks. Crawler loaders are also used for excavation on relatively small projects. For larger-scale work, a hydraulic excavator is often used instead of a crawler loader.

Trencher:

A trencher is used to dig trenches, usually narrow trenches for piping and cabling. Trenchers come in many different types and sizes, from small walk-behind versions to very large trenching machines that can cut into asphalt pavement and other hard surfaces. The trencher has a conveyor system that carries the excavated material and deposits it onto the ground next to the trench. Trenchers can use different digging implements depending on the depth of the trench and material being excavated.

Dump Trucks

Dump trucks are needed on almost every large job site. They offer limited function but perform the all-important task of moving and dumping many types of heavy material. They are also road-ready so they can bring material into or out of site and can travel anywhere large equipment is permitted.

Dump trucks come in many different sizes for different capacity and load needs, ranging from small utility-type trucks with dumping beds to enormous machines used in mining operations.

UNIT – III – Fluid power systems – SME1302

UNIT 3
PNEUMATIC SYSTEMS

Pneumatic technology deals with the study of behavior and applications of compressed air in our daily life in general and manufacturing automation in particular. Pneumatic systems use air as the medium which is abundantly available and can be exhausted into the atmosphere after completion of the assigned task.

1. Basic Components of Pneumatic System:
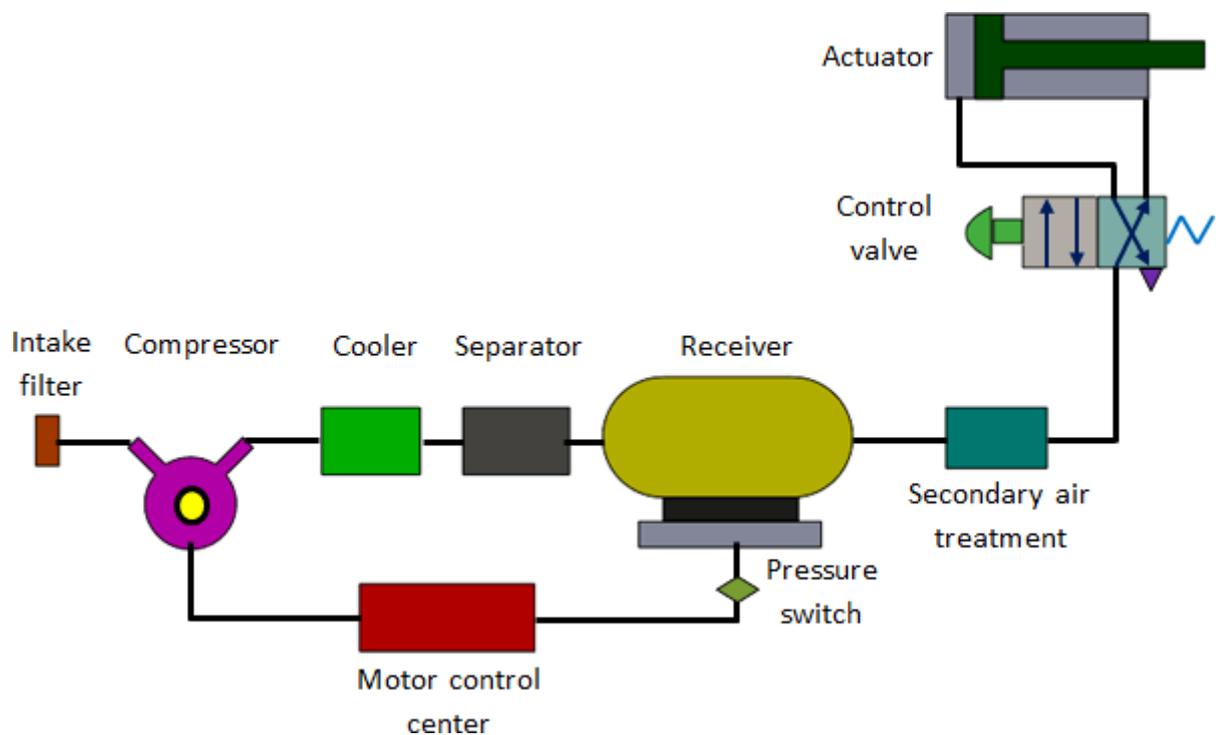
Fig. 1 Components of a pneumatic system

Important components of a pneumatic system are shown in fig. 1.

a) **Air filters:** These are used to filter out the contaminants from the air.
b) **Compressor:** Compressed air is generated by using air compressors. Air compressors are either diesel or electrically operated. Based on the requirement of compressed air, suitable capacity compressors may be used.
c) **Air cooler:** During compression operation, air temperature increases. Therefore coolers are used to reduce the temperature of the compressed air.
d) **Dryer:** The water vapor or moisture in the air is separated from the air by using a dryer.
e) **Control Valves:** Control valves are used to regulate, control and monitor for control of direction flow, pressure etc.
f) **Air Actuator:** Air cylinders and motors are used to obtain the required movements of mechanical elements of pneumatic system.

g) **Electric Motor:** Transforms electrical energy into mechanical energy. It is used to drive the compressor.
h) **Receiver tank:** The compressed air coming from the compressor is stored in the air receiver.

These components of the pneumatic system are explained in detail on the next pages.

2. Receiver tank

The air is compressed slowly in the compressor. But since the pneumatic system needs continuous supply of air, this compressed air has to be stored. The compressed air is stored in an air receiver as shown in Figure 2. The air receiver smoothens the pulsating flow from the compressor. It also helps the air to cool and condense the moisture present. The air receiver should be large enough to hold all the air delivered by the compressor. The pressure in the receiver is held higher than the system operating pressure to compensate pressure loss in the pipes. Also the large surface area of the receiver helps in dissipating the heat from the compressed air. Generally the size of receiver depends on,

* Delivery volume of compressor.
* Air consumption.
* Pipeline network
* Type and nature of on-off regulation
* Permissible pressure difference in the pipelines
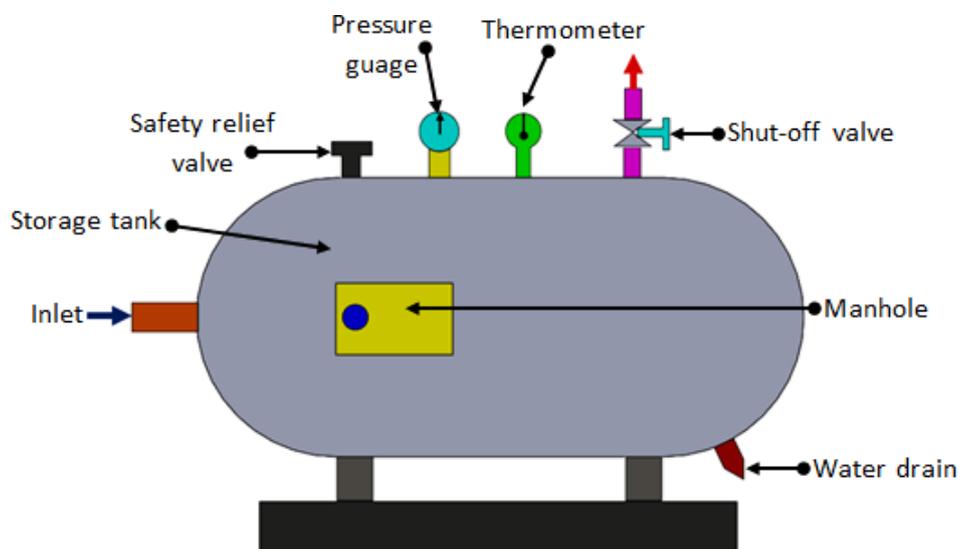
Fig. 2 Air receiver

3. Compressor:

It is a mechanical device which converts mechanical energy into fluid energy. The compressor increases the air pressure by reducing its volume which also increases the temperature of the compressed air. The compressor is selected based on the pressure it needs to operate and the delivery volume.

The compressor can be classified into two main types
      a. Positive displacement compressors and
      b. Dynamic displacement compressor

Positive displacement compressors include piston type, vane type, diaphragm type and screw type.

3.1 Piston compressors
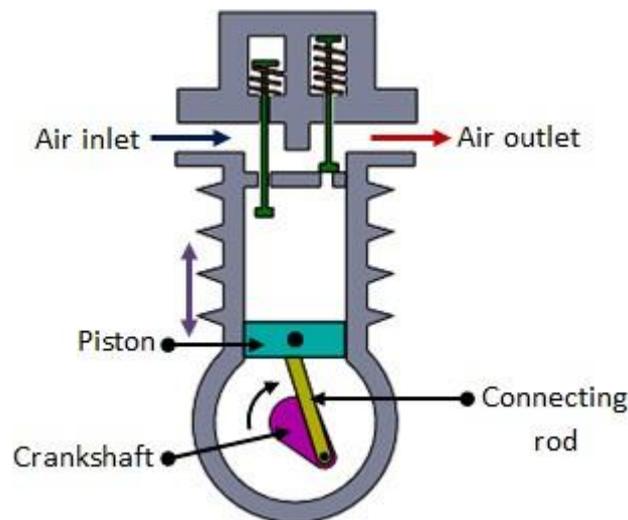
Fig. 3 Single acting piston compressor

Piston compressors are commonly used in pneumatic systems. The simplest form is single cylinder compressor (Fig. 3). It produces one pulse of air per piston stroke. As the piston moves down during the inlet stroke the inlet valve opens and air is drawn into the cylinder. As the piston moves up the inlet valve closes and the exhaust valve opens which allows the air to be expelled. The valves are spring loaded. The single cylinder compressor gives significant amount of pressure pulses at the outlet port. The pressure developed is about 3-40 bar.

3.2 Double acting compressor
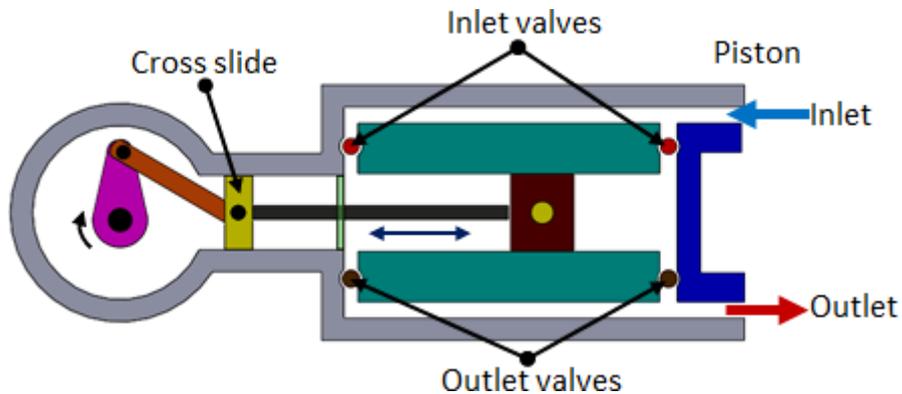
Fig. 4 Double acting piston compressor

The pulsation of air can be reduced by using double acting compressor as shown in Figure 4. It has two sets of valves and a crosshead. As the piston moves, the air is compressed on one side whilst on the other side of the piston, the air is sucked in. Due to the reciprocating action of the piston, the air is compressed and delivered twice in one piston stroke. Pressure higher than 30bar can be produced.

3.3 Multistage compressor
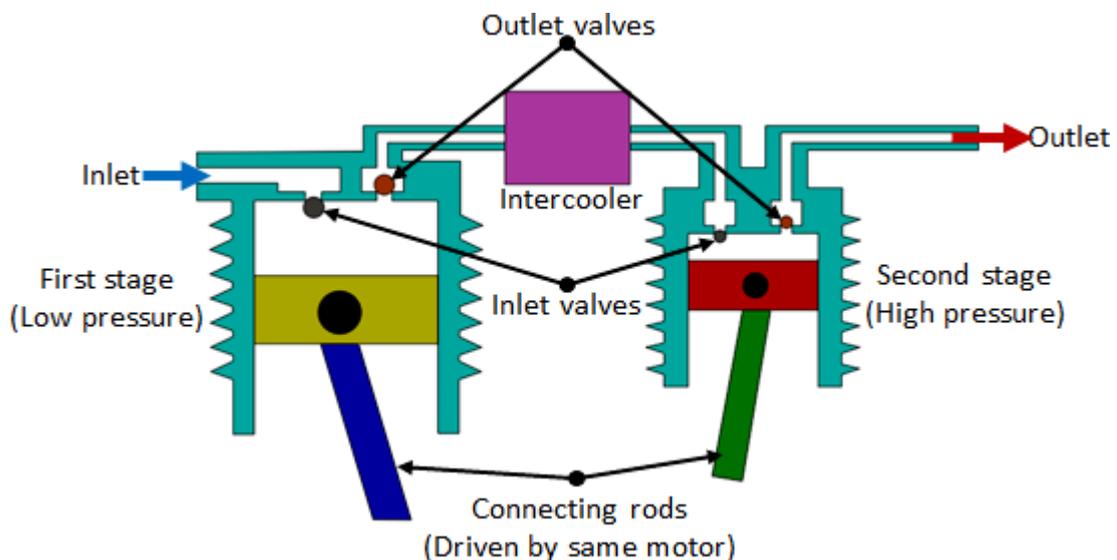
Fig. 5 Multi-stage compressor

As the pressure of the air increases, its temperature rises. It is essential to reduce the air temperature to avoid damage of compressor and other mechanical elements. The multistage compressor with intercooler in-between is shown in Figure.5. It is used to reduce the temperature of compressed air during the compression stages. The inter-cooling reduces the volume of air which used to increase due to heat. The compressed air from the first stage enters the intercooler where it is cooled. This air is given as

input to the second stage where it is compressed again. The multistage compressor can develop a pressure of around 50bar.

3.4 Combined two stage compressors
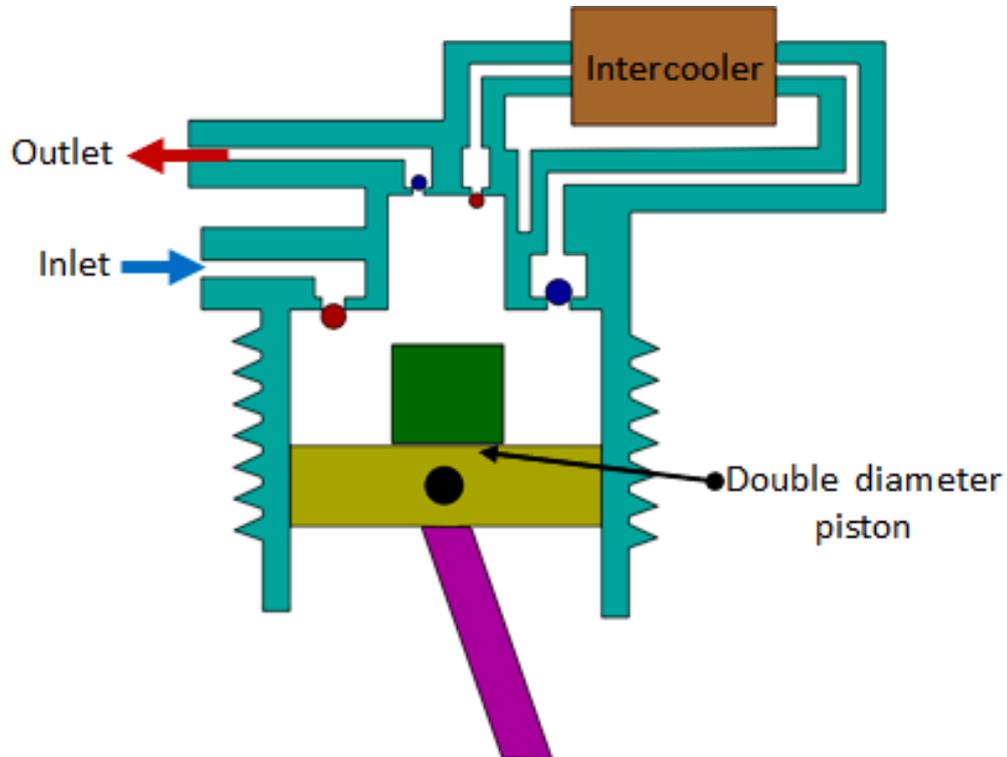
Fig. 6 Combined to stage compressor

In this type, two-stage compression is carried out by using the same piston (Fig. 6). Initially when the piston moves down, air is sucked in through the inlet valve. During the compression process, the air moves out of the exhaust valve into the intercooler. As the piston moves further the stepped head provided on the piston moves into the cavity thus causing the compression of air. Then, this is let out by the exhaust port.

Compressors

1. **Diaphragm compressor**
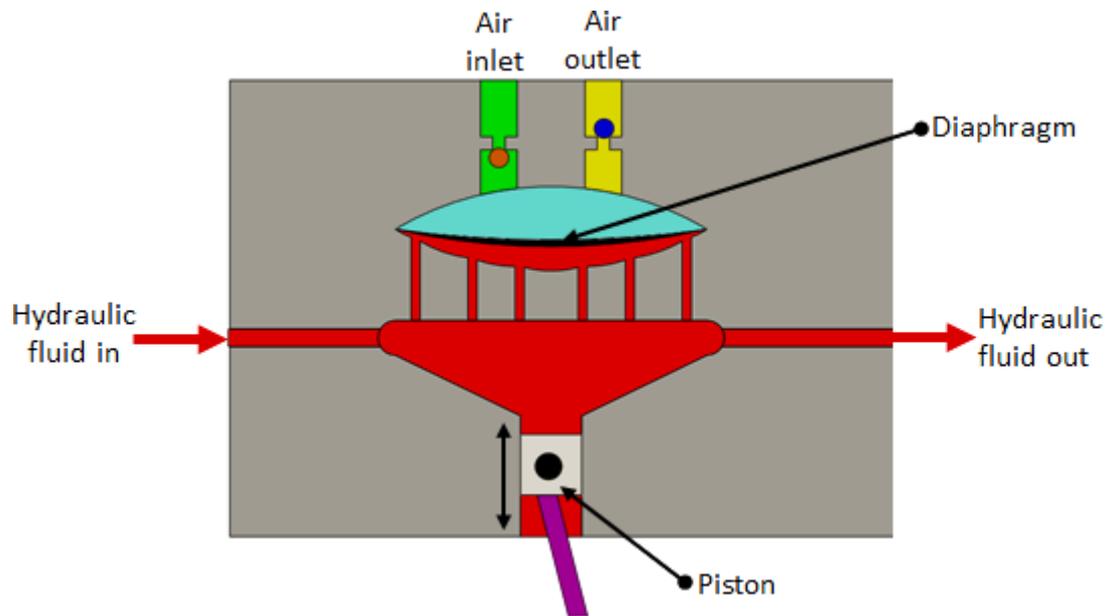
Fig. 7 Diaphragm compressor

These are small capacity compressors. In piston compressors the lubricating oil from the pistons walls may contaminate the compressed air. The contamination is undesirable in food, pharmaceutical and chemical industries. For such applications diaphragm type compressor can be used. Figure 7 shows the construction of Diaphragm compressor. The piston reciprocates by a motor driven crankshaft. As the piston moves down it pulls the hydraulic fluid down causing the diaphragm to move along and the air is sucked in. When the piston moves up the fluid pushes the diaphragm up causing the ejection of air from the outlet port. Since the flexible diaphragm is placed in between the piston and the air no contamination takes place.

2. Screw compressor

Piston compressors are used when high pressures and relatively low volume of air is needed. The system is complex as it has many moving parts. For medium flow and pressure applications, screw compressor can be used. It is simple in construction with less number of moving parts. The air delivered is steady with no pressure pulsation. It has two meshing screws. The air from the inlet is trapped between the meshing screws and is compressed. The contact between the two meshing surface is minimum, hence no cooling is required. These systems are quite in operation compared to piston type. The screws are synchronized by using external timing gears.
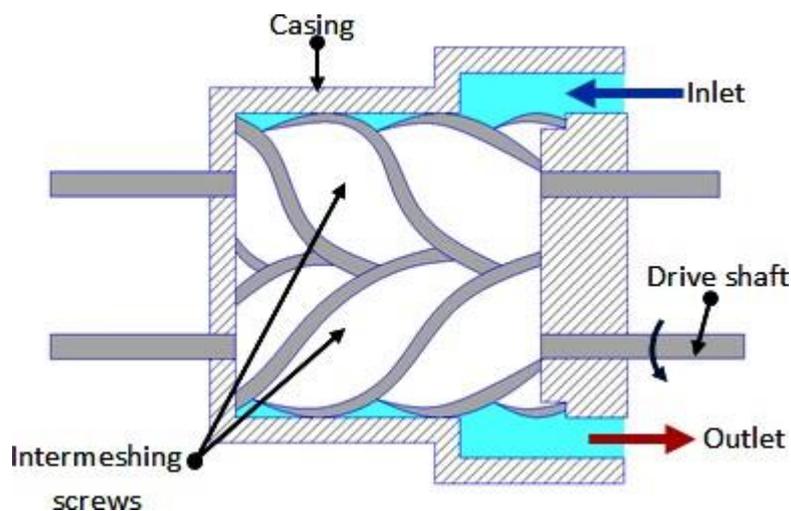
Fig. 8 Screw compressor

3. Rotary vane compressors
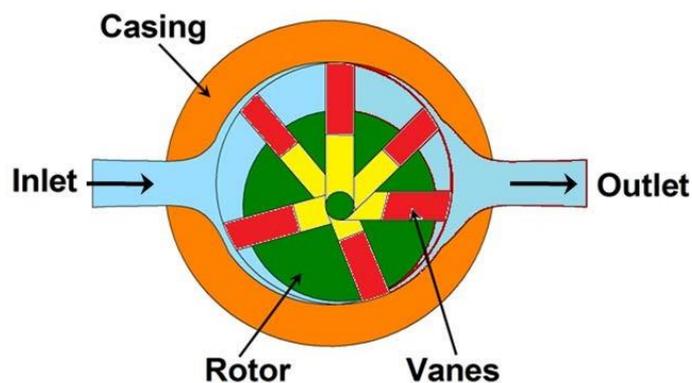
Fig. 9 Rotary vane compressor

The principle of operation of vane compressor is similar to the hydraulic vane pump. Figure 9shows the working principle of Rotary vane compressor. The unbalanced vane compressor consists of spring loaded vanes seating in the slots of the rotor. The pumping action occurs due to movement of the vanes along a cam ring. The rotor is eccentric to the cam ring. As the rotor rotates, the vanes follow the inner surface of the cam ring. The space between the vanes decreases near the outlet due to the eccentricity. This causes compression of the air. These compressors are free from pulsation. If the eccentricity is zero no flow takes place.
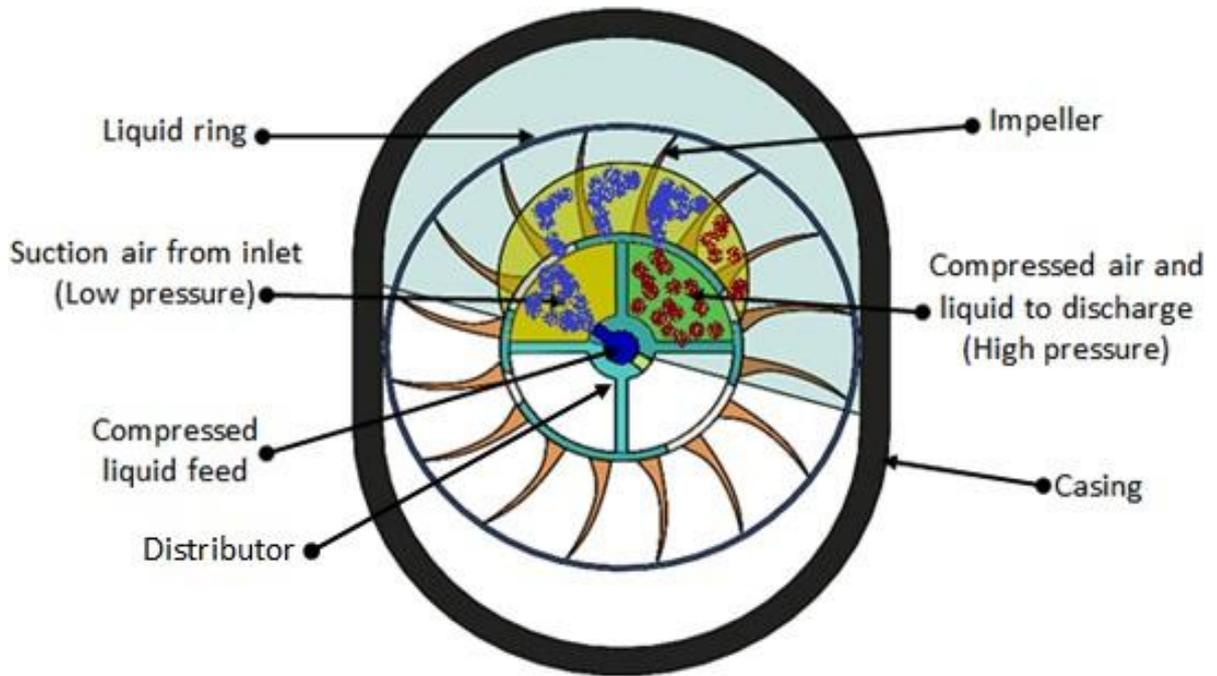
Fig. 10 Liquid ring compressor

Liquid ring vane compressor is a variation of vane compressors. Figure 10 shows the construction of Liquid ring compressor. The casing is filled with liquid up to rotor center. The air enters the compressor through the distributor fixed to the compressor. During the impeller rotation, the liquid will be centrifuged along the inner ring of the casing to form the liquid ring. There are two suction and discharge ports provided in the distributor. During the first quarter of cycle, the air is sucked in both suction chambers of the casing and during the second quarter of the cycle, the air is compressed and pushed out through the two discharge ports. During the third and fourth quarters of the cycle, the process is repeated. This type of compressor has no leakage and has minimal friction. For smooth operation, the rotation speed should be about 3000 rpm. The delivery pressure is low (about 5 bar).

4. Lobe compressor
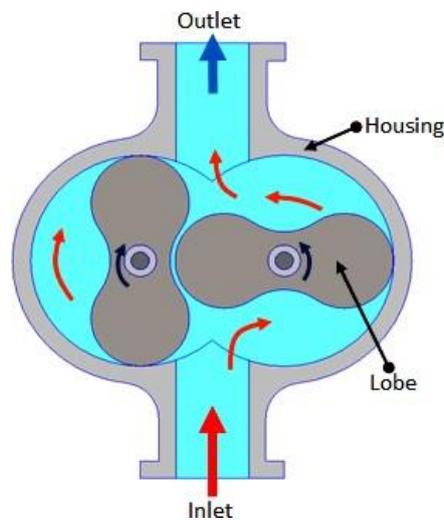
Fig. 11 Lobe compressor

The lobe compressor is used when high delivery volume but low pressure is needed. It consists of two lobes with one being driven and the other driving. Figure 11 shows the construction and working of Lobe compressor. It is similar to the Lobe pump used in hydraulic systems. The operating pressure is limited by leakage between rotors and housing. As the wear increases during the operation, the efficiency falls rapidly.

5. Dynamic compressors
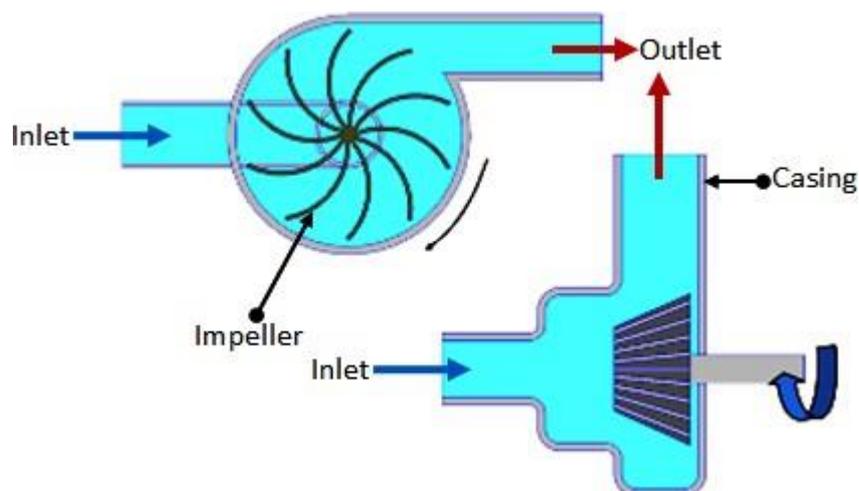
Fig. 12Blower (Centrifugal type)

When very large volume of compressed air is required in applications such as ventilators, combustion system and pneumatic powder blower conveyors, the dynamic compressor can be used. The pressure needed is very low in such applications. Figure 12 shows a typical Centrifugal type blower. The impeller rotates at a high speed. Large volume of low pressure air can be provided by blowers. The blowers draw the

air in and the impeller flings it out due to centrifugal force. Positive displacement Compressors need oil to lubricate the moving parts, whereas the dynamic compressors have no such need. The efficiency of these compressors is better than that of reciprocating types.

Air Treatment and Pressure Regulation

1. **Air treatment stages**

For satisfactory operation of the pneumatic system the compressed air needs to be cleaned and dried. Atmospheric air is contaminated with dust, smoke and is humid. These particles can cause wear of the system components and presence of moisture may cause corrosion. Hence it is essential to treat the air to get rid of these impurities. The air treatment can be divided into three stages as shown in Figure 6.3.1.
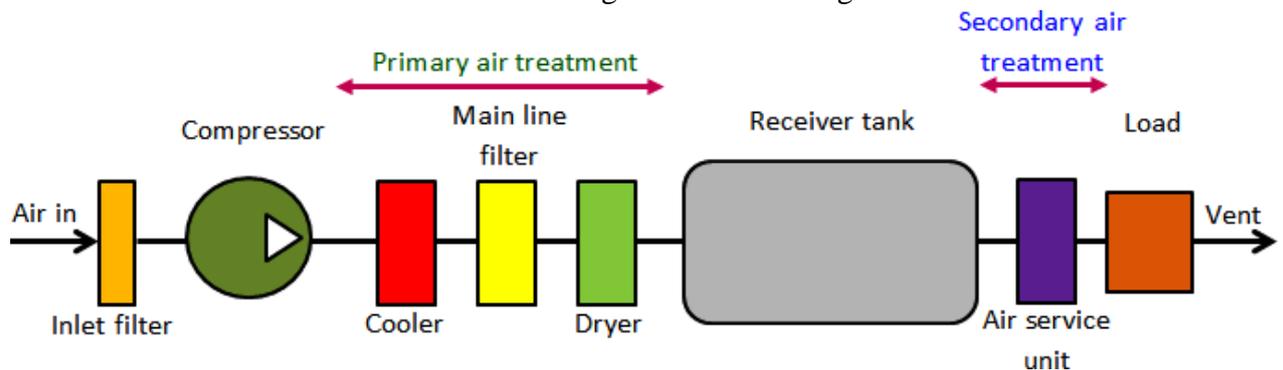
Fig. 6.3.1 Stages of air treatment

In the first stage, the large sized particles are prevented from entering the compressor by an intake filter. The air leaving the compressor may be humid and may be at high temperature. The air from the compressor is treated in the second stage. In this stage temperature of the compressed air is lowered using a cooler and the air is dried using a dryer. Also an inline filter is provided to remove any contaminant particles present. This treatment is called primary air treatment. In the third stage which is the secondary air treatment process, further filtering is carried out. A lubricator introduces a fine mist of oil into the compressed air. This will help in lubrication of the moving components of the system to which the compressed air will be applied.

1.1 Filters

To prevent any damage to the compressor, the contaminants present in the air need to be filtered out. This is done by using inlet filters. These can be dry or wet filters. Dry filters use disposable cartridges. In the wet filter, the incoming air is passed through an oil bath and then through a fine wire mesh filter. Dirt particles cling to the oil drops during bubbling and are removed by wire mesh as they pass through it. In the dry filter the cartridges are replaced during servicing. The wet filters are cleaned using detergent solution.

1.2 Cooler

As the air is compressed, the temperature of the air increases. Therefore the air needs to be cooled. This is done by using a cooler. It is a type of heat exchanger. There are two types of coolers commonly employed viz. air cooled and water cooled. In the air cooled type, ambient air is used to cool the high temperature compressed air, whereas in the water cooled type, water is used as cooling medium. These are counter flow type coolers where the cooling medium flows in the direction opposite to the compressed air. During cooling, the water vapor present will condense which can be drained away later.

2. *Main line filter*

These filters are used to remove the water vapors or solid contaminants present in the pneumatic systems main lines. These filters are discussed in detail as follows.

2.1 Air filter and water trap

Air filter and water trap is used to
- prevent any solid contaminants from entering in the system.
- condense and remove water vapor that is present in the compressed air.
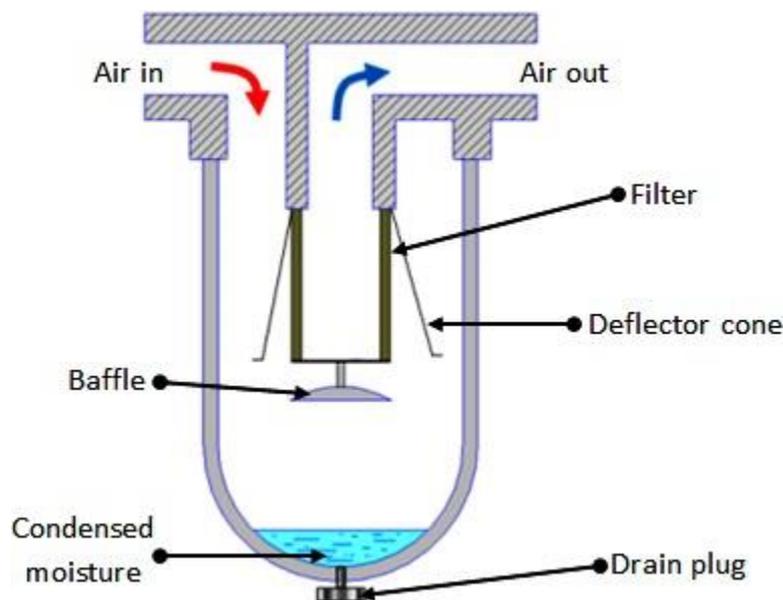
Fig. 6.3.2 Air filter and water trap

The filter cartridge is made of sintered brass. The schematic of the filter is shown in Fig. 6.3.2. The thickness of sintered cartridge provides random zigzag passage for the air to flow-in which helps in arresting the solid particles. The air entering the filter swirls around due to the deflector cone. The centrifugal action causes the large contaminants and water vapor to be flung out, which hit the glass bowl and get collected at the bottom. A baffle plate is provided to prevent the turbulent air from splashing the water into the filter cartridge. At the bottom of the filter bowl there is a drain plug which can be opened manually to drain off the settled water and solid particles.

2.2 Refrigerated dryers
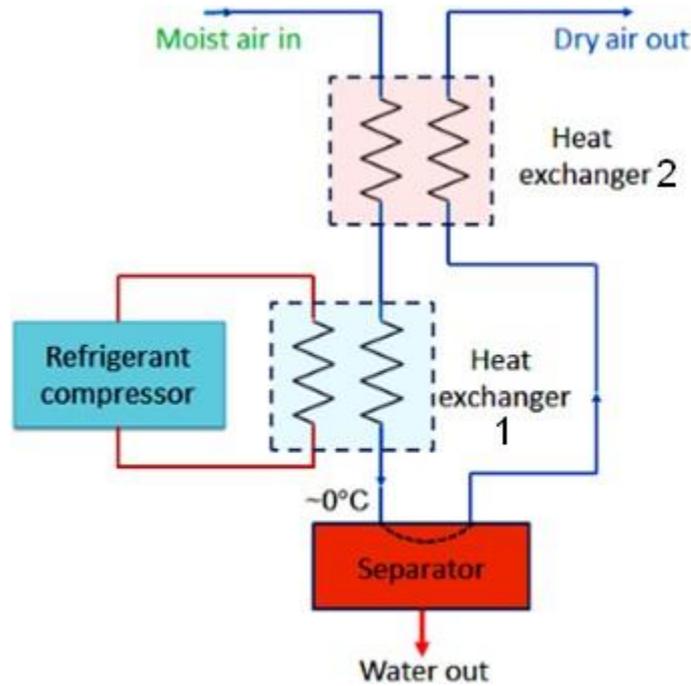
Fig. 6.3.3 Refrigerated dryers

It consists of two heat exchangers, refrigerant compressor and a separator. The system circuitry is shown in Figure 6.3.3. The dryer chills the air just above 0 °C which condenses the water vapor. The condensate is collected by the separator. However such low temperature air may not be needed at the application. Therefore this chilled air is used to cool the high temperature air coming out from the compressor at heat exchanger 2. The moderate temperature dry air coming out from the heat exchanger 2 is then used for actual application; whilst the reduced temperature air from compressor will further be cooled at heat exchanger 1. Thus, the efficiency of the system is increased by employing a second heat exchanger.

2.3 Chemical dryers

When absolute dry air is needed chemical dryers are used. These dryers are of two types viz. adsorption dryer and absorption dryer.

2.3.1 Adsorption dryers
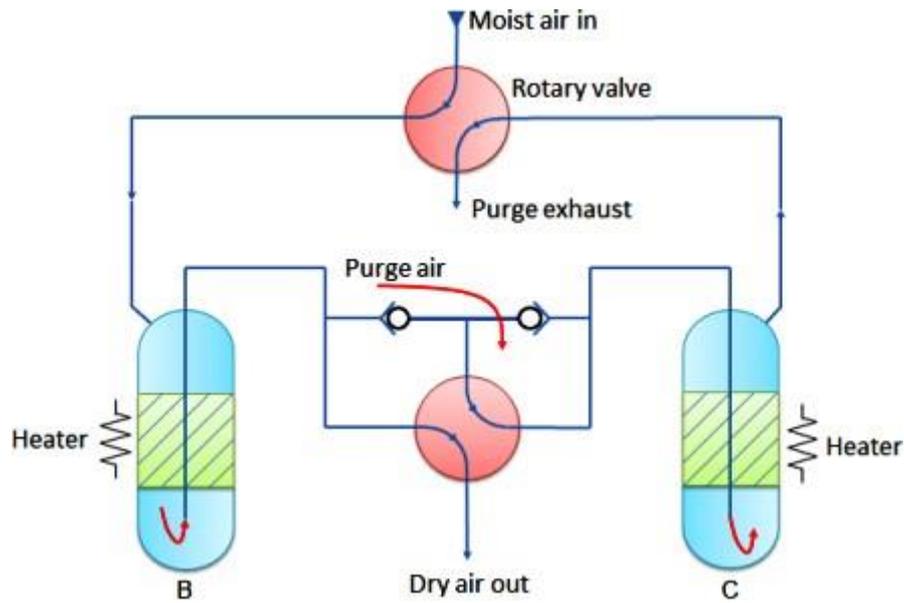
Fig. 6.3.4 Adsorption dryer

In Adsorption dryers, the moisture collects on the sharp edges of the granular material. The adsorbing materials can be silicon dioxide (silica gel) or other materials which exist in hydrated and dehydrated state (copper sulphate, activated alumina). Moisture from the adsorbing material can be released by heating in the column as shown in Fig. 6.3.4. At a given time, one column will dry the air while the other column will regenerate the adsorption material by heating and passing low purge air. The column B dries the air and column C regenerates. The rotary valves are opened using time clock at regular interval to reverse the process. These dryers are also called regenerative dryers.

2.3.2 Absorption dryers

These are also called as deliquescent dryers. Figure 6.3.5 shows a schematic of the same. It uses chemical agents like phosphoric pentoxide or calcium chloride as drying agents. The moisture in the compressed air chemically reacts with the drying agent. The agent dissolves to form a liquid compound which collects at the bottom of the dryer where it can be drained out. The deliquescent agent has to be replenished regularly as it gets consumed during the drying process.
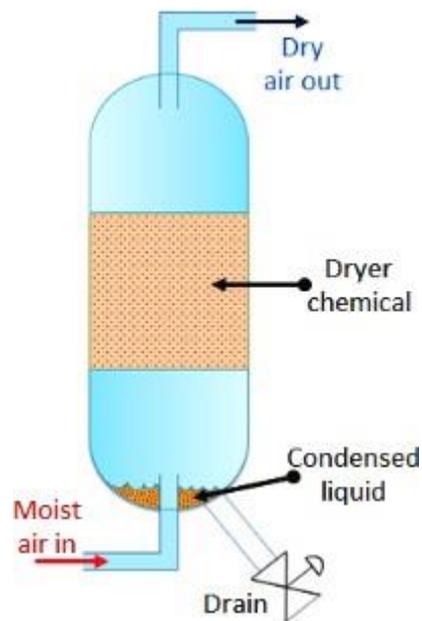
Fig. 6.3.5 Absorption dryer

3. Lubricators
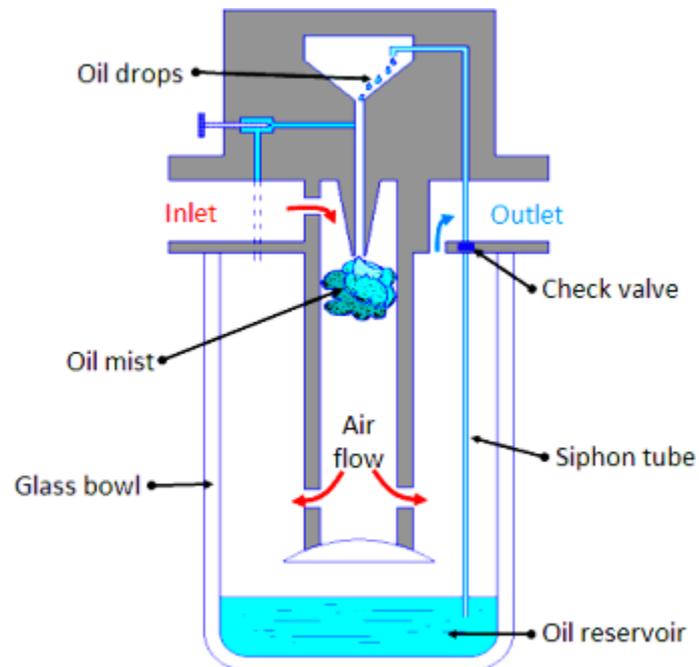
Fig. 6.3.6 Air lubricator

The compressed air is first filtered and then passed through a lubricator in order to form a mist of oil and air to provide lubrication to the mating components. Figure 6.3.6 shows the schematic of a typical lubricator. The principle of working of venturimeter is followed in the operation of lubricator. The compressed air from the dryer enters in the lubricator. Its velocity increases due to a pressure differential between the upper and lower changer (oil reservoir). Due to the low pressure in the upper chamber the oil is pushed into the upper chamber from the oil reservoir through a siphon tube with check valve. The main function of the valve is to control the amount of oil passing through it. The oil drops inside the throttled zone where the velocity of air is much higher and this high velocity air breaks the oil drops into tiny particles. Thus a mist of air and oil is generated. The pressure differential across chambers is adjusted by a needle valve. It is difficult to hold an oil mixed air in the air receiver as oil may settle down. Thus air is lubricated during secondary air treatment process. Low viscosity oil forms better mist than high viscosity oil and hence ensures that oil is always present in the air.

4. Pressure regulation

In pneumatic systems, during high velocity compressed air flow, there is flow-dependent pressure drop between the receiver and load (application). Therefore the pressure in the receiver is always kept higher than the system pressure. At the application site, the pressure is regulated to keep it constant. There are three ways to control the local pressure, these are shown in Figure 6.3.7.
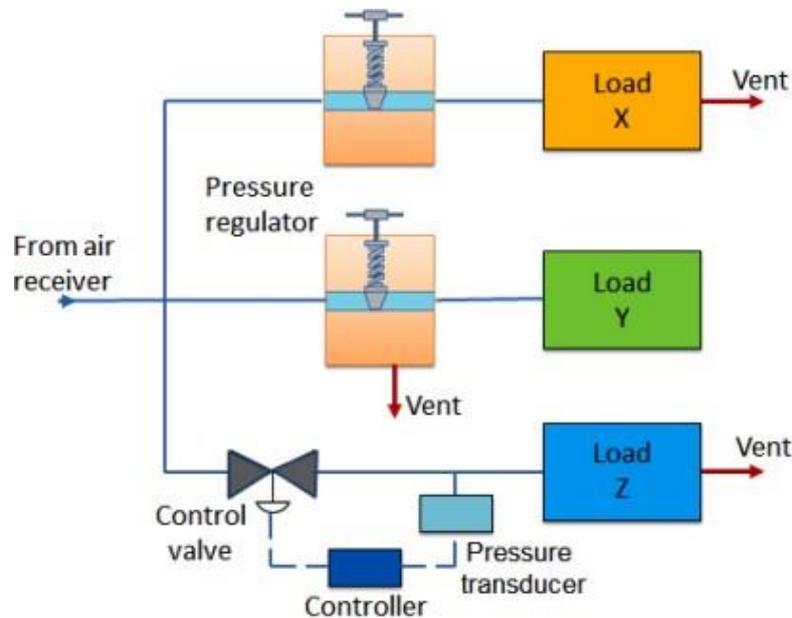
Fig. 6.3.7 Types of pressure regulation

- In the first method, load X vents the air into atmosphere continuously. The pressure regulator restricts the air flow to the load, thus controlling the air pressure. In this type of pressure regulation, some minimum flow is required to operate the regulator. If the load is a dead end type which draws no air, the pressure in the receiver will rise to the manifold pressure. These type of regulators are called as 'non-relieving regulators', since the air must pass through the load.

- In the second type, load Y is a dead end load. However the regulator vents the air into atmosphere to reduce the pressure. This type of regulator is called as 'relieving regulator'.

- The third type of regulator has a very large load Z. Therefore its requirement of air volume is very high and can't be fulfilled by using a simple regulator. In such cases, a control loop comprising of pressure transducer, controller and vent valve is used. Due to large load the system pressure may rise above its critical value. It is detected by a transducer. Then the signal will be processed by the controller which will direct the valve to be opened to vent out the air. This technique can be also be used when it is difficult to mount the pressure regulating valve close to the point where pressure regulation is needed.

5. Relief valve
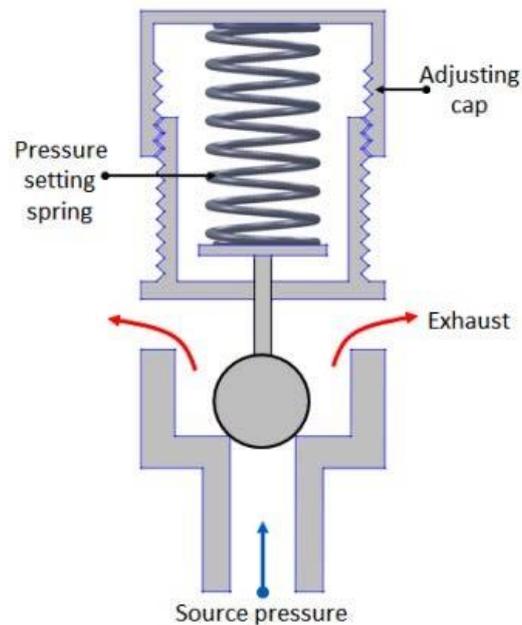
Fig. 6.3.8 Relief valve

Relief valve is the simplest type of pressure regulating device. The schematic of its construction and working is shown in the Figure 6.3.8. It is used as a backup device if the main pressure control fails. It consists of ball type valve held on to the valve seat by a spring in tension. The spring tension can be adjusted by using the adjusting cap. When the air pressure exceeds the spring tension pressure the ball is displaced from its seat, thus releasing the air and reducing the pressure. A relief is specified by its span of pressure between the cracking and full flow, pressure range and flow rate. Once the valve opens (cracking pressure), flow rate depends on the excess pressure. Once the pressure falls below the cracking pressure, the valve seals itself.

6. **Non-relieving pressure regulator**

In a non-relieving pressure regulator (Fig. 6.3.9) the outlet pressure is sensed by a diaphragm which is preloaded by a pressure setting spring. If outlet pressure is too low, the spring forces the diaphragm and poppet to move down thus opening the valve to admit more air and raise outlet pressure. If the outlet pressure is too high the air pressure forces the diaphragm up hence reduces the air flow and causing a reduction in air pressure. The air vents away through the load. At steady state condition the valve will balance the force on the diaphragm from the outlet pressure with the preset force on the spring.
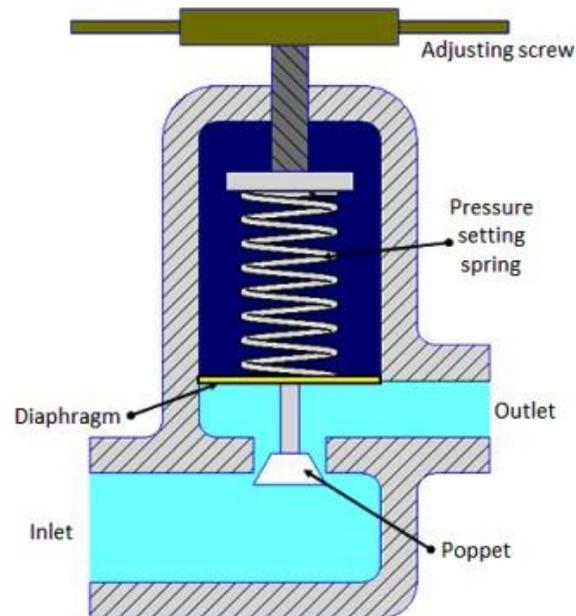
Fig. 6.3.9 Non-relieving type pressure regulator

7. Service units

During the preparation of compressed air, various processes such as filtration, regulation and lubrication are carried out by individual components. The individual components are: separator/filter, pressure regulator and lubricator.

Preparatory functions can be combined into one unit which is called as 'service unit'. Figure 6.3.10 shows symbolic representation of various processes involved in air preparation and the service unit.

(a)   (b)
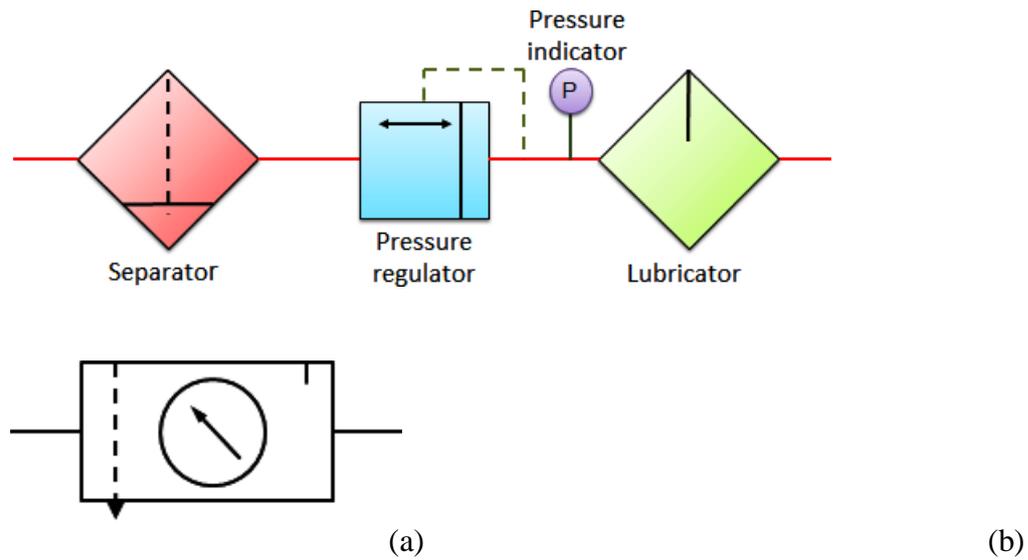
Fig. 6.3.10 (a) Service unit components (b) Service unit symbol

Actuators

Actuators are output devices which convert energy from pressurized hydraulic oil or compressed air into the required type of action or motion. In general, hydraulic or pneumatic systems are used for gripping and/or moving operations in industry. These operations are carried out by using actuators.

Actuators can be classified into three types.

1. Linear actuators: These devices convert hydraulic/pneumatic energy into linear motion.
2. Rotary actuators: These devices convert hydraulic/pneumatic energy into rotary motion.
3. Actuators to operate flow control valves: these are used to control the flow and pressure of fluids such as gases, steam or liquid.

The construction of hydraulic and pneumatic linear actuators is similar. However they differ at their operating pressure ranges. Typical pressure of hydraulic cylinders is about 100 bar and of pneumatic system is around 10 bar.

1. Single acting cylinder
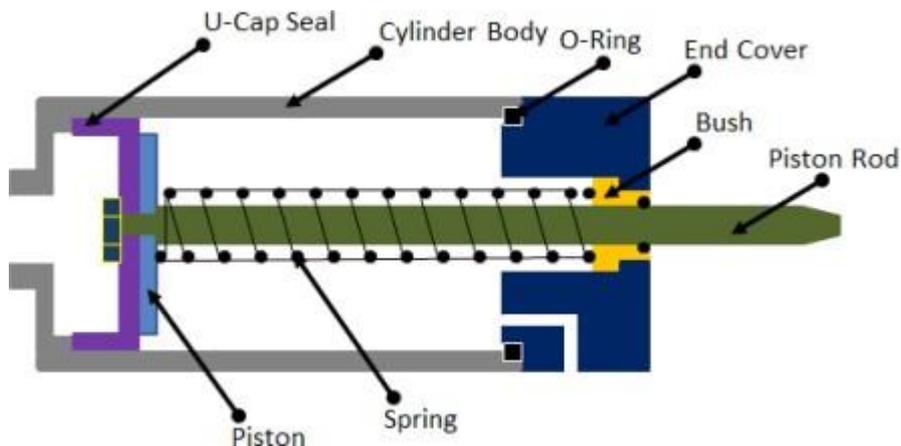
Fig. 6.4.1 Single acting cylinder

These cylinders produce work in one direction of motion hence they are named as single acting cylinders. Figure 6.4.1 shows the construction of a single acting cylinder. The compressed air pushes the piston located in the cylindrical barrel causing the desired motion. The return stroke takes place by the action of a spring. Generally the spring is provided on the rod side of the cylinder.

2. Double acting cylinder
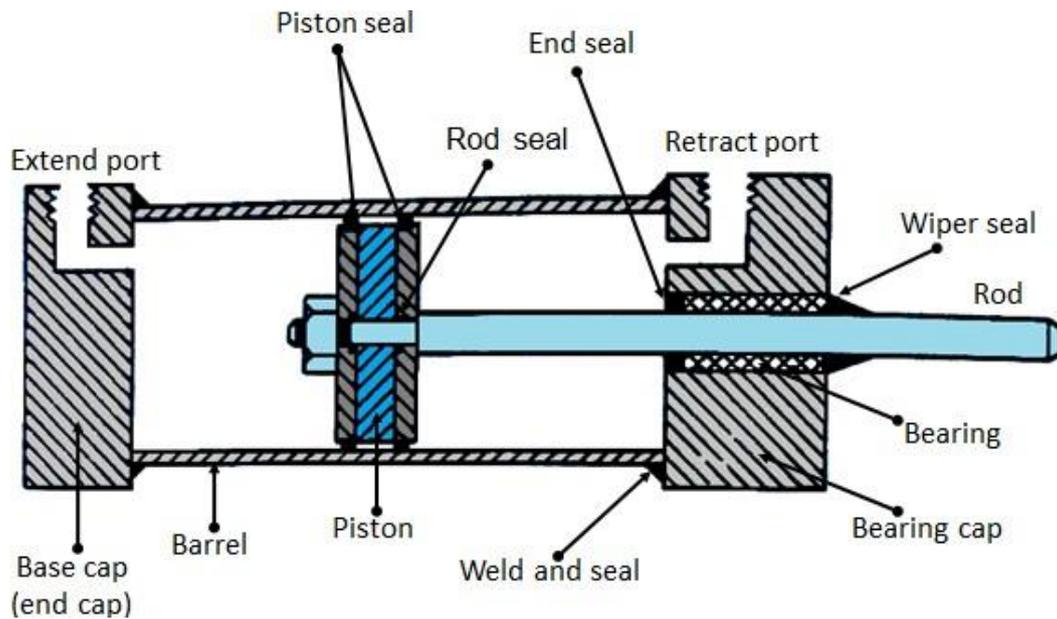
Fig. 6.4.2 Double acting cylinder

The main parts of a hydraulic double acting cylinder are: piston, piston rod, cylinder tube, and end caps. These are shown in Figure 6.4.2. The piston rod is connected to piston head and the other end extends out of the cylinder. The piston divides the cylinder into two chambers namely the rod end side and piston end side. The seals prevent the leakage of oil between these two chambers. The cylindrical tube is fitted with end caps. The pressurized oil, air enters the cylinder chamber through the ports provided. In the rod end cover plate, a wiper seal is provided to prevent the leakage of oil and entry of the contaminants into the cylinder. The combination of wiper seal, bearing and sealing ring is called as cartridge assembly. The end caps may be attached to the tube by threaded connection, welded connection or tie rod connection. The piston seal prevents metal to metal contact and wear of piston head and the tube. These seals are replaceable. End cushioning is also provided to prevent the impact with end caps.

3. **Cylinder end cushions**
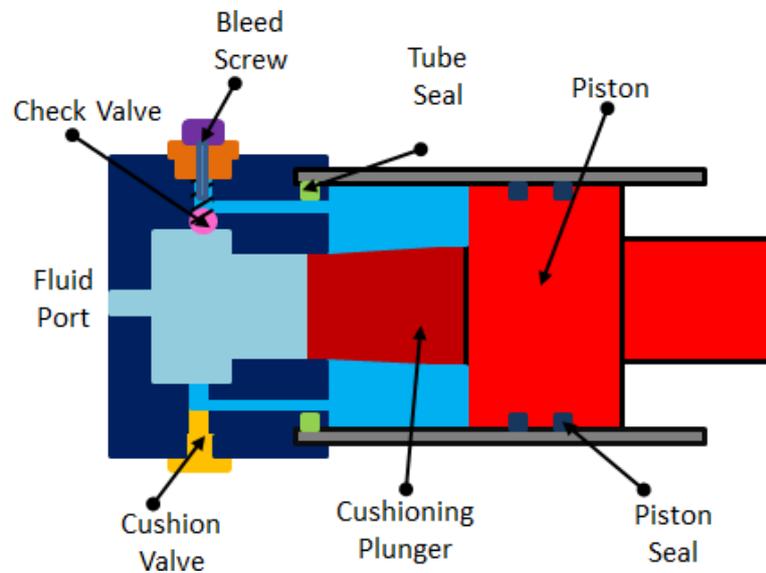
Fig. 6.4.3 Cylinder end cushioning

Double acting cylinders generally contain cylinder cushions at the end of the cylinder to slow down the movement of the piston near the end of the stroke. Figure 6.4.3 shows the construction of actuating cylinder with end cushions. Cushioning arrangement avoids the damage due to the impact occurred when a fast moving piston is stopped by the end caps. Deceleration of the piston starts when the tapered plunger enters the opening in the cap and closes the main fluid exit. This restricts the exhaust flow from the barrel to the port. This throttling causes the initial speed reduction. During the last portion of the stroke the oil has to exhaust through an adjustable opening since main fluid exit closes. Thus the remaining fluid exists through the cushioning valve. Amount of cushioning can be adjusted by means of cushion screw. A check valve is provided to achieve fast break away from the end position during retraction motion. A bleed screw is built into the check valve to remove the air bubbles present in a hydraulic type system.

4. Gear motor: a rotary actuator

Rotary actuators convert energy of pressurized fluid into rotary motion. Rotary actuators are similar to electric motors but are run on hydraulic or pneumatic power.
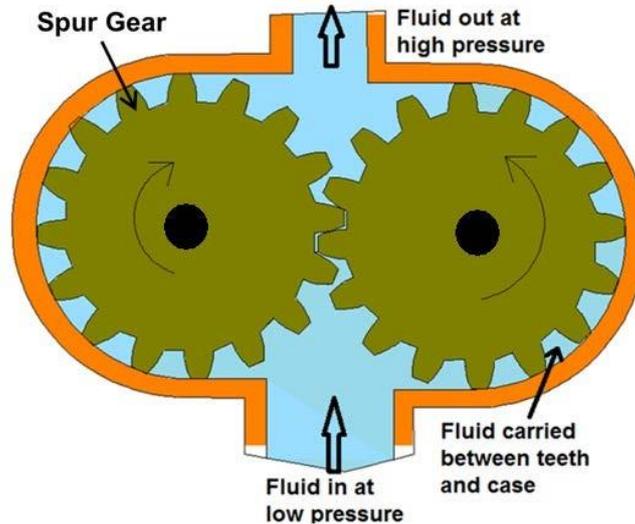
Fig. 6.4.4 Gear motor

It consists of two inter meshing gears inside a housing with one gear attached to the drive shaft. Figure 6.4.4 shows a schematic diagram of Gear motor. The air enters from the inlet, causes the rotation of the meshing gear due to difference in the pressure and produces the torque. The air exists from the exhaust port. Gear motors tend to leak at low speed, hence are generally used for medium speed applications.

5. Vane motor: a rotary actuator

A rotary vane motor consists of a rotor with sliding vanes in the slots provided on the rotor (Fig. 6.4.5). The rotor is placed eccentrically with the housing. Air enters from the inlet port, rotates the rotor and thus torque is produced. Air is then released from the exhaust port (outlet).
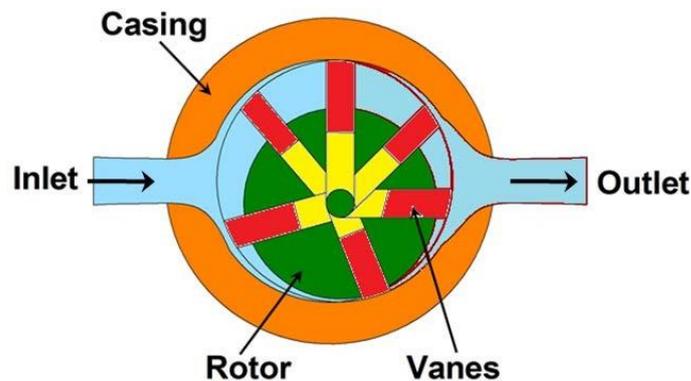
Fig. 6.4.5 Vane motor

6. Limited rotation actuators

It consists of a single rotating vane connected to output shaft as shown in Figure 6.4.6. It is used for double acting operation and has a maximum angle of rotation of about 270°. These are generally used to actuate dampers in robotics and material handling applications. Other type of limited rotation actuator is a rack and pinion type actuator.
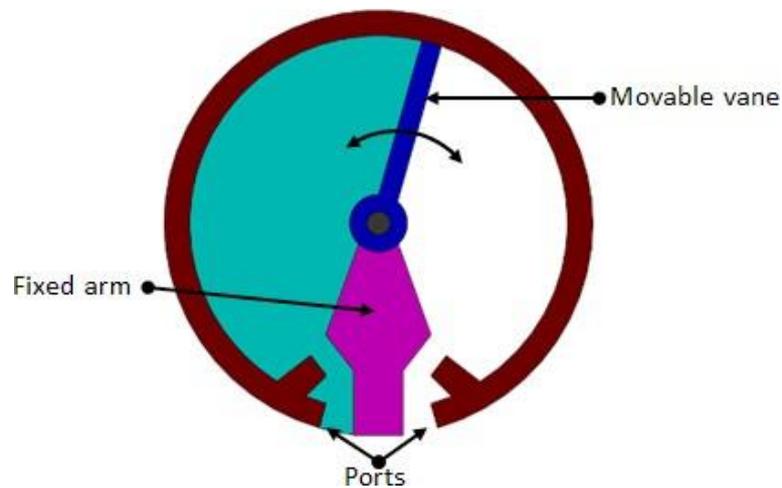
Fig. 6.4.6 Semi rotary vane type actuator

7. Speed control

For an actuator, the operational speed is determined by the fluid flow rate and the cylinder actuator area or the motor displacement. The speed can only be controlled by adjusting the fluid flow to the actuator, because the physical dimension of the actuator is fixed. Since the air is compressible, flow control is difficult as compared to the hydraulic system. There are various ways of controlling the fluid flow. One of the methods is discussed as below-
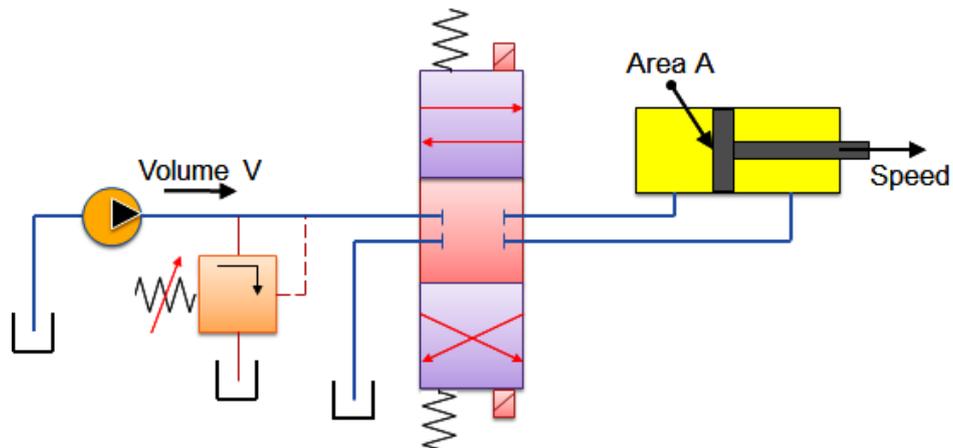
Fig. 6.4.7 Speed control by pump volume

Figure 6.4.7 shows the circuit diagram of hydraulic system developed to control the speed of motion of a piston. Consider a pump which delivers a fluid volume of 'V' per minute. The pump has a fixed displacement. The volume of fluid goes either to the pump or to the actuator. When the direction control valve moves from its center position the actuator of area 'A', the piston moves with a velocity,

$$v = \frac{V}{A} \qquad (6.4.1)$$

If the pump delivery volume 'V' can be adjusted by altering swash plate angle of a piston pump or by using a variable displacement vane pump, no further speed control will be needed.

Pneumatic controllers

In automated industrial processes, it is always essential to keep the process variables such as temperature, flow rate, system pressure, fluid level, etc. at the desired value for safety and economical operation. Consider an example where the flow of water through a pipe has to be kept constant at some predetermined value (Fig. 6.5.1). Let the value of flow to be measured is 'V' (process variable PV). This flow rate is compared with the required flow value say 'V$_1$' (set point SP). The difference between these two values is the error which is sent to the controller. If any error exists, the controller adjusts the drive signal to the actuator, informing it to move the valve to give the required flow (zero error). This type of control system is called closed loop control system. It mainly includes a controller, actuator and a measuring device.
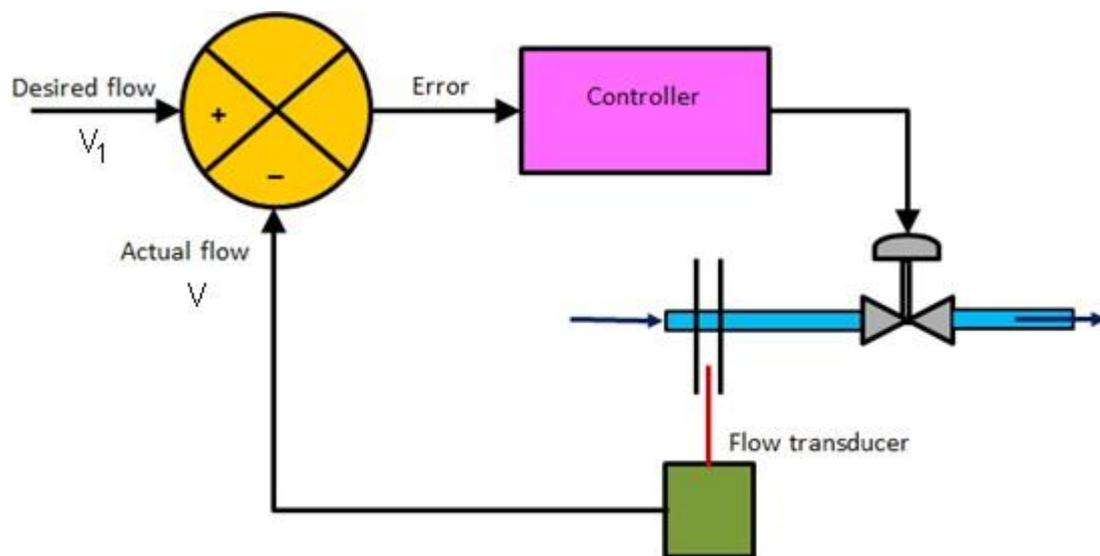
Fig. 6.5.1 Closed loop control system

The control can be achieved by using control electronics or by pneumatic process control. The pneumatic systems are quite popular because they are safe. In the process industries like refinery and chemical plants, the atmosphere is explosive. Application of electronics based systems may be dangerous in such cases. Since the pneumatic systems use air, there are very scant chances of any fire hazards. Even though electrical actuators are available, but most of the valves employed are driven by pneumatic signals.

1. Components of a pneumatic controller

- Flapper nozzle amplifier
- Air relay
- Bellows
- Springs
- Feedback arrangements

1.1 Flapper nozzle amplifier

A pneumatic control system operates with air. The signal is transmitted in the form of variable air pressure (often in the range of 0.2 to 1.0 bar (3-15 psi)) that initiates the control action. One of the basic building blocks of a pneumatic control system is the flapper nozzle amplifier. It converts very small displacement signal (in order of microns) to variation of air pressure. The basic construction of a flapper nozzle amplifier is shown in Figure 6.5.2
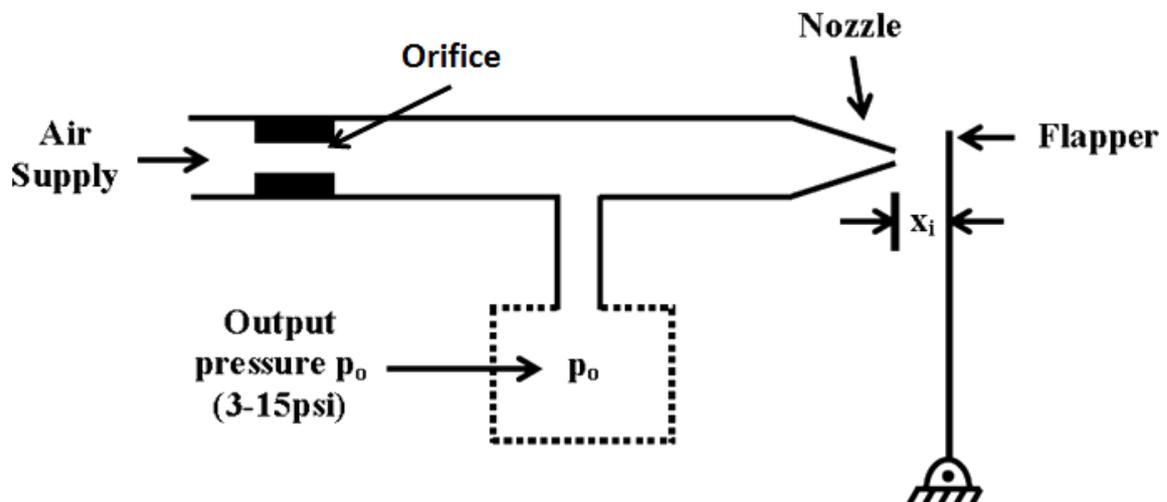
Fig 6.5.2 Nozzle flapper amplifier

Constant air pressure is supplied to one end of the pipeline. There is an orifice at this end. At the other end of the pipe, there is a nozzle and a flapper. The gap between the nozzle and the flapper is set by the input signal. As the flapper moves closer to the nozzle, there will be less airflow through the nozzle and the air pressure inside the pipe will increase. On the other hand, if the flapper moves further away from the nozzle, the air pressure decreases. At the extreme, if the nozzle is open (flapper is far off), the output pressure will be equal to the atmospheric pressure. If the nozzle is blocked, the output pressure will be equal to the supply pressure.

1.2 Air Relay

The major limitation of a flapper nozzle amplifier is its limited air handling capacity. The variation of air pressure obtained cannot be used for any useful application, unless the air handling capacity is increased. It is used after the flapper nozzle amplifier to enhance the volume of air to be handled. The principle of operation of an air relay can be explained using the schematic diagram shown in Figure 6.5.3. It can be seen that the air relay is directly connected to the supply line (no orifice in between). The output pressure of the flapper nozzle amplifier (p_2) is connected to the lower chamber of the air relay with a diaphragm on its top. The variation of the pressure p_2 causes the movement (y) of the diaphragm. There is a double-seated valve fixed on the top of the diaphragm. When the nozzle pressure p_2 increases due to decrees in x_i, the diaphragm moves up, blocking the air vent line and forming a nozzle between the output pressure line and the supply air pressure line. More air goes to the output line and the air pressure increases. When p_2 decreases, the diaphragm moves downwards, thus blocking the air supply line and connecting the output port to the vent. The air pressure will decrease.
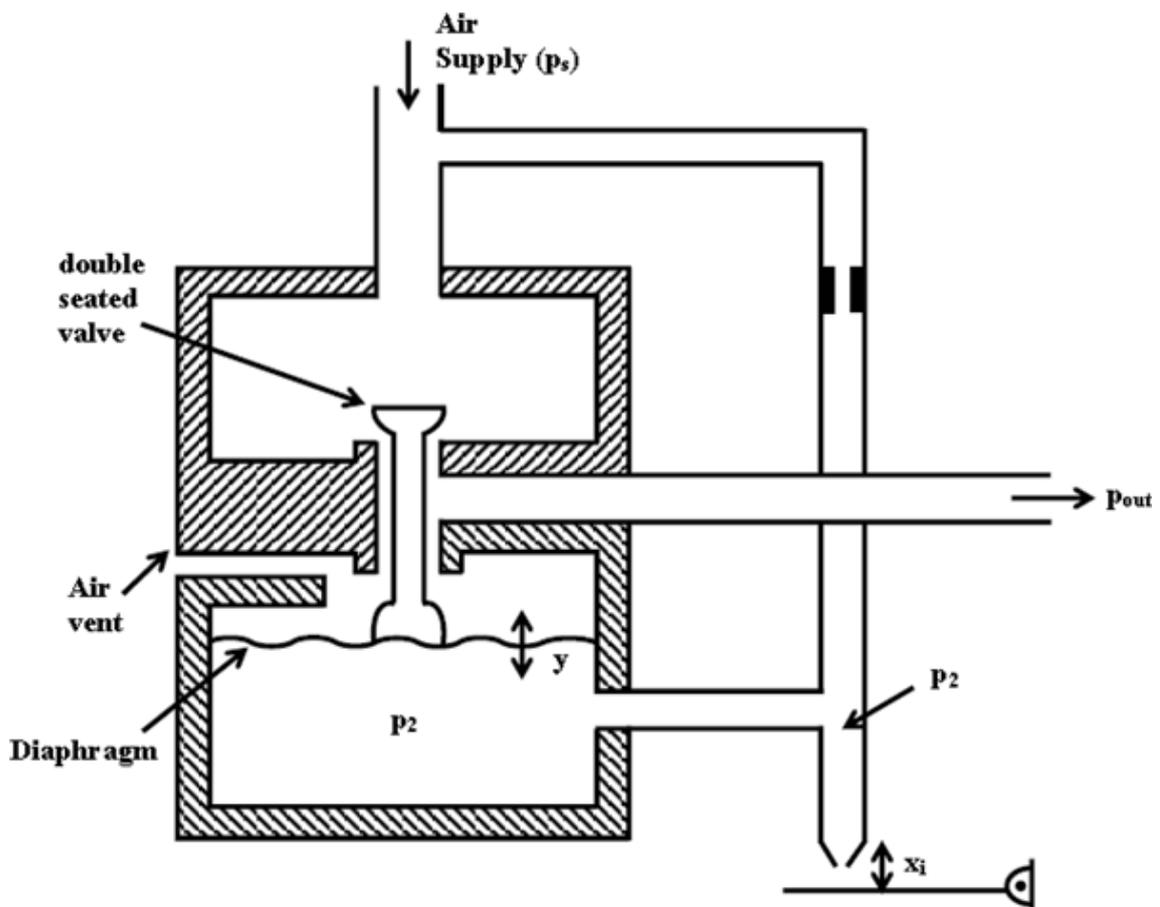
Fig 6.5.3 Air relay

2. Types of pneumatic controllers

Following is the list of variants of pneumatic controllers.

- Proportional only (P) controller
- Proportional-Derivative (PD) controller
- Proportional-Integral (PI) controller
- Proportional-Integral-Derivative (PID) controller

2.1 Proportional only (P) controller

The simplest form of pneumatic controller is proportional only controller. Figure 6.5.4 shows the pneumatic circuit of 'proportional only' controller. The output signal is the product of error signal multiplied by a gain (K).

$$\text{Output} = (\text{Error} * \text{gain})$$
(6.5.1)
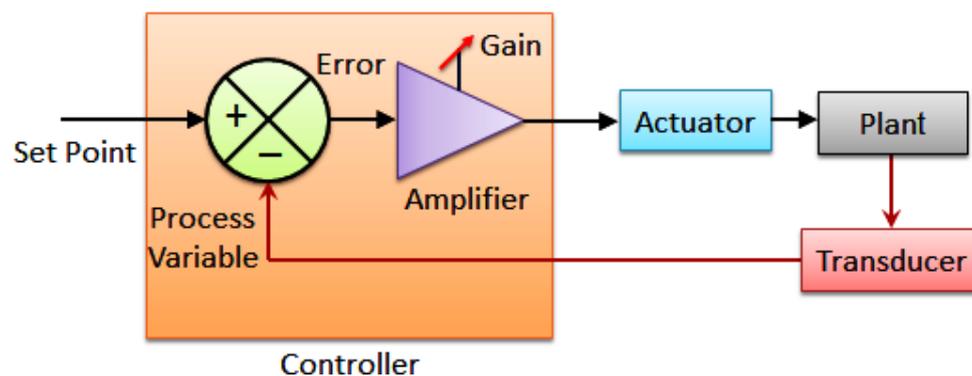
Fig. 6.5.4 Proportional only controller

Consider the pneumatic system consisting of several pneumatic components, viz. flapper nozzle amplifier, air relay, bellows and springs, feedback arrangement. The overall arrangement is known as a pneumatic proportional controller as shown in Figure 6.5.5.
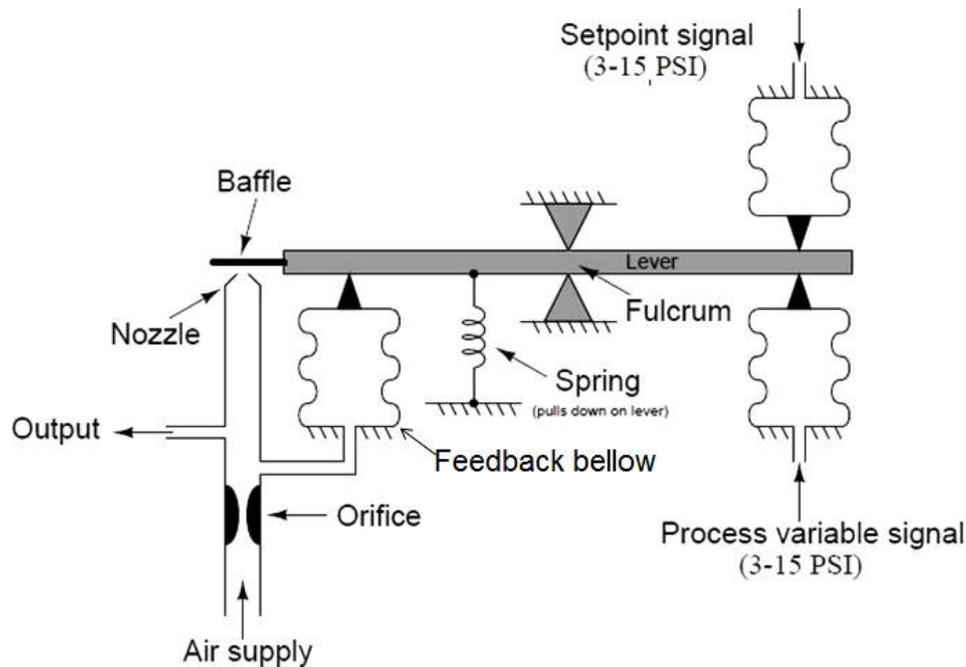
Fig 6.5.5 Proportional only (P) controller elements

It acts as a controller in a pneumatic system generating output pressure proportional to the displacement at one end of the beam. The action of this particular controller is direct, since an increase in process variable signal (pressure) results in an increase in output signal (pressure). Increasing process variable (PV) pressure attempts to push the right-hand end of the beam up, causing the baffle to approach the nozzle. This blockage of the nozzle causes the nozzle's pneumatic backpressure to increase, thus increasing the amount of force applied by the output feedback bellows on the left-hand end of the beam and returning the flapper (very nearly) to its original position. If we wish to reverse the controller's action, we need to swap the pneumatic signal connections between the input bellows, so that the PV pressure will be applied to the upper bellows and the SP pressure to the lower bellows. The ratio of input pressure(s) to output pressure is termed as a gain (proportional band) adjustment in this mechanism. Changing bellows area (either both the PV and SP bellows equally, and the output bellows by itself) influences this ratio. Gain also affects by the change in output bellows position. Moving the fulcrum left or right can be used to control the gain, and in fact is usually the most convenient to engineer.

2.2 Proportional-Derivative (PD) controller

A proportional-derivative (PD) controller is shown in Figure 6.5.6. To add derivative control action to a P-only controller, all we need to place a restrictor valve between the nozzle tube and the output feedback bellows, causing the bellows to delay filling or emptying its air pressure over time.
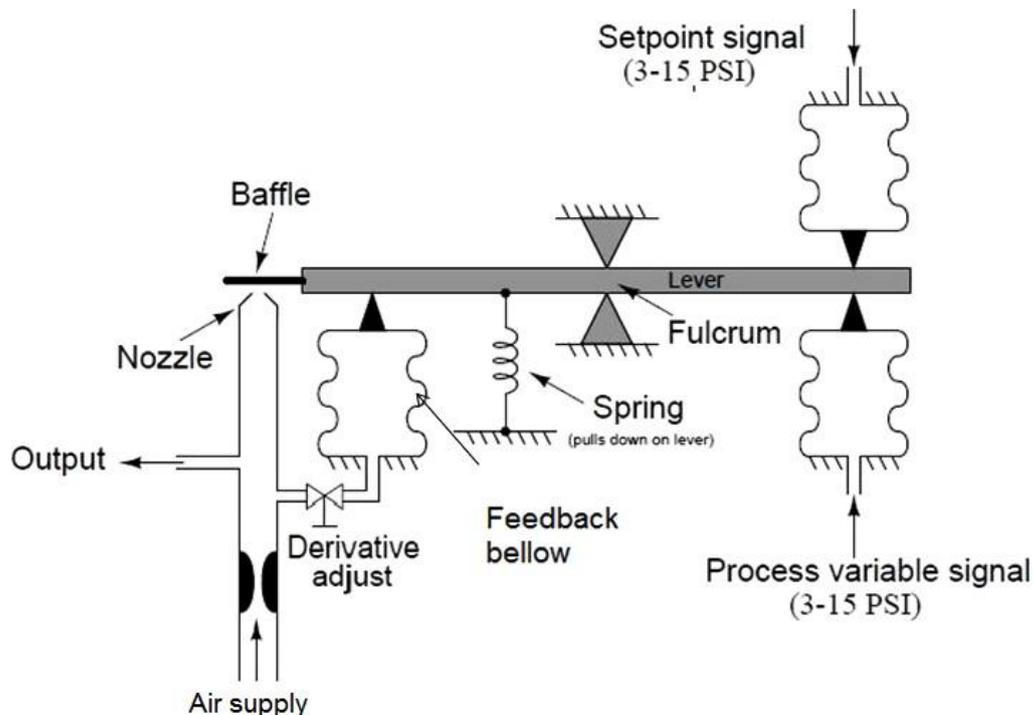

Fig 6.5.6 Proportional-Derivative (PD) controller

If any sudden change occurs in PV or SP, the output pressure will saturate before the output bellows has the opportunity to equalize in pressure with the output signal tube. Thus, the output pressure "spikes" with any sudden "step change" in input: exactly what we would expect with derivative control action. If either the PV or the SP ramps over time, the output signal will ramp in direct proportion (proportional action). But there will be an added offset of pressure at the output signal in order to keep air flowing either in or out of the output bellows at a constant rate to generate the necessary force to balance the changing input signal. Thus, derivative action causes the output pressure to shift either up or down (depending on the direction of input change) more than it would with just proportional action alone in response to a ramping input.

2.3 Proportional-Integral (PI) controller

In some systems, if the gain is too large the system may become unstable. In these circumstances the basic controller can be modified by adding the time integral of the error to control the operation (Fig 6.5.7). Thus the output can be given by an equation,

$$OP = K \left(error + \frac{1}{T_i} \int error \ dt \right)$$

(6.5.2)
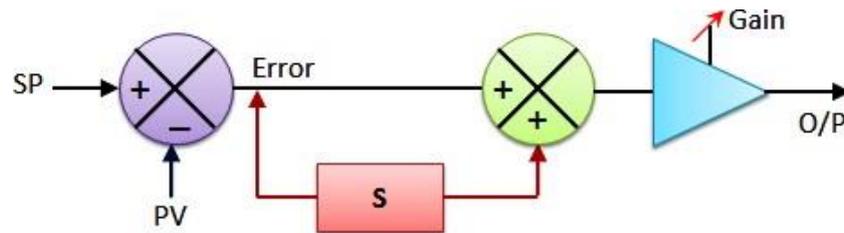
Fig. 6.5.7 Block diagram of P-I controller

The T_i is a constant called integral time. As long as there is an error the output of the controller steps up or down as per the rate determined by T_i. If there is no error then the output of the controller remains constant. The integral term in the above equation removes any offset error.

Figure 6.5.8 shows the configuration of pneumatic proportional plus integral controller. Integral action requires the addition of a second bellows (a "reset" bellows, positioned opposite the output feedback bellows) and another restrictor valve to the mechanism.
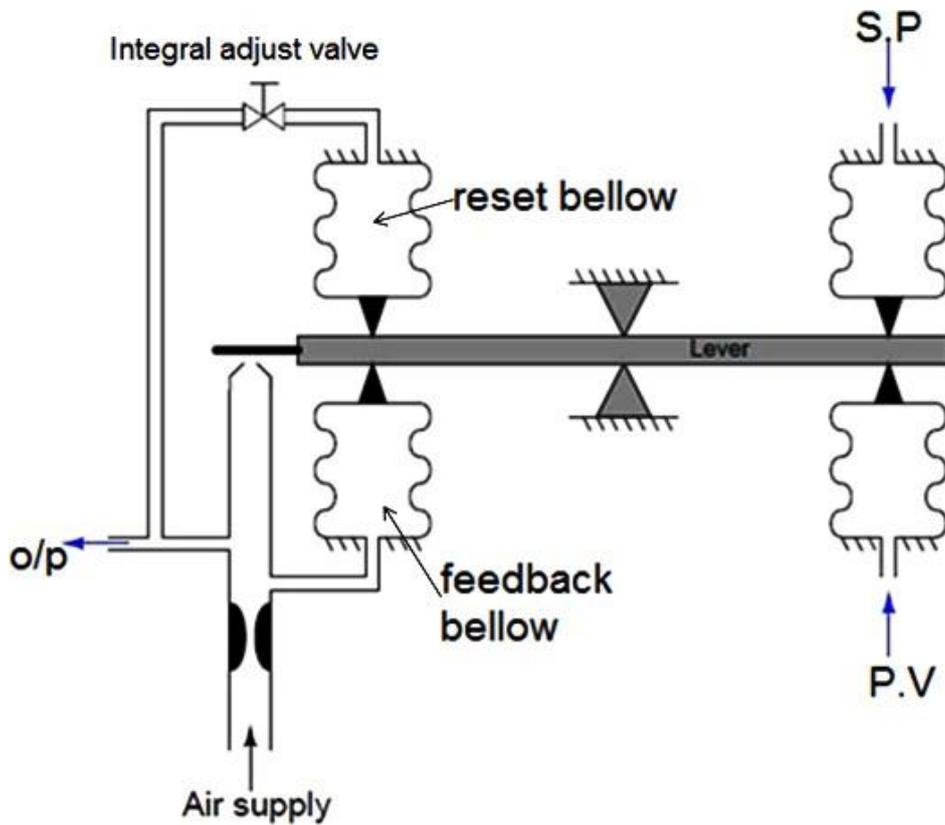

Fig. 6.5.8 Proportional-Integral (P-I) controller

As the reset bellows fills with pressurized air, it begins to push down the left-hand end of the force beam. This forces the baffle closer to the nozzle, causing the output pressure to rise. The regular output bellows has no restrictor valve to impede its filling, and so it immediately applies more upward force on the beam with the rising output pressure. With this greater output pressure, the reset bellows has an even greater "final" pressure to achieve, and so its rate of filling continues.

2.4 Proportional-Integral-Derivative (PID) controller

Three term pneumatic control can be achieved using a P-I-D controller. Here the action of the feedback bellows is delayed. The output is given by,

$$OP = K \left(error + \frac{1}{T_i} \int error \, dt + T_d \frac{d \, error}{dt} \right)$$

(6.5.3)

The terms gain K, derivative time T_d, integral time T_i which can be set by beam pivot point and two bleed valves (Fig. 6.5.9). This is a combination of all the three controllers described above. Hence it combines the advantages of all three. A derivative control valve is added to delay the response at feedback bellow. Addition of derivative term makes the control system to change the control output quickly when SP and PV are changing quickly. This makes the system more stable.
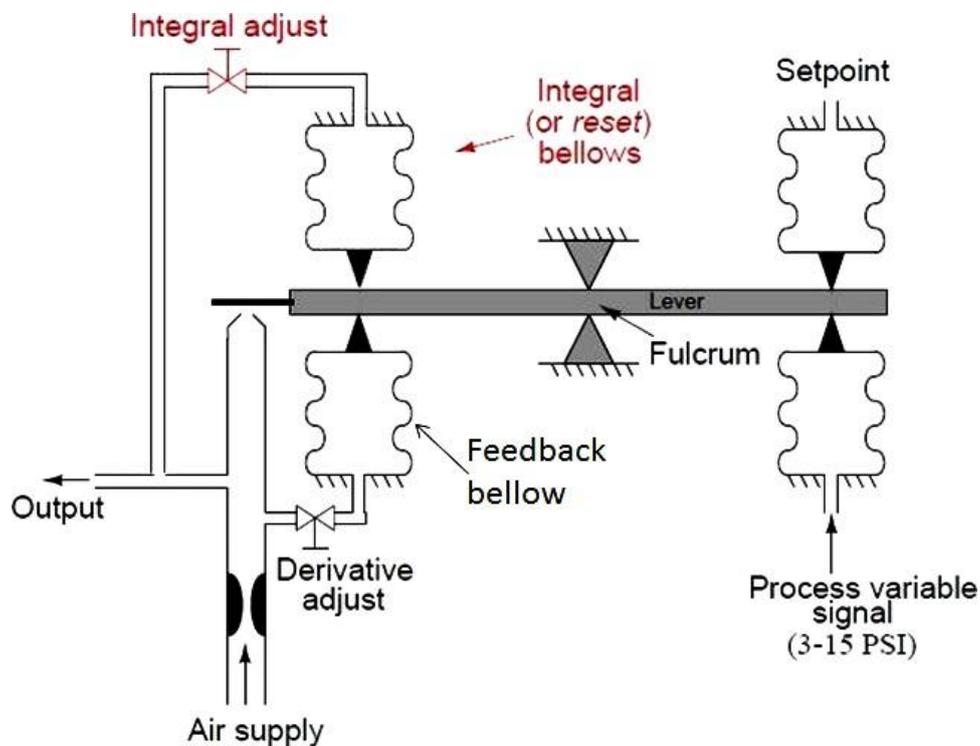
Fig. 6.5.9 Proportional-Integral-Derivative (P-I-D) controller

Advantages of pneumatic controllers
- Simplicity of the components and no complex structure
- Easy maintainability
- Safe and can be used in hazardous atmospheres
- Low cost of installation
- Good reliability and reproducibility
- Speed of response is relatively slow but steady
- Limited power capacity for large mass transfer

Limitations of pneumatic controllers
- Slow response
- Difficult to operate in sub-normal temperatures
- Pipe-couplings can give rise to leaks in certain ambient conditions
- Moving parts - more maintenance

Applications of pneumatic systems

In this section we will study the application of various pneumatic components in designing a pneumatic circuit. The graphical symbols of pneumatic components and equipments have already been discussed in lecture 7 of module 5.

1. Case study A

Consider a simple operation where a double-acting cylinder is used to transfer parts from a magazine. The cylinder is to be advanced either by operating a push button or by a foot pedal. Once the cylinder is fully advanced, it is to be retracted to its initial position. A 3/2-way roller lever valve is to be used to detect the full extension of the cylinder. Design a pneumatic circuit for the above-mentioned application.

1.1 Components used

The pneumatic components which can be used to implement the mentioned task are as follows:
- double acting cylinder
- 3/2 push button valve
- 3/2 roller valve
- shuttle valve
- 3/2 foot pedal actuated valve
- 5/3 pneumatic actuated direction control valve
- compressed air source and connecting piping

1.2 Working
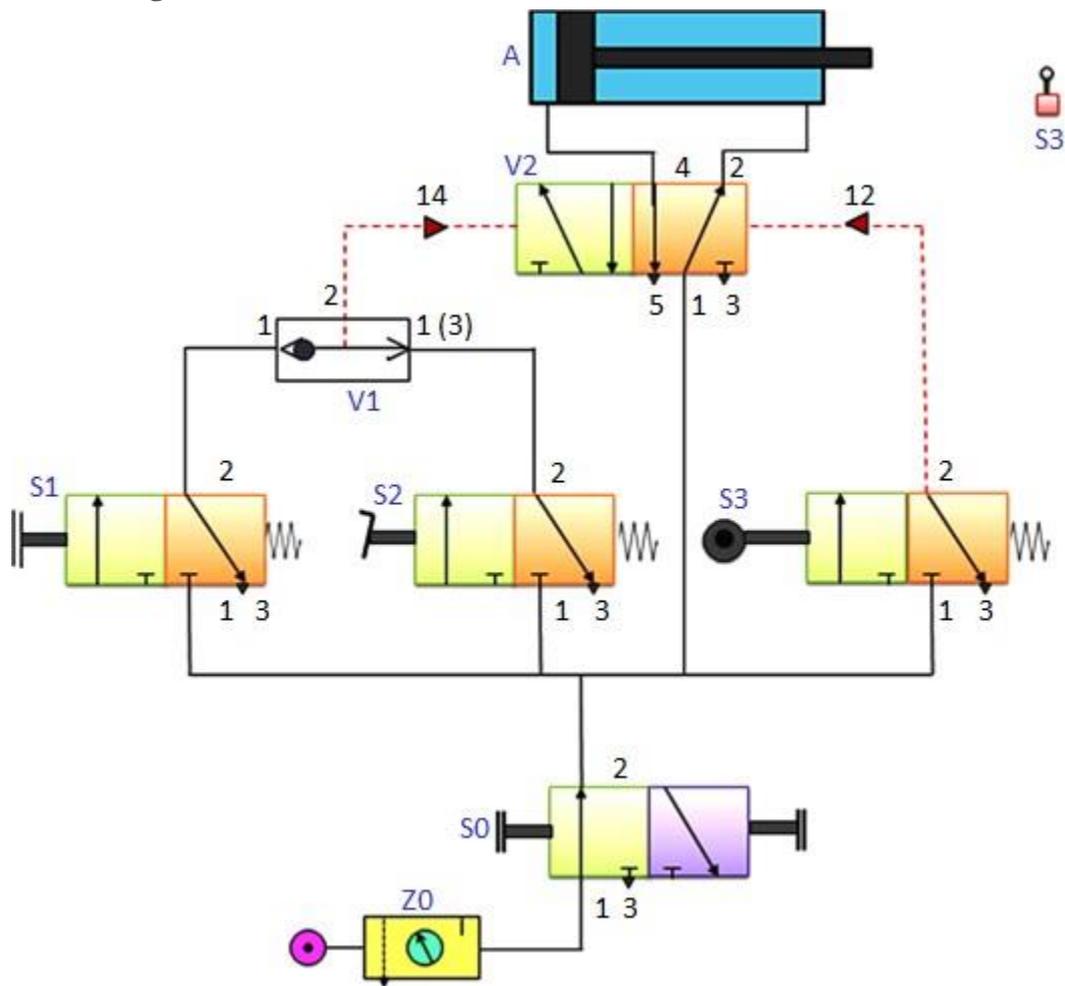
Fig. 6.6.1 Pneumatic circuit for shuttle valve operation

Figure 6.6.1 shows the proposed circuit diagram. As the problem stated, upon actuation of either the push button of valve (S1) or the foot pedal valve (S2), a signal is generated at 1 or 1(3) side of the shuttle valve. The OR condition is met and the signal is passed to the control port 14 of the direction control valve (V2). Due to this signal, the left position of V2 is actuated and the flow of air starts. Pressure is applied on the piston side of the cylinder (A) and the cylinder extends. If the push button or pedal valve is released, the signal at the direction control valve (V2) port is reset. Since DCV (V2) is a double pilot valve, it has a memory function which doesn't allow switching of positions. As the piston reaches the rod end position, the roller valve (S3) is actuated and a signal is applied to port 12 of the DCV (V2). This causes actuation of right side of DCV (V2). Due to this actuation, the flow enters at the rod-end side of the cylinder, which pushes the piston towards left and thus the cylinder retracts.

2. Case study B

A plastic component is to be embossed by using a die which is powered by a double acting cylinder. The return of the die is to be effected when the cylinder rod has fully extended to the embossing position and the preset pressure is reached. A roller lever valve is to be used to confirm full extension. The signal for retracting must only be generated when the piston rod has reached the embossing position. The pressure in the piston chamber is indicated by a pressure gauge.

2.1 Components used

The pneumatic components to be used to implement this task are:
- double acting cylinder
- 3/2 push button valve
- 3/2 roller valve
- shuttle valve
- 5/3 pneumatic actuated direction control valve
- pressure sequence valve
- compressed air source
- pressure gauge and connecting piping

2.2 Working
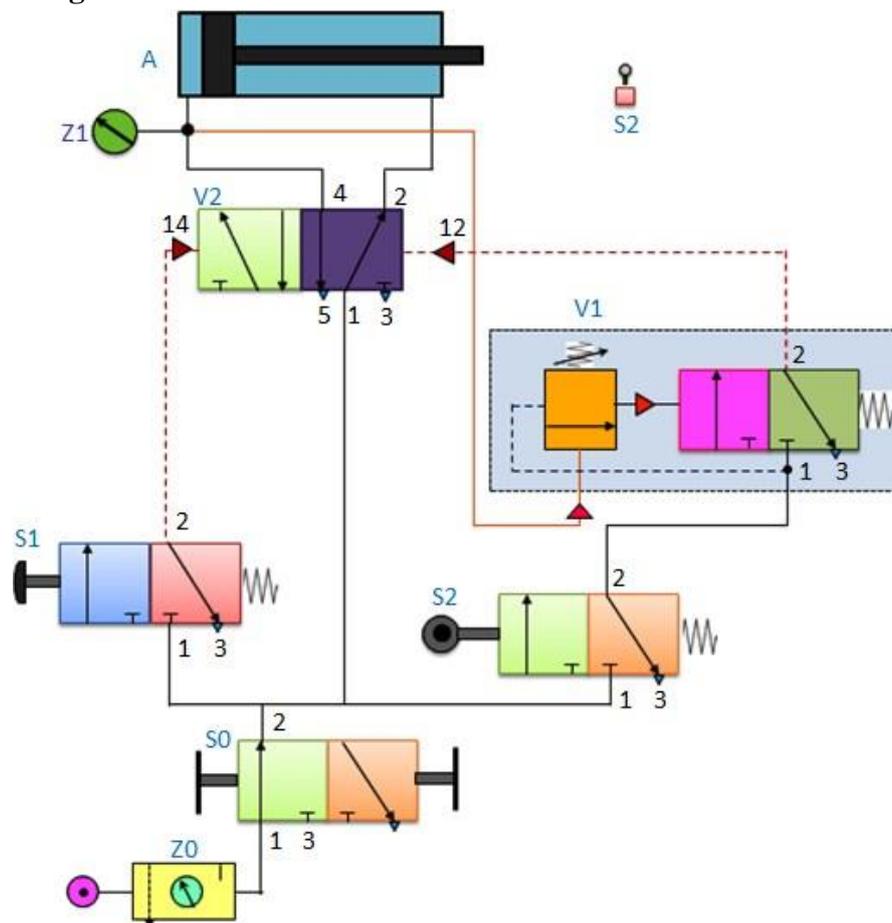
Fig. 6.6.2 Pneumatic circuit for embossing application

The proposed pneumatic circuit diagram for embossing application is shown in fig. 6.6.2. When the push button valve (S1) is pressed, the flow takes place through the valve and a signal is sent to the control port 14 of the direction control valve (V2). The left position of the direction control valve (V2) is switched-on and the flow enters at the piston-end of the cylinder (A). It causes the extension of the cylinder. Even if the push button is released the position of the DCV (V2) will not change due to its memory function. As the piston nears the end position, the roller valve (S2) is actuated and pressure line is connected to the pressure sequence valve (V1). During the embossing process the pressure at the piston-side of the cylinder (A) increases. This increase in pressure is indicated by the pressure regulator (Z1). When the pressure reaches to its pre-set value in the pressure sequence valve (V1), the 3/2 valve of pressure sequence valve switches and the signal is applied to port 12 of the DCV (V2). The right position of the DCV is actuated and the piston retracts. During the retracting movement, the roller valve (S2) is released and the signal at the control port 12 of the DCV (V2) is reset and the pressure sequence valve is also reset.

3. **Case study C**

Sequencing application

In process control applications such as sequencing, the Pneumatics systems are generally employed. Electrical components such as relays, programmable logic controllers are used to control the operations of Pneumatic systems. A simple example of a pneumatic sequencing is shown in Figure 6.6.3.
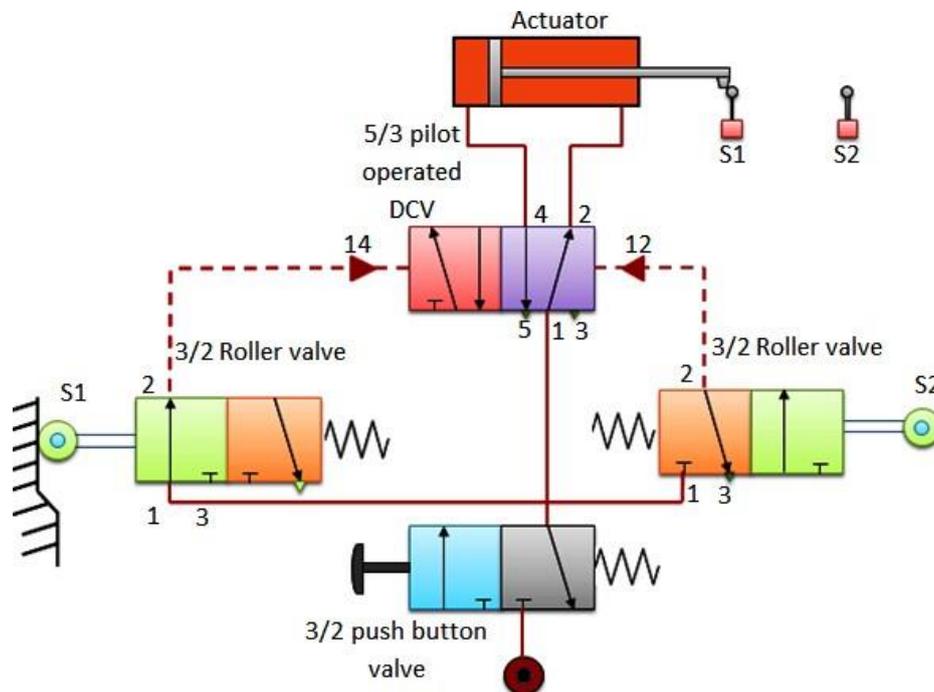
Fig. 6.6.3 Cylinder sequencing- Oscillating cylinder

3.1 Components used

The components used in the circuit are: double acting cylinder, 3/2 roller lever valve, 5/3 pilot operated direction control valve and a 3/2 push button valve. By using this circuit, a continuous to and fro motion of the actuator is obtained.

3.2 Working

When the 3/2 push button is actuated, the air flows from the source through the push button valve to the 3/2 roller valve (S1). The roller valve is already actuated by the cylinder when the piston rod hits the lever of S1. Therefore, there is continuous flow to the 5/3 pilot operated direction control valve (DCV). The flow given to the pilot line 14 actuates the first position of DCV. The air flows from port 1-4 pushes the piston head which causes the extension of the cylinder. As the cylinder fully extends it actuates the 3/2 roller lever valve (S2). The roller valve is actuated and air flows through the valve to the 5/3 DCV. The air enters the DCV through pilot port 12 actuating the second position. Hence the air flows from port 1-2 to the actuator rod end, causing its retraction. The cylinder reciprocates till the supply is stopped. In this way, we can achieve the sequencing operation by controlled actuation of various valves in a pneumatic system.

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – IV –Fluid power systems– SME1302

UNIT 4 PNEUMATIC CIRCUITS

PNEUMATIC CYLINDERS

Drive Elements are Actuators – used to perform the task of exerting the required force at the end of the stroke or used to create displacement by the movement of the piston. Pneumatic Actuators can be classified as

•Single Acting Cylinders
   Conventional Cylinder with Spring Loaded Piston or
   Diaphragm type
•Double Acting Cylinders

2.1 Symbolic Representation of Pneumatic Cylinders -Linear Actuators

Single Acting Cylinder

Double Acting Cylinder

Double Ended Piston Rod Cylinder

Double Acting Cylinder with fixed Cushion On One Side

Double Acting Cylinder with Variable Cushion On One Side

Double Acting Cylinder with Variable Cushion on both sides
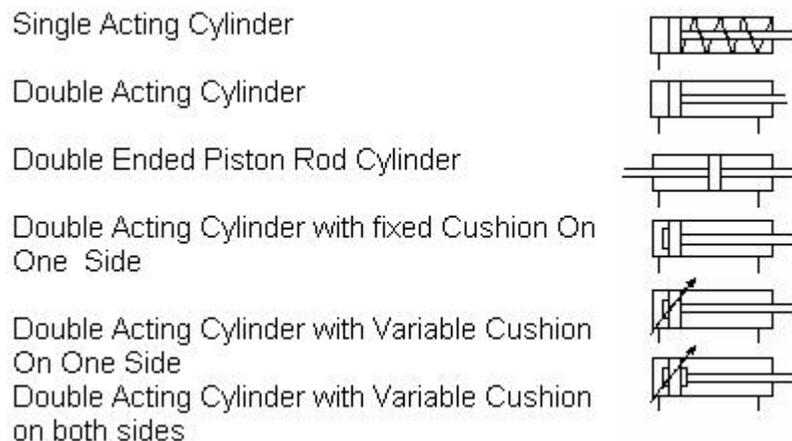
Figure 2.1 Symbolic representation of Pneumatic Cylinders

2.2 Single Acting Cylinder

•Single acting cylinder has one working port
•Forward motion of the piston is accomplished to due to supply of compressed air behind the piston.
•Return motion of piston takes place only due to built in reset spring placed on the rod side of the cylinder.
•Single acting cylinders are used for applications such as clamping, feeding, sorting, locking, ejecting, braking etc., where force is required to be exerted only in one direction..
•Single acting cylinder are usually available in short stroke lengths [maximum length up to 80 mm] due to the natural length of the spring.

Single Acting Cylinder exert force only in one direction.
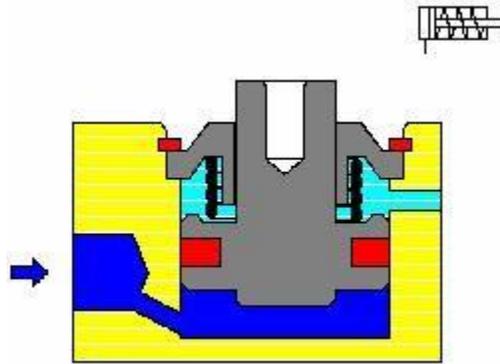
Figure 2.2 Single Acting Cylinder

2.3 Double Acting Cylinders

They are available in different constructions such as

•Conventional,
•Double ended piston rod type,
•Rod less type
•Tandem type
•Multi-position type and
•Rotary type..

Conventional Cylinders

•Double Acting Cylinders are equipped with two working ports- one on the piston side and the other on the rod side.
•To achieve forward motion of the cylinder, compressed air is admitted on the piston side and the rod side is connected to exhaust. During return motion supply air admitted at the rod side while the piston side volume is connected to the exhaust. Force is exerted by the piston both during forward and return motion of cylinder
•Double acting cylinders are available in diameters from few mm to around 300 mm and stroke lengths of few mm up to 2 meters
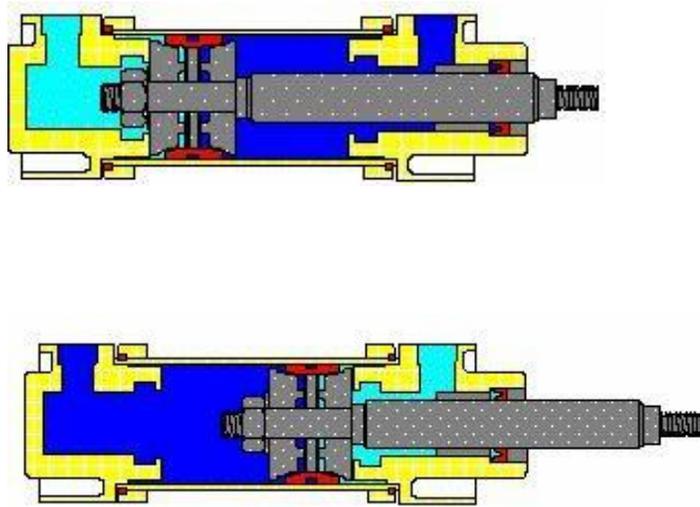
Figure 2.3 Double Acting Cylinder –Retracted and Advanced Positions

2.4 End Position Cushioning

•Pneumatic cylinders operates at much higher speeds than Hydraulic cylinders. Due to this, there is a tendency of the piston to ram against the end covers as the piston approaches the ends at high velocity especially in cylinder with large mass. This impact force can damage the cylinder as well as the piston due to repetitive action .
•All Double acting cylinders excepting for small sizes, are provided with end position cushioning arrangement.
•This arrangement decelerates the piston motion as it approaches the end of the stroke
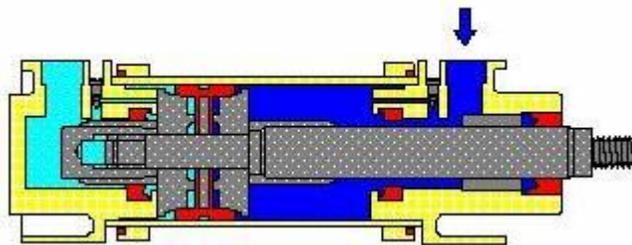
Figure 2.4 Double Acting Cylinder with Cushions

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2.5 <u>Tandem Cylinder</u>

•Tandem cylinder is essentially a combination of two cylinders in tandem such that force derived from the first cylinder, supplements the force obtained by the second cylinder. More or less the force produced by a tandem cylinder is as twice as that of a conventional double acting cylinder of the same diameter.
•This type of cylinder is used where more force is to be generated and there is no scope for increasing the diameter of cylinder due constraint of space
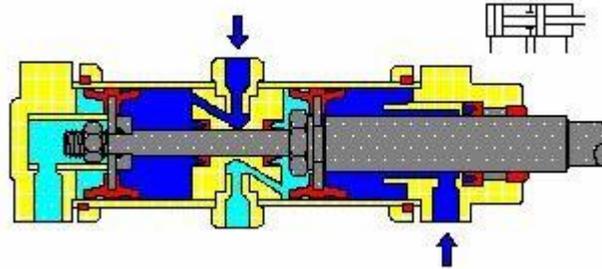
Figure 2.5 Tandem Cylinder

2.6 Rod less Cylinders

Different operational principals are used for the construction of Rod less cylinders:

1. Cable Cylinder
2. Sealing band Cylinder with slotted cylinder barrel
3. Cylinder with Magnetically Coupled Slide

Rod less cylinder have the following advantages:

•Available in long lengths –up to 4 m or even higher (as there is no buckling)
•Most ideally suited for stopping and fixing (Robotic application)
•Occupies less space as the extension of piston rod is not present

2.6.1 Rod less Cylinder with Magnetic Coupling

This cylinder has a hermetically sealed arrangement where piston is housed inside a sealed cylinder barrel. The piston is provided with number of annular ring magnets, radially polarised. An external sleeve which slides over the cylinder, is also provided with similar arrangement of ring magnets. Thus a magnetic coupling is established between the piston and slider. As the piston reciprocates due to supply of compressed air, the slider also reciprocates over the cylinder
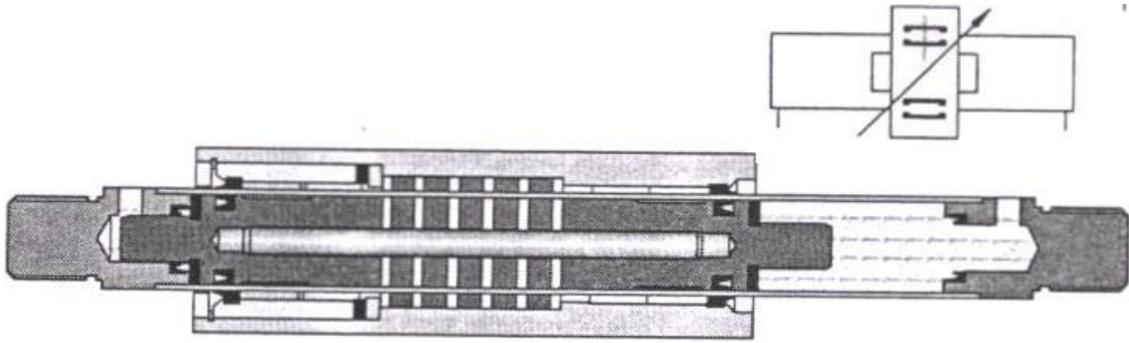
Figure 2.10 Rod less cylinder with Magnetic coupling

2.6.2 Rod less Cylinder- Mechanically Coupled

The cylinder barrel is provided with a slot across the entire length. The force is transmitted through a slide permanently connected to the piston. The connection from piston to slide is directed outwards through the slotted cylinder barrel. The slot is sealed by means of a sealing band, which seals the inside of the slot. The sealing band is guided between the piston seals and passed under the slide. A second metallic cover strip, covers the slot from the outside to prevent the ingress of dirt
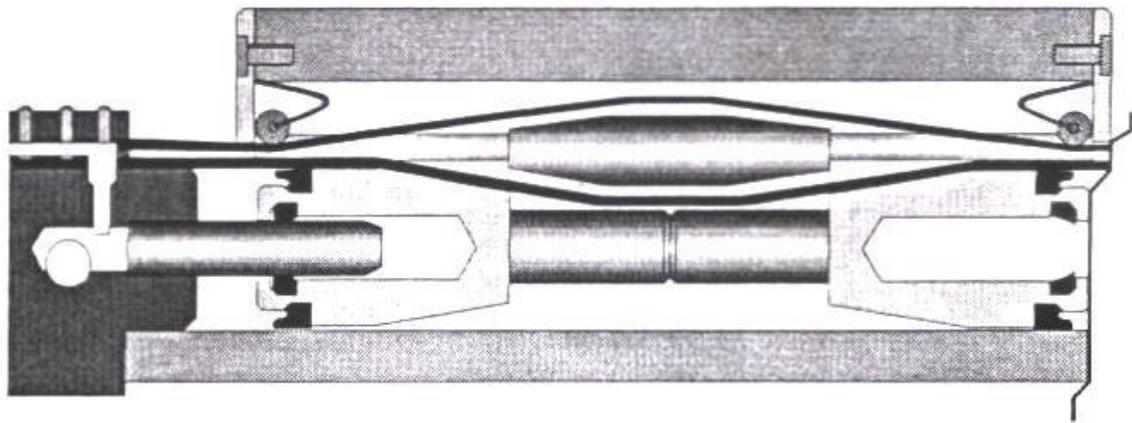
Figure 2. 12 Rod less Cylinder Mechanical Coupled

2.7 Rotary Actuators

•In order to achieve angular motion, Rotary Actuators are used. Rotary actuators are mainly available in two designs.

•Vane type Construction: Further these actuators are available with 180^0 rotation or 270^0 angle of rotation. These actuators can be used for low torque requirement up to 10 N-m.
•Rack and Pinion type construction: Can be used for angle or rotation close to 360^0. These actuators can develop torques up to 100-150 N-m depending on the diameter of the cylinder

2.7.1 Vane type Rotary Actuator

•A rotating vane connected to a shaft divides cylindrical chamber in to two compartments. Compressed air is alternately admitted and exhausted from the chambers. The compressed air pressure acting on the vane surface results in a torque. Hence rotary motion is obtained.

•The magnitude of the torque produced, depends on the surface area of the vane, air pressure and mean radius of the vane.
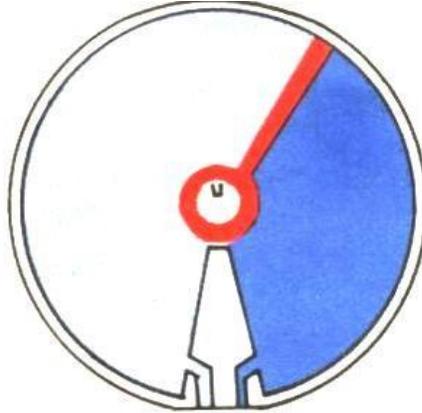
Figure 2.13 Vane Type Rotary Actuator

2.7.2 Rotary Actuator of Rack and Pinion Type

This is essentially a double acting cylinder with a rack arrangement provided on the piston rod and a pinion engages with this rack. Out put rotation of the pinion shaft can be used for obtaining angular motion from 0-360^0. This type of rotary actuators are used for higher torque requirement up to 150 N-m.
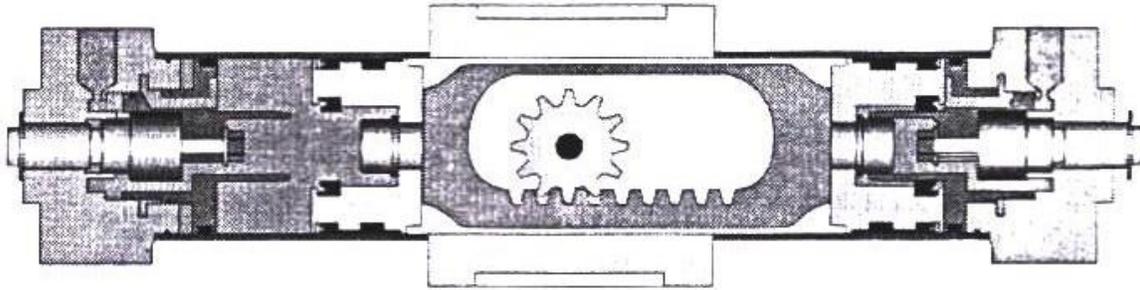
Figure 2.14 Rotary Actuator- Rack and Pinion Type

2.8 Cylinder Seals

•Cylinder seals of single cup or double cup type are often used for dynamic sealing between piston and cylinder walls.
•Single cup seals are used for single acting cylinder and double cup seals are used in Double acting cylinders
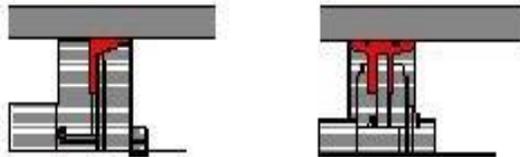
Figure 2.15 Single and Double Cup Seals

Sealing material such as Perbunan, Viton and Teflon are commonly used. Per bunan seals are used for temperatures in the range of -20^0 C to 80^0 C while Viton seals are used for high temperature range from -20^0 to 200^0 C. Teflon seals have applications at low temperature range -50^0 to 200^0 C

2.9 Mounting Arrangement for cylinders
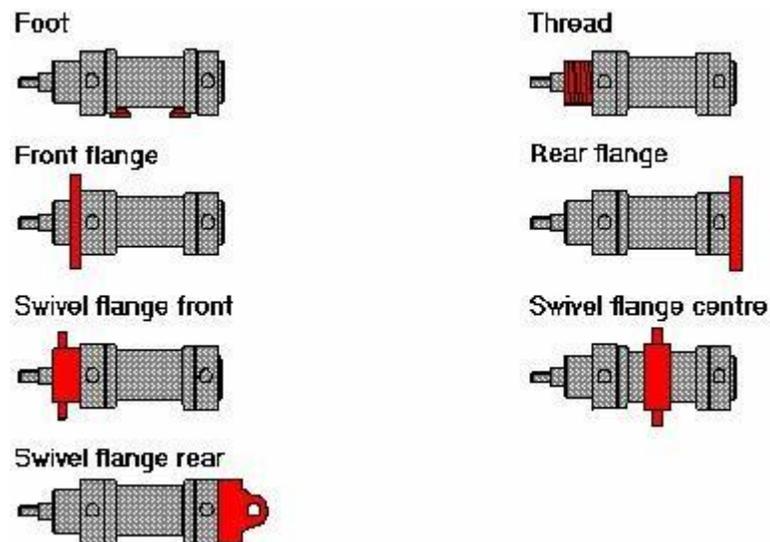
Figure 2.16 Mounting Arrangement of Cylinders

The type of mounting is determined by the manner of fitting the cylinder to fixtures and machines. Flange mounting arrangement is generally used for small cylinders. Large cylinders are usually foot mounted.

Directional Control Valves

Directional Control valves are mainly used to change the direction of flow path of working medium or signal medium. They are used for admitting or exhausting working medium to the cylinder or from the cylinder for actuation of the cylinder. Also used to start or stop the pneumatic signal as well as for signal processing

Directional control valves are designated as per the following functions:

•Number of ports on the valves
•Number of switching positions
•Method of actuation
•Method of reset
•Design and constructional features

## 3.1 Symbolic Representation of Directional Control Valves

Each Square represents a
swithching position

Number of Squares represents
number of swithching positions

Lines indicates the arrow path.
Arrows indicates the direction

Shut off positions are indicated
by lines drawn at right angles

Connections to the valves
are indicated by short lines
drawn out side the boxes
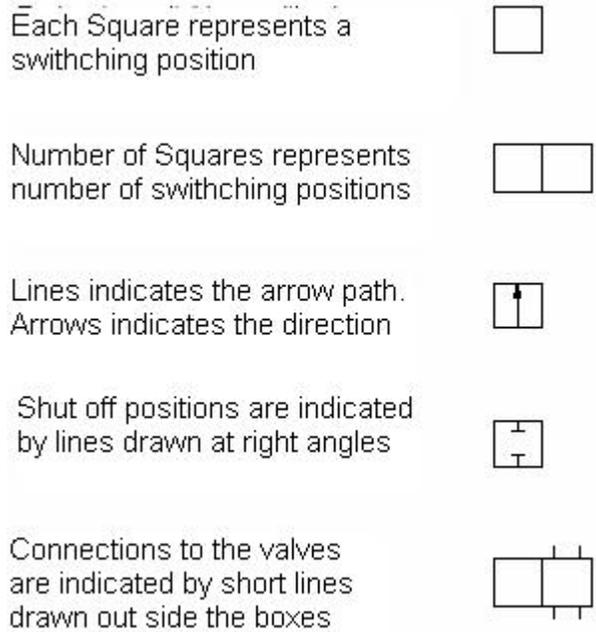
Figure 3.1 Symbolic Representation of Directional Control Valves

Number of ports
Number of positions
2/2 Way Directional Control
Valves Normally Open

3/2 Way Directional Control
Valves Normally Closed

3/2 Way Directional Control
Valves Normally Open

Number of ports
Number of positions
4/2 Way Valve

5/2 Way Valve

5/3 Way Valve ,
Mid Position Closed
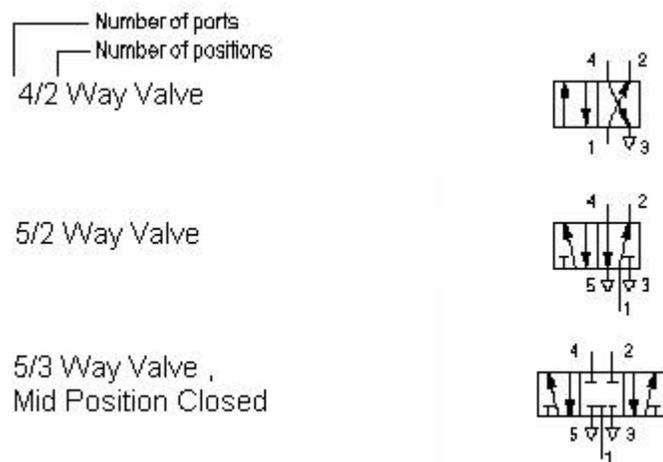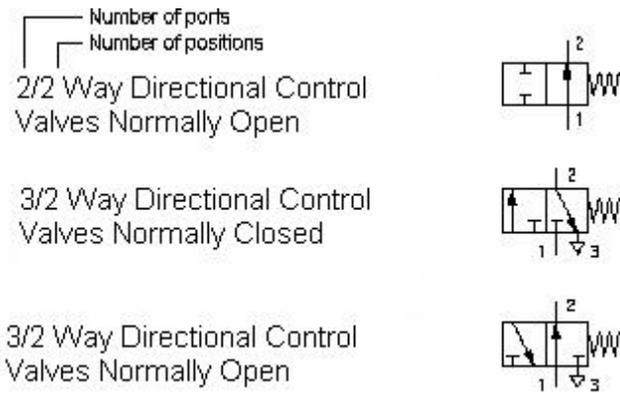
Figure 3.2 Symbolic Representation of Directional Control Valve

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PUSH BUTTON OPERATED VALVE

PEDAL OPERATED VALVE

SPRING RESET

ROLLER LEVER OPERATED LIMIT SWITCH

PILOT OPERATED VALVE

SOLENIOD ACTUATED VALVE

SOLENIOD ACTUATION AND RESET

PILOT ASSISTED SOLENIOD ACTUATION AND RESET WITH MANUAL OVER RIDE

SOLENIOD ACTUATION AND SPRING RESET
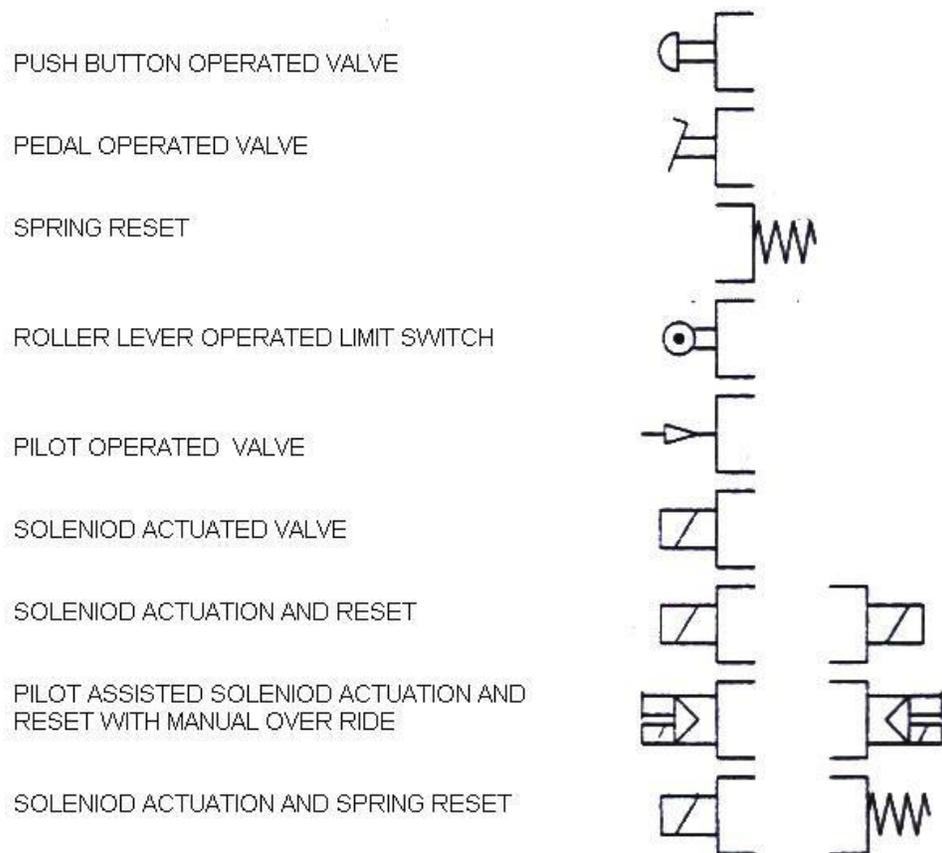
Figure 3.3 Method of Actuation and Reset of Directional Control Valves

3.3 Energy Elements

Pressure Source

Air Service Unit
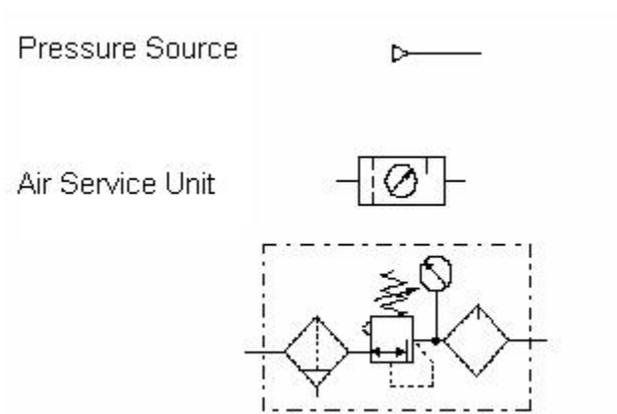
Figure 3.4 Symbols for Energy Elements

3.4 Port Marking of Direction Control Valve

As per IS 1219		As per IS 5599	
•Supply Port	A	Supply Port	1
•Exhaust Ports	R & S	Exhaust Ports	3 & 5
•Out put Pots	A & B	Out put Ports	2 & 4
•Pilot Port [Set]	Z	Pilot Port [Set]	14
•Pilot Port [Reset]	Y	Pilot Port [Reset]	12

3.6 Design and Construction Features of D.C. Valves

Directional Control Valves are available in the following types of constructions:

Poppet type of Valves
    Ball Seat Type [Pneumatic/ Solenoid actuation]
    Disc Seat ype[Pneumatic/ Solenoid actuation] Slide Valves [Pneumatic/ Solenoid actuation]
Suspended Disc type of Valve [Pneumatic/ Solenoid actuation]
Plate of Valve [Manual actuation]

3.7 Selection Criteria of D.C. Valves

Selection of a particular design of D.C. valve depends on the   following factors
•Actuation force
•Leak tightness
•Ease of servicing
•Sensitive to contamination by dirt
•Travel length of the valve stem
•Size
•Cost

3.8 3/2 Way- D.C. Valve N.C-Ball Seat Type

•These type of valves are often used as signal input valves, operated either with push button or with limit switches rollers, to interrogate the cylinder position
•A spring loaded ball initially blocks the supply ports 1. Out put port 2 is connected to exhaust port 3.
•On actuation, the plunger first isolates the exhaust port 3 and further descending of the plunger, the ball is pushed down wards, there by opening the supply port 1 to out put port 2.
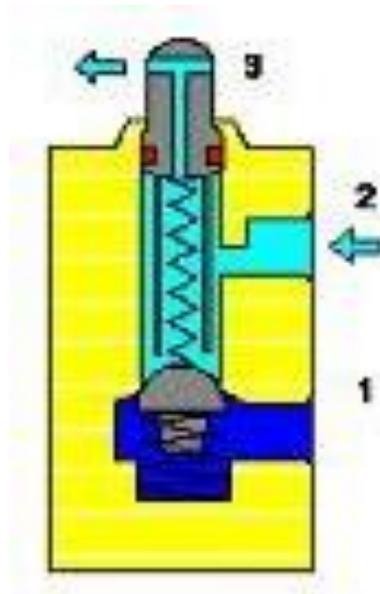
Figure3. 5 Ball Seat Type Directional Control Valve [NC]

•These type of valves are often used as signal input valve either push button operation or as limit switches to interrogate the cylinder position
•A spring loaded ball initially blocks the supply port 1 and out put port 2 is connected to exhaust port 3.
•On actuation, the supply port 1 is connected to out put port 2. The exhaust port 3 is isolated

3.9 3/2 Way Disc Seat Valve [Normally Closed]
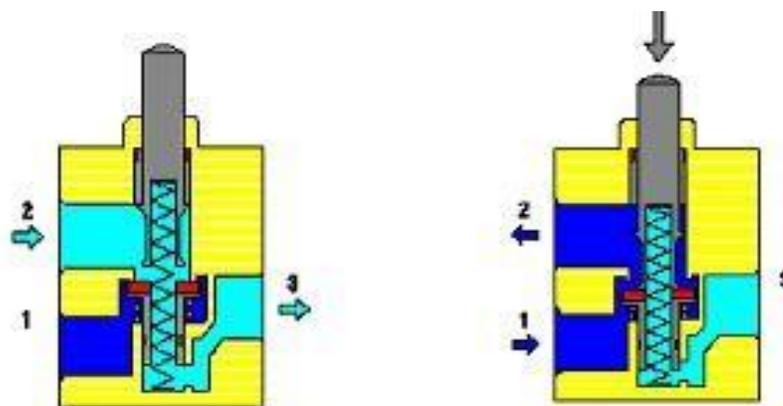
Figure 3.6   3/2 Way Disc Seat Valve [Normally Closed]

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Comparison of Ball Seat and Disc Seat Valves Ball

Seat Valves

•They are inexpensive
•Relatively small size
•Insensitive to dirt
•Operated manually or mechanically

Disc Seat Valve
•Offers large area and hence lift required is very small
•Time of response is good
•Insensitive to dirt
•Can be actuated manually, mechanically, electrically or pneumatically

## 3.11   5/2 Way Suspended Disc Seat Type of Valve
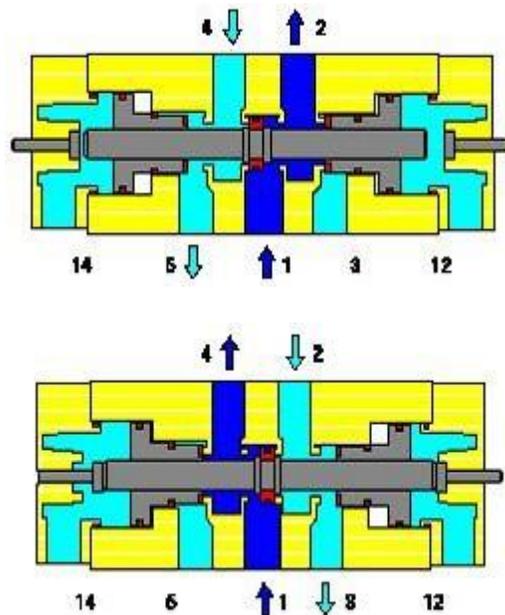
Figure 3.7 Suspended Disc Seat Directional Control Valve

These types of valves are widely used as it is insensitive to plugging by impurities, require low actuation force. A manual over ride is shown on both sides to manually set or reset the valves in case of signal locking. With pilot signal at pilot port 14, The valve communicates ports 4 to 5 and 1 to 2. With pilot signal at pilot port 12., ports of the valve 1 and 4 and 2 and 5 are communicated.. Used as final control element or for signal processing.

Controlling of Pneumatic Cylinders

Pneumatic cylinders can be controlled by the following methods:
1. Direct control of Single or Double acting cylinder
2. Indirect Control of Cylinder with Single Piloted Final Control Valve
3. Indirect Control of Cylinder with Double Piloted Final Control Valve

In the indirect control actuation, a pilot signal from a 3/2 N.C. valve is used to activate pilot ports of final control valve.

4.1 Direct Control of Single Acting Cylinder
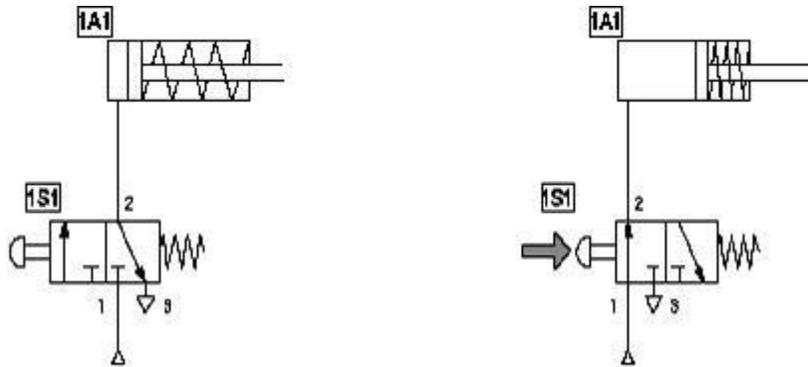
Figure 4.1 Direct Control of Single Acting Cylinder

Pneumatic cylinders can be directly actuated by actuation of final control valve, manually or electrically in small cylinders as well as cylinders which operates 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. When the push button is released, the reset spring of the valve restores the valve to the initial position [closed]. The cylinder space is connected to exhaust port there by piston retracts either due to spring or supply pressure applied from the other port.

4.2 Indirect Control of Single Acting Cylinder
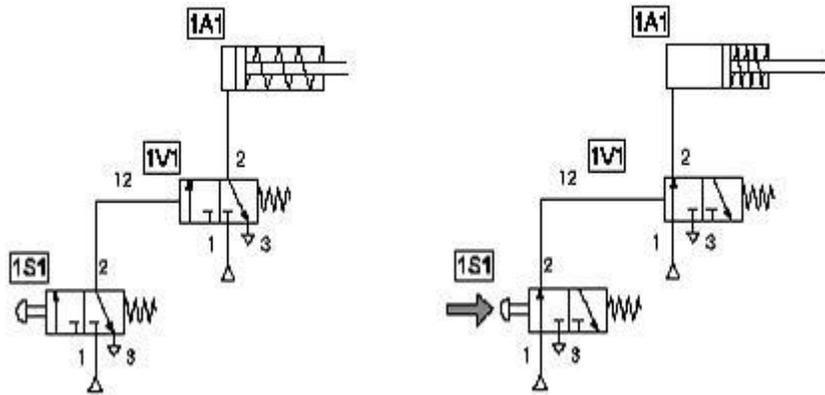
Figure 4.2: Indirect Control of Single and Double Acting Cylinders

Large cylinders as well as cylinders operating at high speed are generally actuated indirectly as the final control valve is required to handle large quantity of air. In the case of pilot operated valves, a signal input valve [3/2 way N.C type, 1S1] either actuated manually or mechanically is used to generate the pilot signal for the final control valve. 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 [4-6 bar]. Indirect control as permits processing of input signals.

Single piloted valves are rarely used in applications where the piston has t o retract immediately on taking out the set pilot signal -.suitable for large single acting cylinders.

4.3 Use Double Piloted Valve

Double piloted valve [Fig 3.3] is also called as the Memory valve
With the actuation of Forward push button, the out put signal activates the set pilot port [14] of final control valve. This results forward motion of the cylinder
Now even if this push button is released the final control valve remains in the actuated status as the both the pilot ports are exposed to the atmosphere pressure and the piston remains in the forward end position.
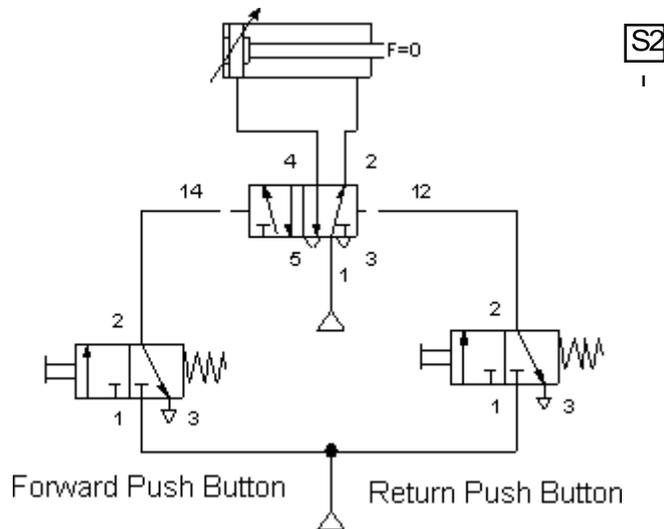
Figure 4.3 Use of Double Piloted Valve

In order to retract the cylinder, the Return push button is activated. This will convey reset signal from signal source to the pilot port of final control valve [12] . The piston retracts. Now even if the Return push button is released the status of the cylinder will not change.

4.4 Methods of Checking The End Positions

The following methods are commonly used to interrogate the end positions of piston in the cylinder:

1. Mechanically operated limit switches (Roller lever or idle return roller type)
2. Reed sensors, either with electrical or pneumatic out put [the piston is incorporated with ring magnet]
3. Electrical proximity switches
4. Pneumatic Signal generators

4.5 Use of Limit Switches

•S1 and S2 are the limit switches corresponding to home position and extended position
•Although they are located in the path of the movement of piston rod, normal practice is to represent the symbol of the limit switches on either side of the final control valve with out put signals connected to the pilot ports of the valve. The limit switches of Roller lever type are essentially 3/2 way ball seat or disc seat type of valves handling pneumatic signals. These are available with direct actuation type and internally pilot actuation type versions. Limit switches of idle return roller type are used for actuation only in one direction are used as signal elimination device in case of signal overlap.

18
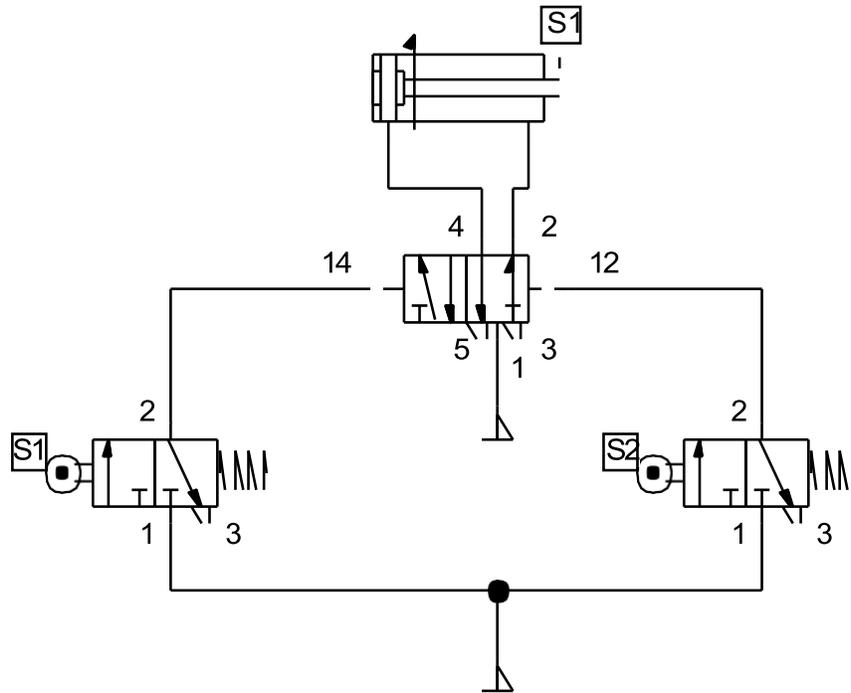
Figure 4.4 Use of Mechanically operated Roller lever Limit Switches

Example 4.1 : Pin Feeding Device

Pins are to be fed from a hopper to the next station one at a time using a Pneumatic Cylinder. Speed of the cylinder should be adjustable both during forward and return motion. The process of feeding should be initiated using a detent push push button. Develop a suitable Pneumatic control circuit .
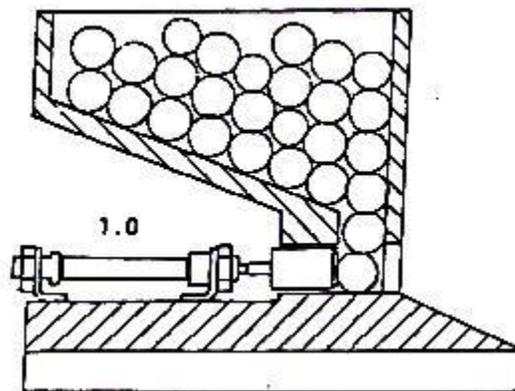


Figure 4.7 Pin Feeding Device
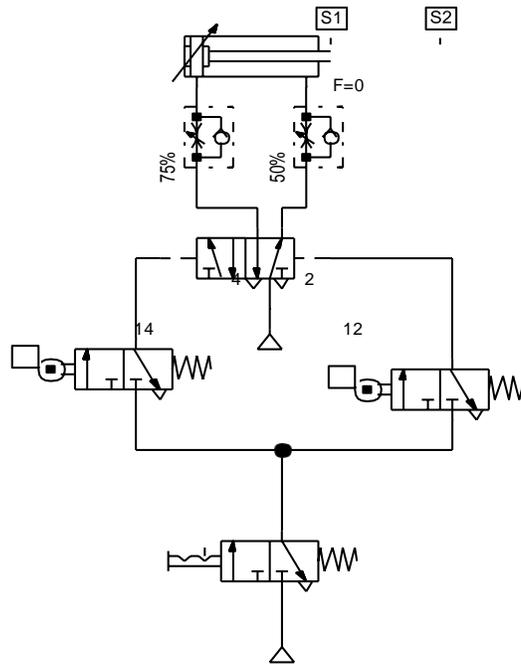
Figure 4.8 Pin Feeding Device

Exercise 4.1 : Rotary Indexing Table

Cans are required to be transferred from one conveyor to the other through a filling and capping station. A rotary indexing device is used which should be able to operate using a pneumatic cylinder with ratchet arrangement. The process should start on actuation of a push button operated valve. The process should stop when no cans are present from the incoming conveyor. The can sensor can be roller lever type of limit switch . Draw a suitable pneumatic control circuit.
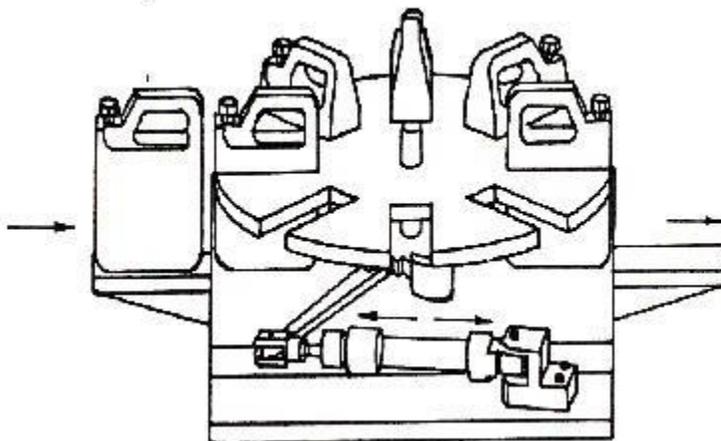

Figure 4.9 Rotary indexing device

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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

Flow Control Valves

- One way flow control valve is often used to achieve independent speed control of cylinder in the forward and return motion. This has a variable restrictor and a non return valve in parallel
- Two flow control valve is essentially a valve with variable restrictor which offers resistance to passage of air in both direction.
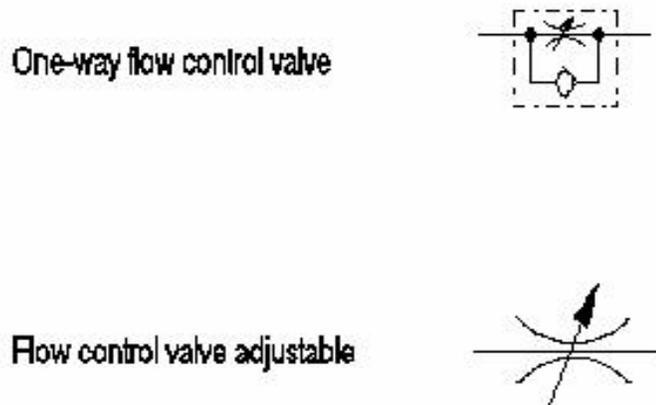

Figure 4A.1 Symbol for Flow Control Valves

One Way Flow Control Valve

- This valve is also called as the Throttle Relief Valve
- Generally used for Speed Control of Cylinder and is installed in the working pressure line, between the final control valve and the cylinder ports

- One way flow control valve has a needle and an orifice arrangement . A Non return valve in the form of an elastic diaphragm is secured to the bottom of the

valve orifice. The diaphragm when subjected to air pressure from the top, seals against seat in the valve body and prevents any direct air flow to the down stream side. The compressed air has to necessarily pass through the flow control valve and under goes throttling. When the flow takes place form bottom to top, the diaphragm deflects upwards and allows air to pass directly to the down stream side of the valve, thus by passing the flow control valve.

- When Compressed air is admitted in the direction of throttling, [left to right] it exerts force above the diaphragm and holds it against the seat. This prevents by passing of air through the gap between diaphragm and seat.
- Then compressed air has to pass through the gap between needle and orifice of the valve which results in throttling
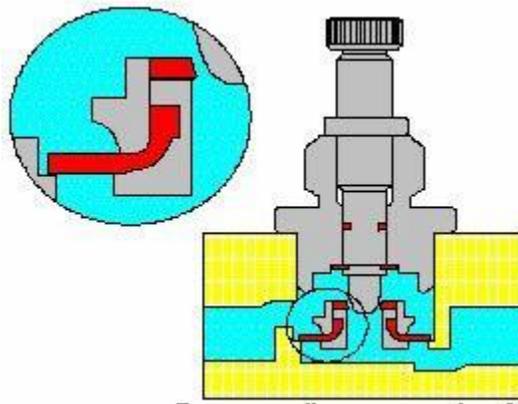
Figure 4A.2 One Way Flow Control Valve During Throttling

- When the flow takes place in the reverse direction, pressure exerted by the compressed air from the bottom of the diaphragm, opens it up against the seat and directly by passes the air without undergoing throttling
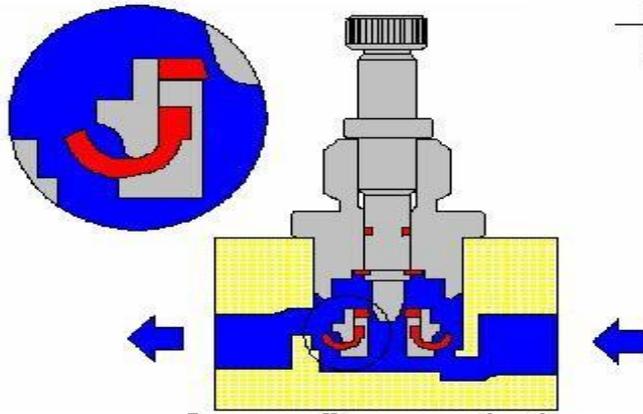
**Figure 4A.3 One Way Flow Control Valve During Throttling**
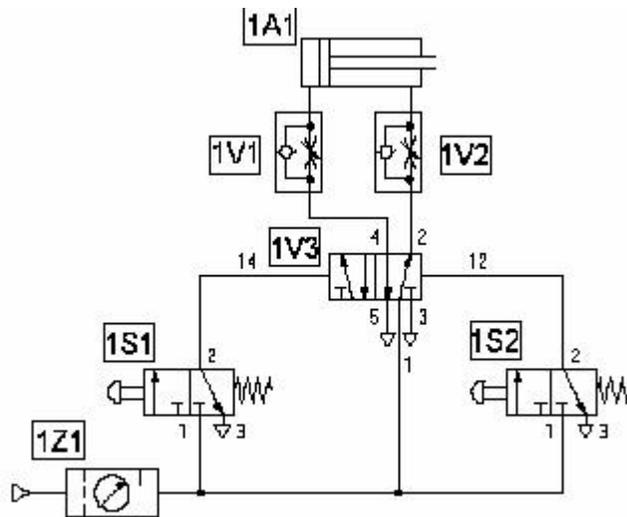
Figure 4A.4 Use of Flow Control Valve for Speed Control of Cylinder

Supply Air Throttling

Supply Air Throttling
- Supply air entering the cylinder through either of the working ports, undergoes throttling as the non return valve is closed in the direction of flow.
- During exhaust , the compressed air leaving the cylinder is by passed through the non return valve and escapes freely as it does not under go throttling
- Supply air throttling is used for single acting cylinder and small volume cylinder

Exhaust Air Throttling

- Supply air flows freely to the cylinder through the bypass passage of the non return valve. The supply air does not under go any throttling
- Exhaust air leaving the cylinder has to under go throttling as the non return valve is closed in the return direction
- The piston is loaded between two cushions of air
- Exhaust throttling should always be used for double acting cylinder
- Not suitable for small volume cylinders and cylinders with short strokes as effective pressure cannot build up sufficiently.

Speed Control of cylinder
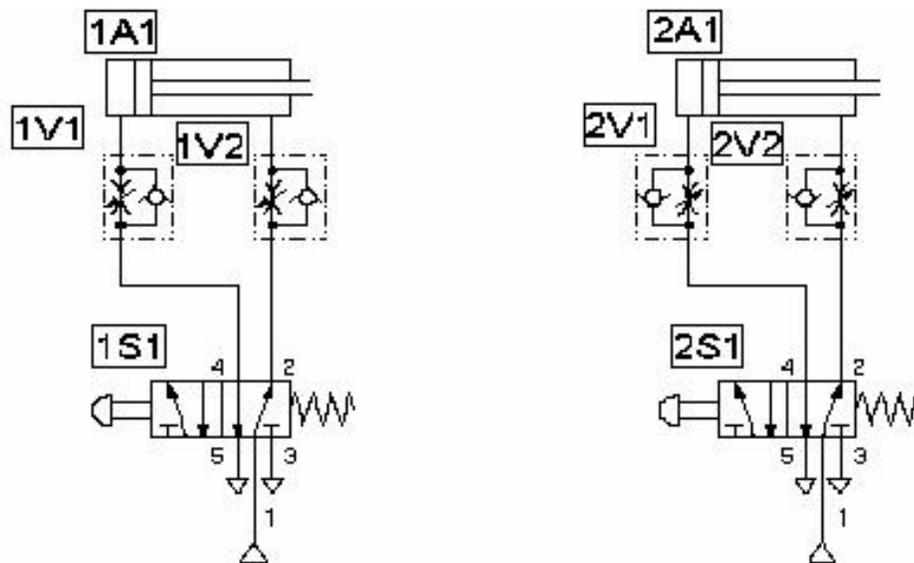
Figure 4A.5 Speed Control Valve

Stick Slip Effect

- There is a limitation is achieving smooth movement of cylinder with low speed setting of flow control valve. This results in jerky motion of piston which is called as the stick slip effect
- When the flow control valve is set for low flow rates, it takes considerable time for the supply air to build up to the required pressure [corresponding to the load]

behind the piston. Every time this pressure is reached, the piston jerks in the direction of motion which results in increase in cylinder volume. This further results in drop in pressure in the cylinder and the piston momentarily halts until the pressure build up takes place. This intermittent motion is called as the Stick Slip Effect

Quick Exhaust Valve

- In many applications especially with single acting cylinders, it is a common practice to increase the piston speed during retraction of the cylinder to save the cycle time
- This is carried out by incorporating a Quick exhaust valve.

- The Quick exhaust valve has essentially three ports
  Supply port 1, is connected to the out put of the final control element (Directional control valve). The Output port, 2 of this valve is directly fitted on to the working port of cylinder. The exhaust port, 3 is left open to the atmosphere

2
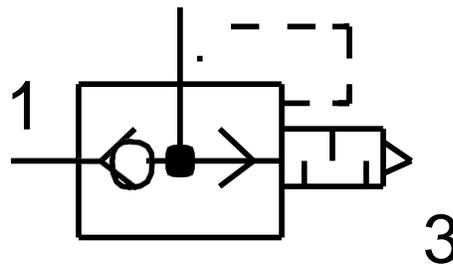
Figure 4A.6 Symbol for Quick Exhaust Valve

Forward Motion

During forward movement of piston, compressed air is directly admitted behind the piston through ports 1 and 2 Port 3 is closed due to the supply pressure acting on the diaphragm. Port 3 is usually provided with a silencer to minimise the noise due to exhaust.
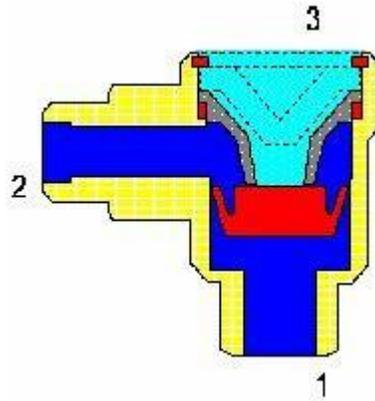
Figure 4A.7 Quick Exhaust Valve during Forward Motion

Return Motion

During return movement of piston, exhaust air from cylinder is directly exhausted to atmosphere through opening 3 (usually larger and fitted with silencer) .Port 2 is sealed by the diaphragm. Thus exhaust air is not required to pass through long and narrow passages in the working line and final control valve
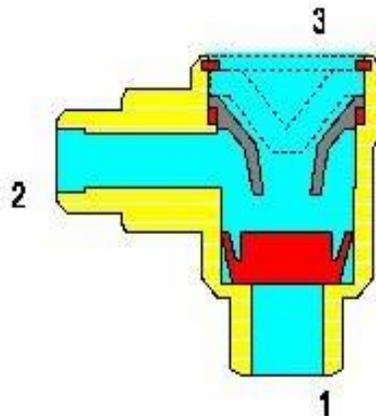
Figure 4A.8 Quick Exhaust Valve during Return Motion

Use of Quick Exhaust Valve
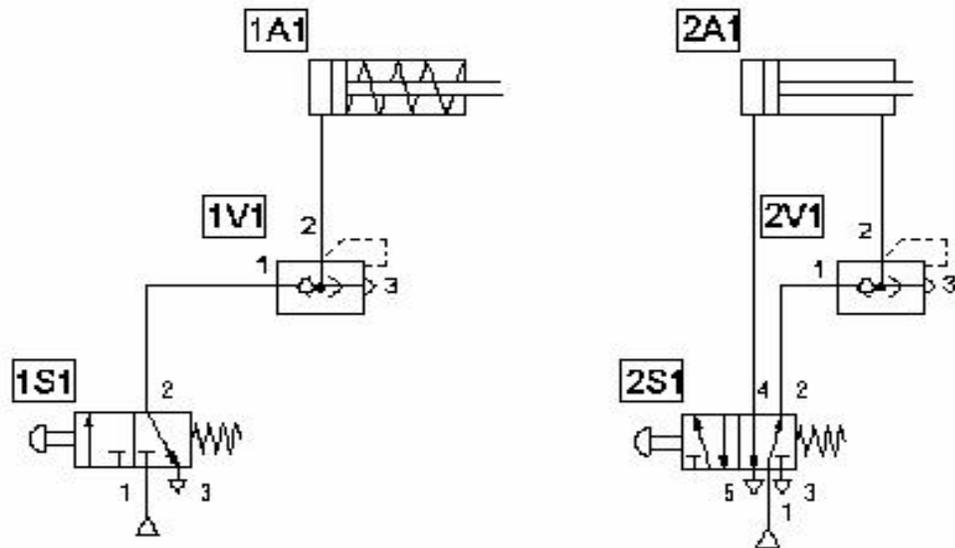
Figure 4A.9 Use of Quick Exhaust Valve

Example 4. 1

Liquid metal is drawn from a smelting crucible by a casting ladle and cast in moulds. The raising and lowering of the ladle is controlled by separate manual push buttons. The raising and lowering speed is separately adjustable . Design a Pneumatic control circuit for this application
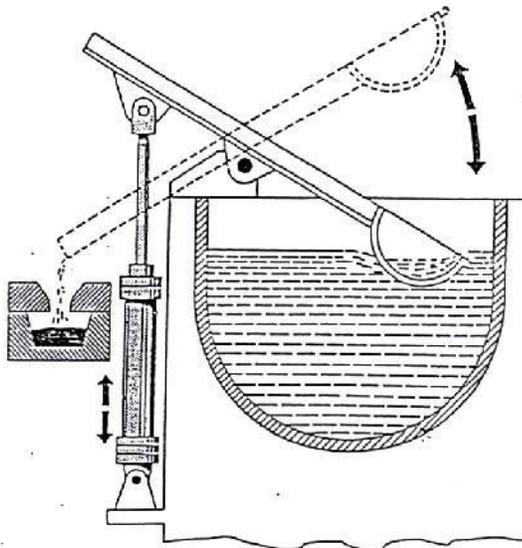
Figure 4A. 10 Casting Ladle Controlled by Cylinder
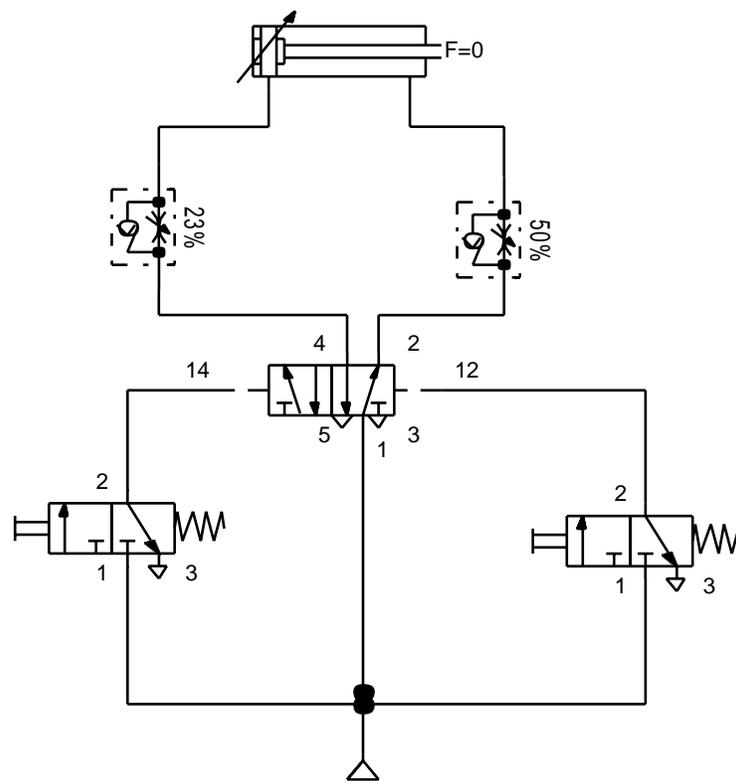
Figure 4A.11 Pneumatic Control for Casting Ladle

Coordinated Motion Control

In majority of the pneumatic applications more than one cylinder is used . The movement of these cylinders are coordinated as per the required sequence

- 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

Motion Diagram Step Displacement Diagram
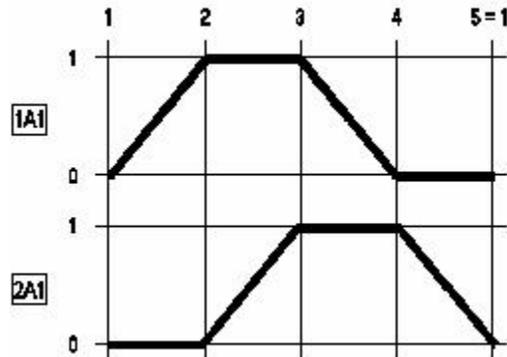
Figure 6.1 Motion Diagram –Displacement Step Diagram

• 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

Example: Coordinated Motion Control for a Stamping Application
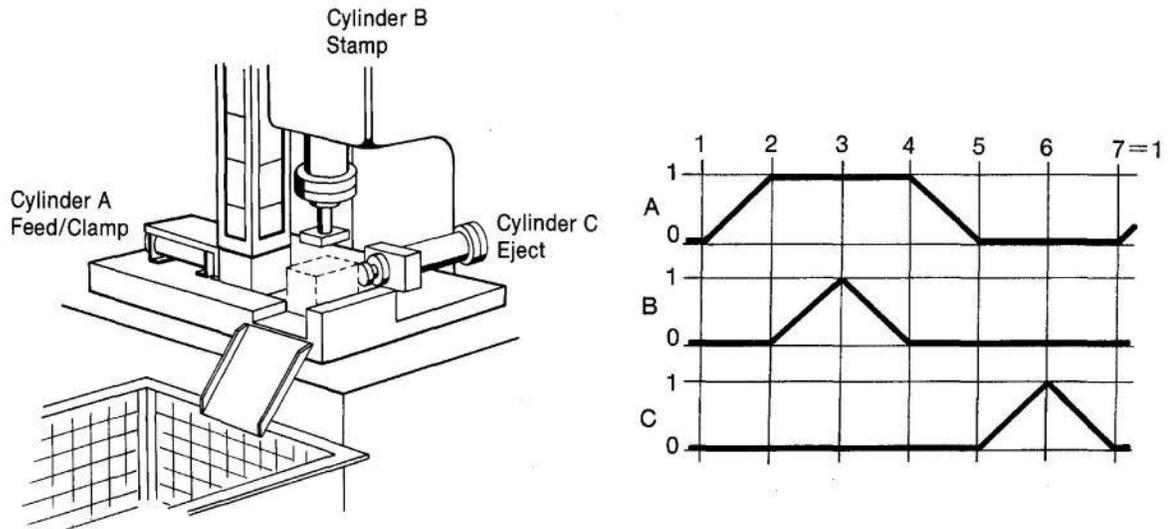
Figure 6.2: Clamping, Stamping and Ejection Application

Multi Cylinder Application with Two Cylinders A and B

Input Signals

-         Cylinder A – Limit switch at home position ao
-            Limit switch at home position a1
-         Cylinder B - Limit switch at home position bo
-            Limit switch at home position b1

Out put Signals
-         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+

Designation of Signals

a 0   a 1   b 0   b 1

A +   14   — 12 A -   B + 14   — 12 B -

5   3   5
  1   1
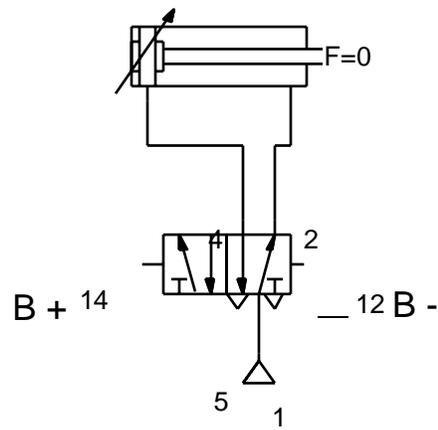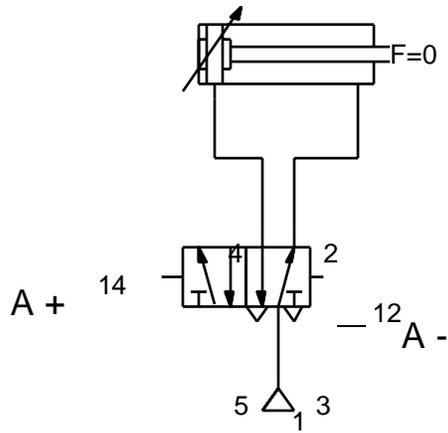
Figure 6.3 Designation of Signals Sequential Motion of

Cylinders

It is possible to have the following sequence of operation with **two** cylinders

Sequence	Example of Application
A+, B+, A-,B-	Lifting & Shifting / shifting of parts in two directions ,
A+, B+. B-,A-	Clamping & Stamping/Riveting
A+, A-, B+, B-	Feeding and Ejection of parts

Example 1: Lifting and Shifting

- Products are required to be transferred from lower level conveyor to higher level conveyor using two Pneumatic Cylinders
- Lifting Cylinder A lifts the product on receiving it at lower level
- Shifting Cylinder B shifts the product from the platform to the higher level conveyor
- Lifting cylinder retracts
- Shifting cylinder retracts

Cylinder B

Cylinder A
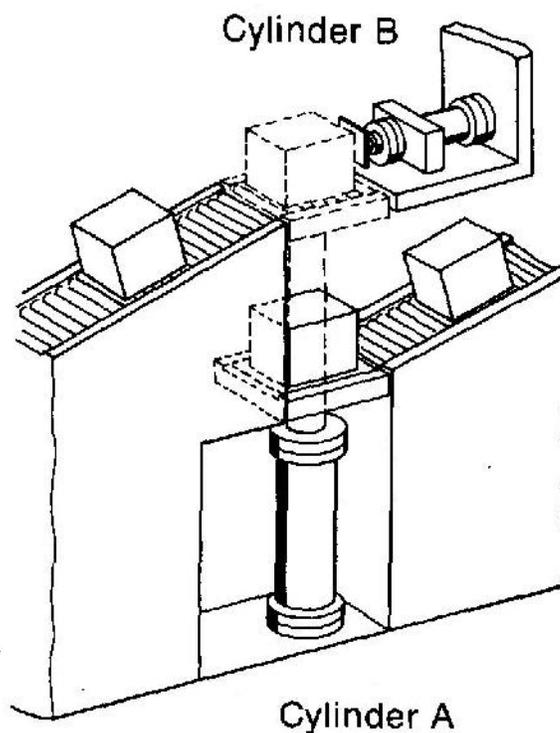
Figure 6.4 : Schematic of Lifting and Shifting Application

Motion Diagram Lifting and Shifting

- Motion and Control Diagrams are shown for Lifting and Shifting Application: A+,B+,A-,B-
- Signal 1.2 –Start Signal
- Signal 1.3- Extended position limit switch for cylinder B
- Signal 2.2- Extended position limit switch for cylinder A
- Signal 2.3-Home position limit switch for cylinder A

- NO SIGNAL OVER LAP
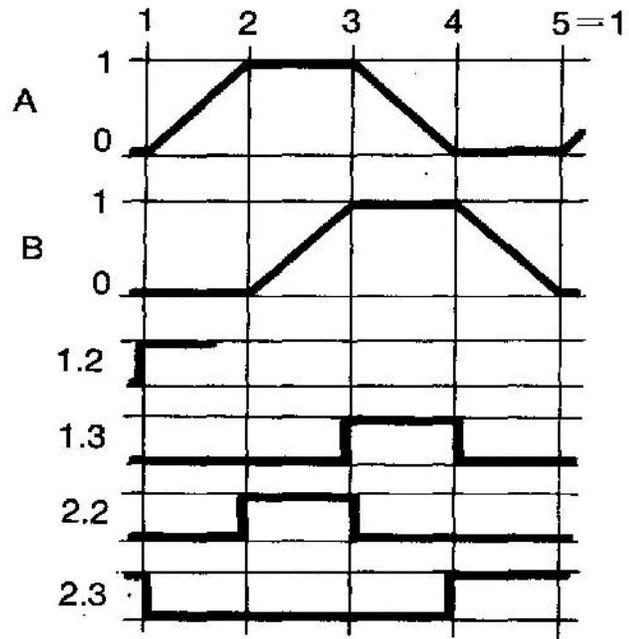
Figure 6.5 Control Diagram

Lifting and Shifting
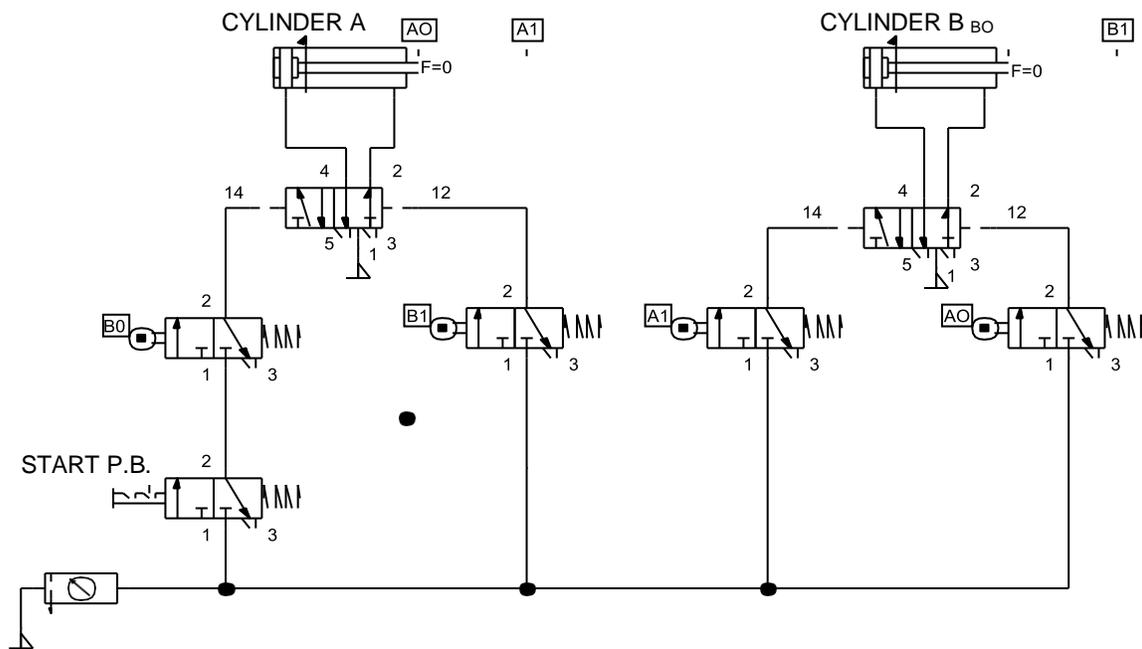
Figure 6.6: Pneumatic Circuit Diagram for Lifting and Shifting

Signal Overlap

Signal Overlap can occur when simultaneously two active signals appear on both set and reset pilot ports of Final Control Valve. This is due to the required sequencing of cylinder. At the start, both signals ao and bo appear at the same time. This will not result in any change.

6.7. Illustration of Signal over lap

Multi Cylinder Applications Signal Elimination

On analyzing the status of **set** signal and **reset** signal for final control valve for different cylinders, it is observed that both set and reset signals could be present simultaneously at any instant of time, depending on the sequential operation of the cylinder. This does not permit further change in status of the valve. This situation is termed as signal over lap. To overcome this problem signal elimination techniques are used as listed below:

- **Use of Idle return lever limit switches**
- Use of N.O Timers
- Use of Cascading with the help of reversing valves
- Use of Stepper Sequencer modules

Example 2: Clamping and Riveting

- Sheet metal components are to be riveted using two Pneumatic Cylinders. A Clamping cylinder (A) first advance and clamps the sheet metal parts.
- While the parts are clamped a second cylinder (B) advance and performs riveting operation
- The riveting cylinder retracts and finally clamping cylinder retracts

Figure: 6.8 : Clamping and Riveting Using Pneumatic Cylinders

- Control Diagram is drawn below the motion diagram represents the status of various signals- the limit switches used to interrogate the piston position
- Signals 1.4 and 1.3 correspond to home position and extended position limit switches of cylinder A respectively
- Signals 2.2 and 2.3 correspond to home position and extended position limit switches of cylinder B respectively
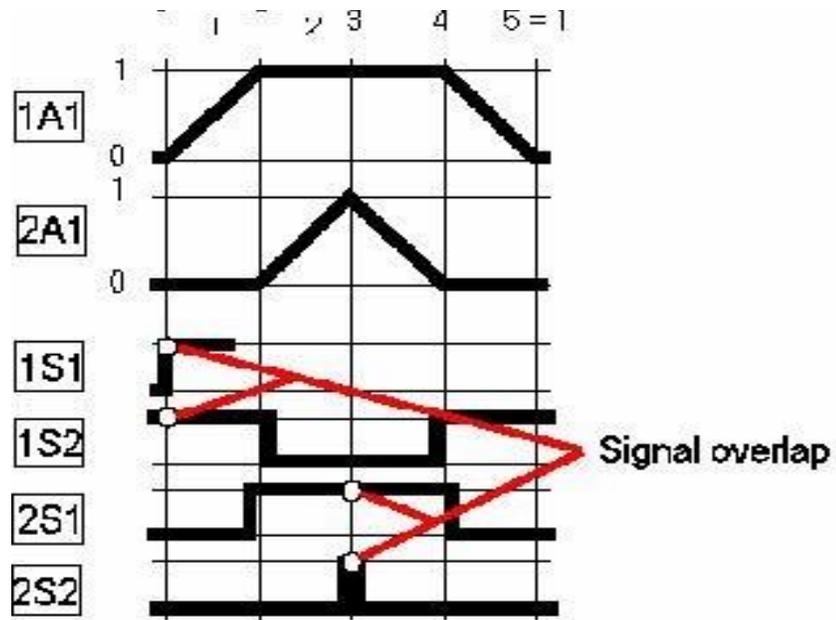
Figure 6..9 Control Diagram for Sequence A+,B+,B-, B-
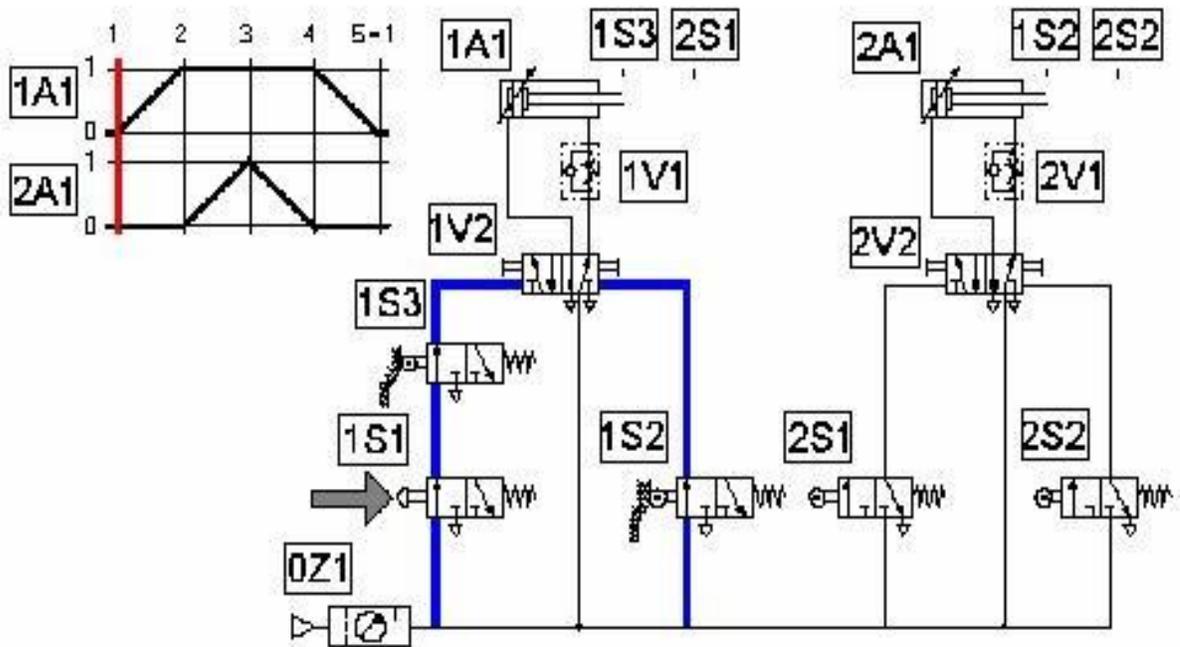
Figure 6. 10 Pneumatic Control Circuit and Control Diagram
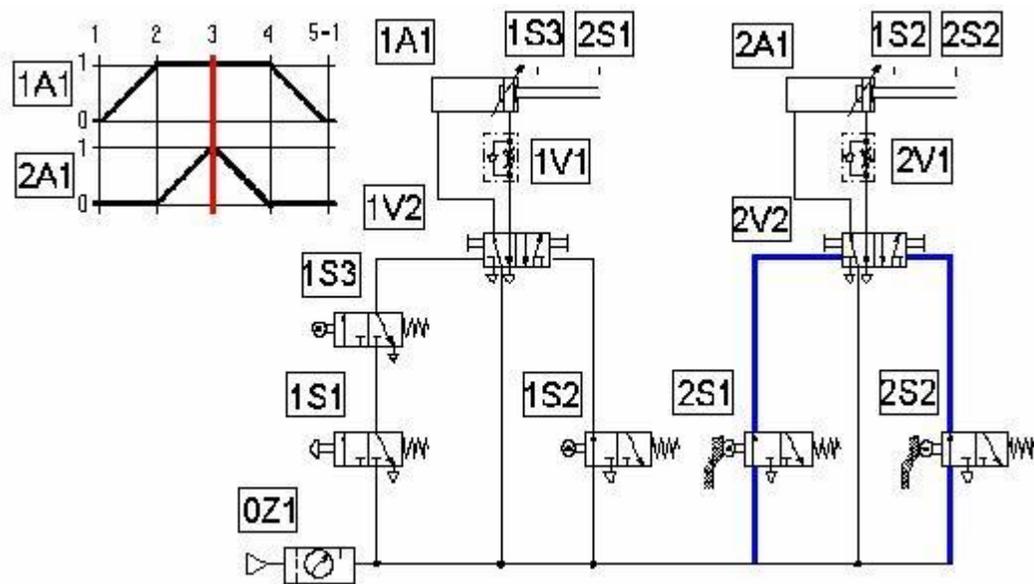
Figure 6.11 : Signal Over Lap at Step 3

Use of Idle Return Roller Limit Switch
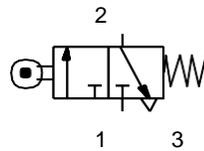
ROLLER LEVER LIMIT SWITCH
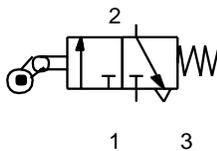
IDLE RETURN ROLLER LIMIT SWITCH

Figure 6.12: Limit Switches

- Roller Lever type Limit Switch gives mechanical signal which can be sensed in both direction movement of piston rod cam

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- Idle Return Roller Limit Switch gives mechanical signal due to actuation of roller only in one direction. This is conveniently used in **Signal Elimination**

Use of Idle Return Roller Limit Switches for Signal Elimination
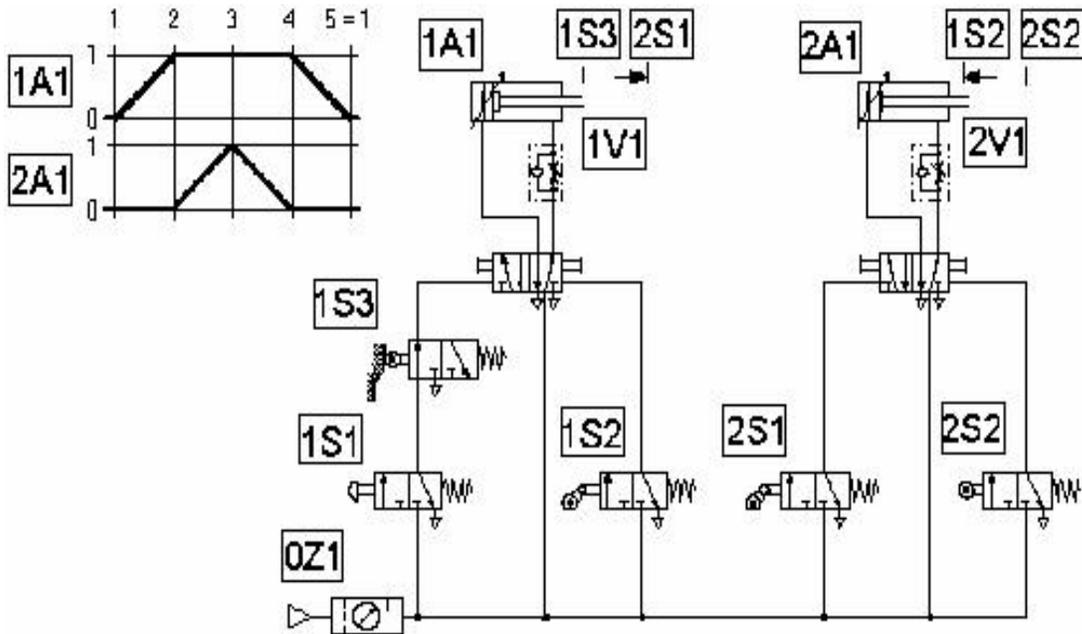
Figure 6.13 Use of Idle Return Roller Limit Switch

Exercise for practice:

Develop Pneumatic control Circuit for Sequence of Operation A+,A-, B+,B-
Using Control Diagram to find out the signal overlap status.

Electro Pneumatics

Electro Pneumatic control integrates pneumatic and electrical technologies, is more widely used for large applications. In Electro Pneumatics, the signal medium is the electrical signal either AC or DC source is used. Working medium is compressed air. Operating voltages from around 12 V to 220 Volts are often used. The final control valve is activated [setting] by solenoid actuation

The resetting of the valve is either by spring [single Solenoid]or using another solenoid [Double solenoid Valve] . More often the valve actuation/reset is achieved by pilot assisted solenoid actuation to reduce the size and cost of the valve

Control of Electro Pneumatic system is carried out either using combination of Relays and Contactors
or with the help of   Programmable
Logic Controllers [PLC]

A Relay is often is used to convert signal input from sensors and switches to number of
out put signals [either normally closed or normally open] .
Signal processing can be easily achieved using relay and contactor combinations

A Programmable Logic Controller can be conveniently used to obtain the out puts as per
the required logic, time delay and sequential operation.. Finally the out put signals are
supplied to the solenoids activating the final control valves which controls the movement
of various cylinders. The greatest advantage of electro pneumatics is the integration of
various types of proximity sensors [electrical] and PLC for very effective control. As the
signal speed with electrical signal, can be much higher, cycle time can be reduced and
signal can be conveyed over long distances.

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

1. Signal input devices -Signal generation such as switches and contactor, Various
types of contact and proximity sensors
2. Signal Processing – Use of combination of Contactors of Relay or using
Programmable Logic Controllers
3. Signal Out puts – Out puts obtained after processing are used for activation of
solenoids, indicators or audible alarms
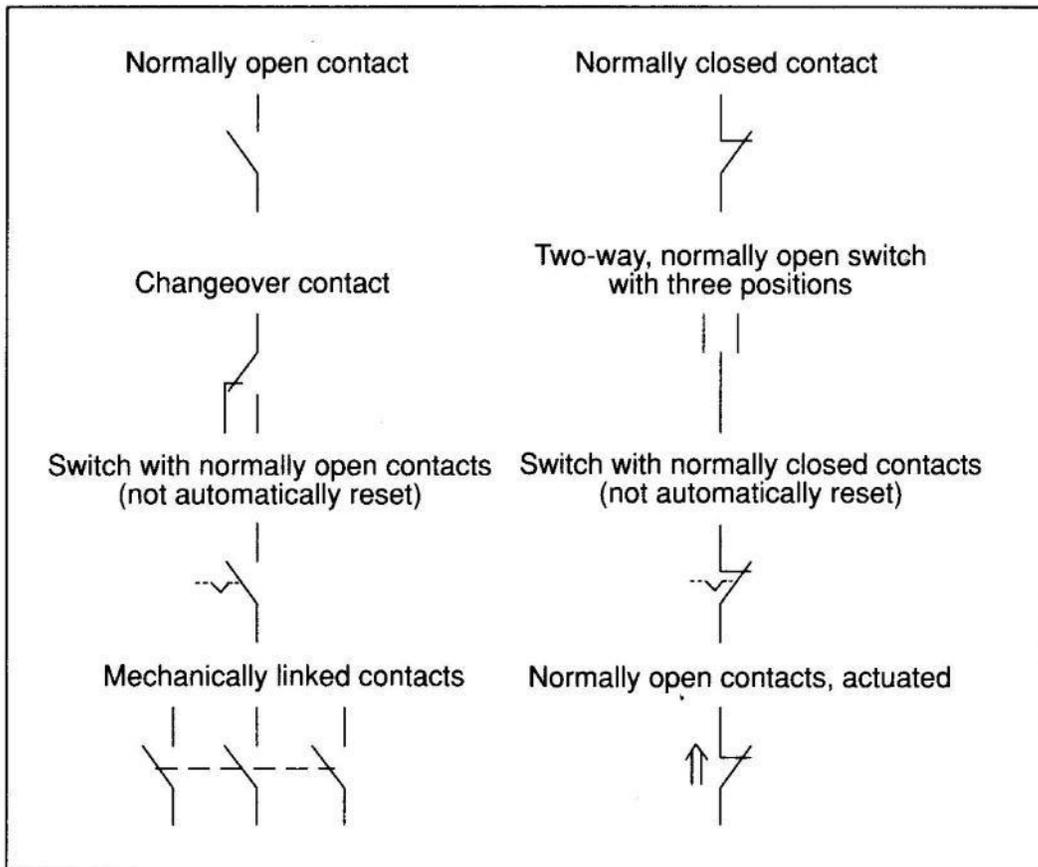
Figure 9.1 Symbols for Switches and contactors

Symbol- Single solenoid Valves
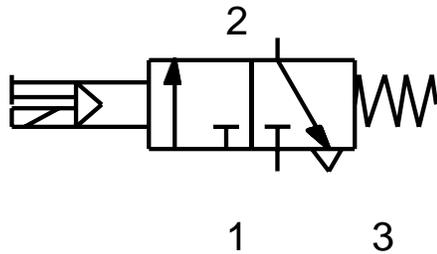
Single Solenoid Valve- Pilot assisted
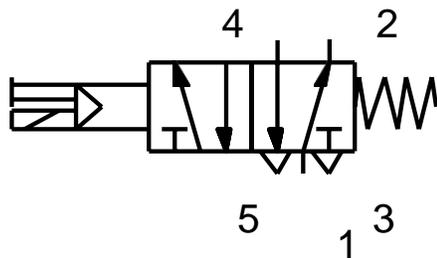
Double Solenoid Valve- Pilot assisted

Figure 9.3 Symbolic Representation for Solenoids and Relays

Electromagnetically actuated on both sides

Electromagnetically actuated on one side, with spring return

Representation in electrical circuit diagrams

Electromagnetically actuated, with pilot control

Relay with specification of DC resistor

Contactor or relay with three normally open and one normally closed contacts
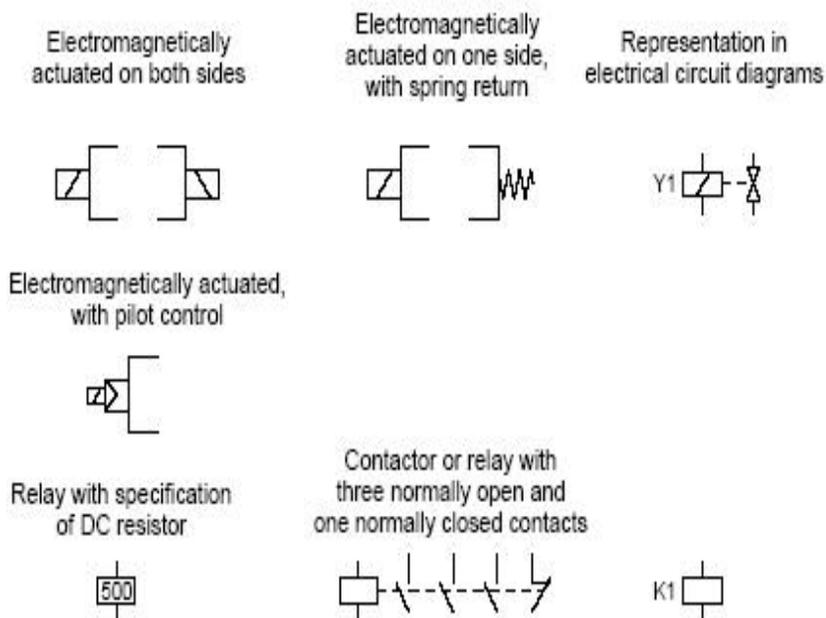
Figure 9.4. Symbols of Solenoid Valves and Relays

Types of Relays
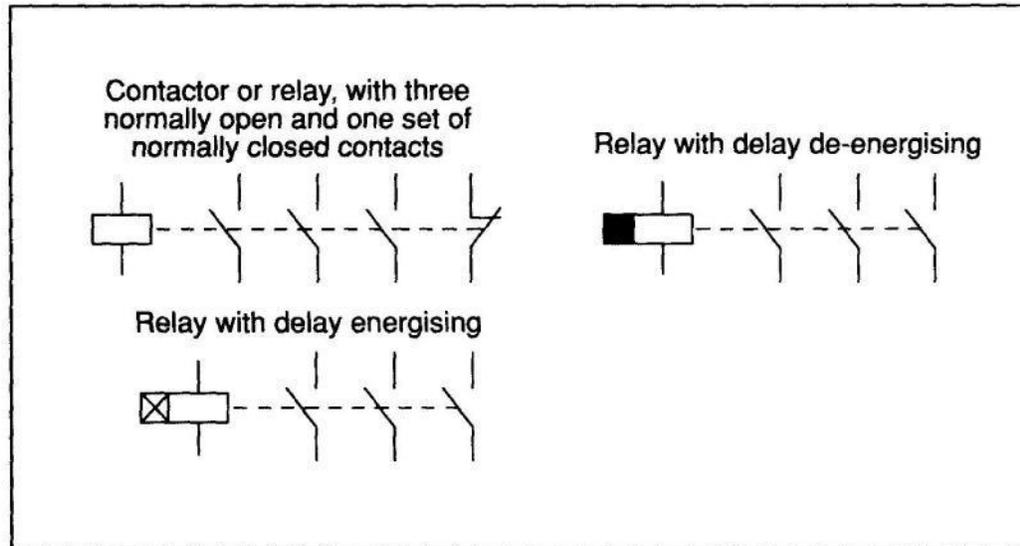
Figure 9.5 Types of Relays

Signal flow in Electro Pneumatic Circuit

Electro Pneumatic Control
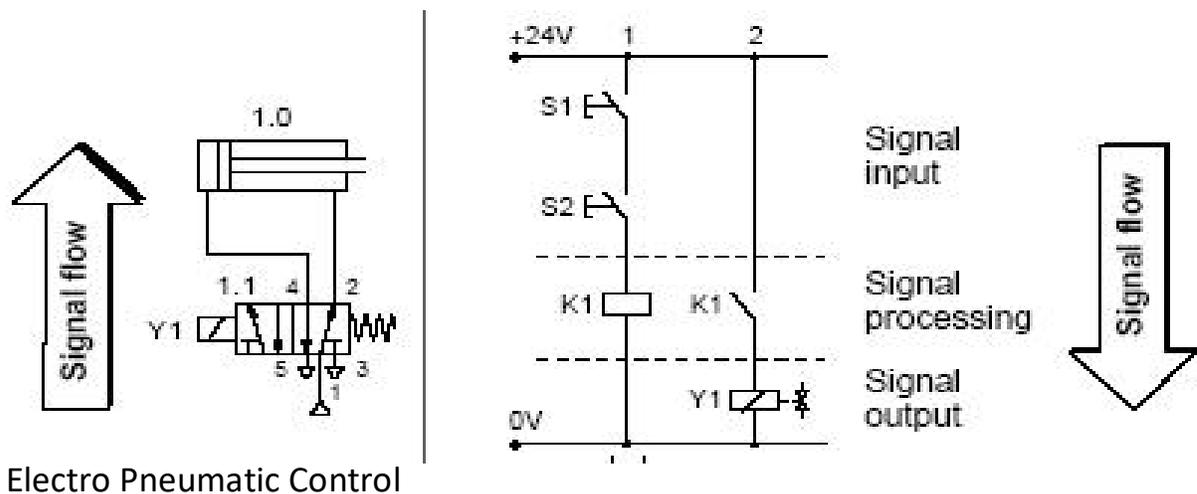
Fig 9.6 Signal Flow in Pneumatic and Electrical Control Circuit

Control of Double Acting Cylinder

Indirect Action of Double Acting Cylinder Using a Relay
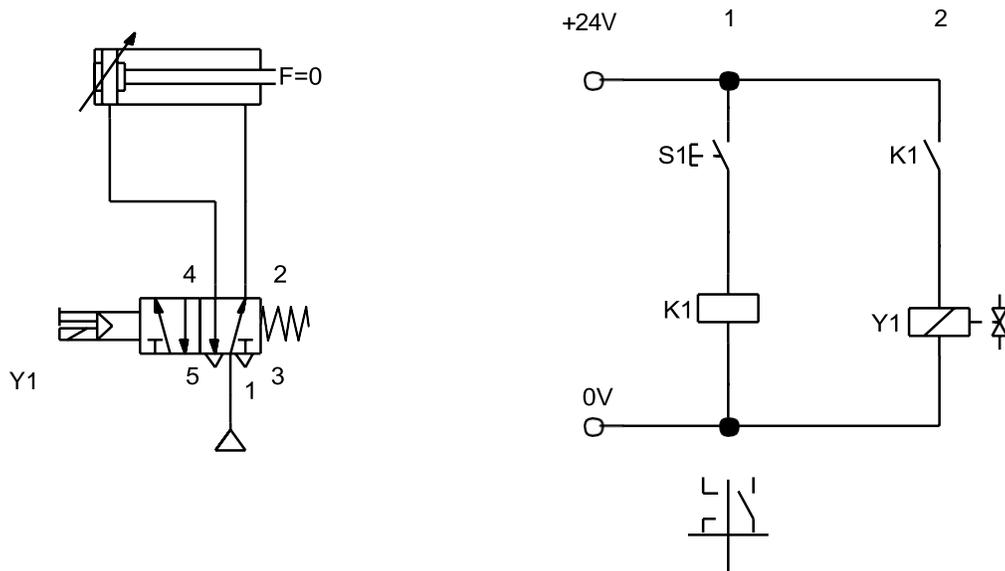
Figure 9.7 Control of Cylinder Movement indirectly using Relay

Indirect Actuation of Double Acting Cylinder for Forward and Return Motion

45
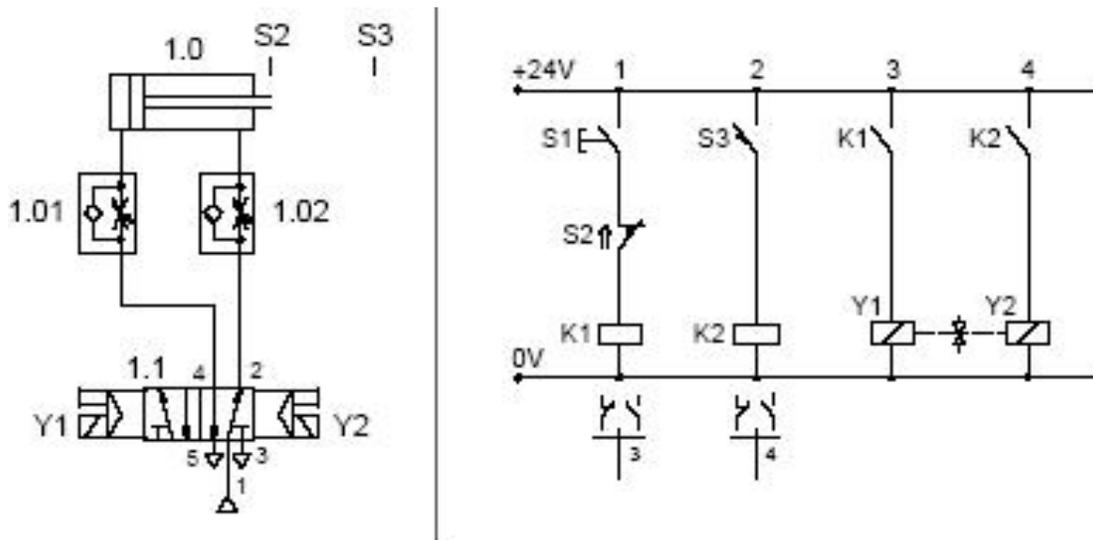
Figure 9.8 Indirect Control of Double Acting Cylinder
With continuous Reciprocating Motion

Logic Circuits
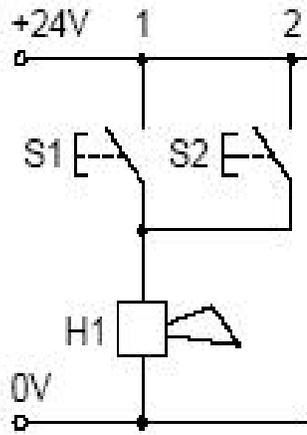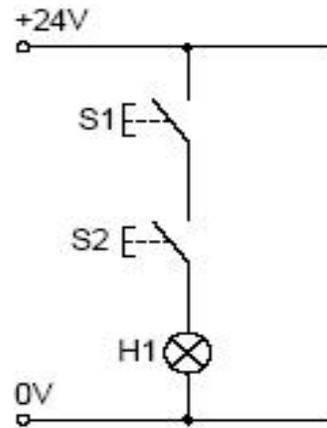
OR Logic Circuit   AND Logic Circuit

Figure 9.9: OR and AND Logic Circuit

Magnetic Reed Switches
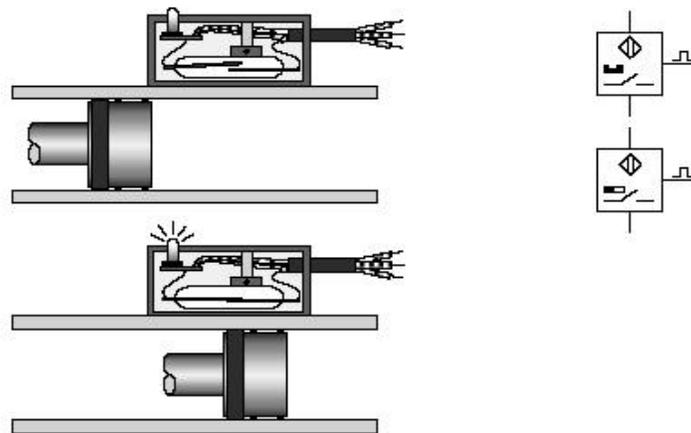
Figure: 9.10 : Magnetic Reed Switches

•Magnetically operated Reed Switches consists of electrical contactors in a sealed glass tube. The terminals of the contactors are taken out through an indicating lamp. The glass tube is encapsulated in a housing filled with epoxy resin. It is necessary to have a magnetic ring incorporated in the piston, so that when the piston is in the proximity of reed switch ,the contactor will get closed and out put is available at the terminal

Electro Magnetic Relay

Relay is essentially a electromagnetic switch, operated at low voltage,
Relay has a relay coil and several contactors
Commonly 24V D.C source is used for relay coil and contactor circuit
Relay contactor out puts either NO or NC can be conveniently used for signal processing
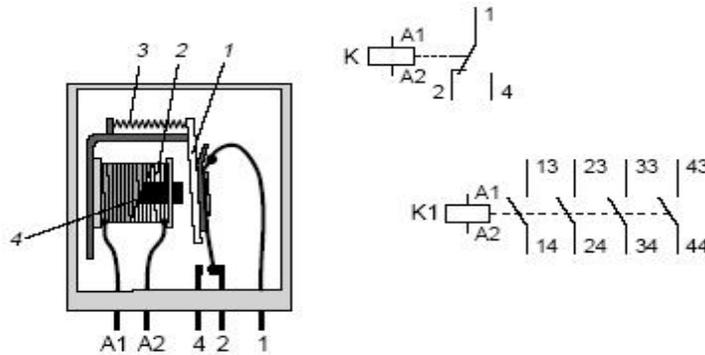
Figure 9.11 Electro Magnetic relay with Symbol for multiple contactor

<u>**Holding Circuits**</u>
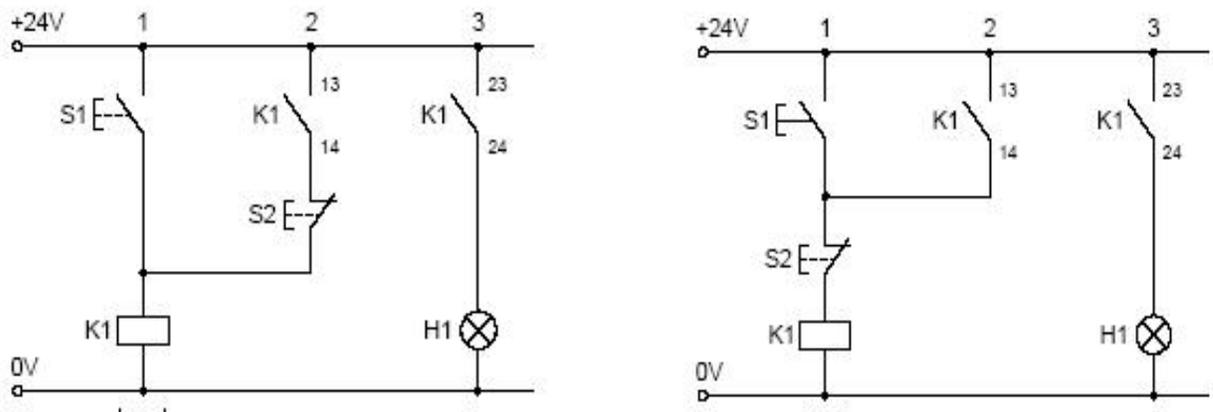
Dominant On circuit Dominant Off circuit Figure 9.12 Holding Circuits

Pilot Assisted Solenoid Valve
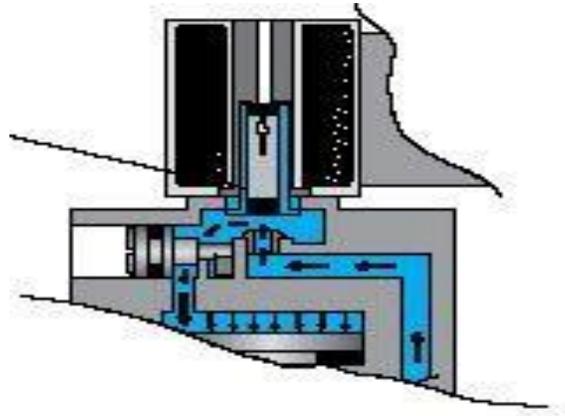
Figure 9.13 Pilot Assisted solenoid Valve
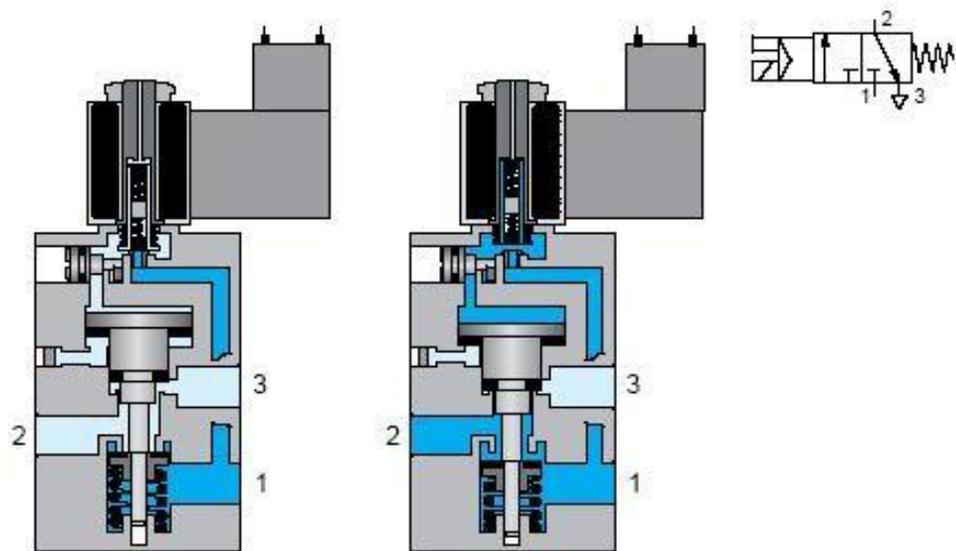
3/2-way solenoid valves with pilot control

Figure 9.14 3/2 Way Pilot Assisted Single Solenoid Valve [Normally Closed]

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – V – Fluid power system– SME1302

UNIT 5 TROUBLESHOOTING AND APPLICATIONS

Hydraulic safety

Before attempting to perform any testing or checks on a system or dismantling any components, you should make sure that working conditions are safe. The following rules must be observed. They are essential for safety – and will be included in the assessment for this unit of competency.

1. **Isolate** the machine from external power supplies.

2. Use the 'tag system' to prevent other people from trying to operate the machine. This is extremely important – particularly if the machine may be left unattended. The types of tags most commonly used are illustrated below.

Figure 1: Danger Tags

(Provide support for pressure-held loads that could fall when the pressure is removed through disconnection of the working unit.

3. Relieve the system pressure. It is dangerous to remove a hose that contains oil under pressure. Operate valves each way after the pump has been switched off and the system is at rest, to bleed it of any line pressures.

   Note: Although oil under pressure does not contain any stored energy, as compressed air does, stored energy may be present in pressurised flexible hoses, in a cylinder holding up a load or in a charged accumulator.

4. Some hydraulic pumps and control valves are heavy – so you must provide a means of support, such as a chain hoist, floor jack or blocks, before removing them.

5. When working on machines with mobile parts, make sure there's enough space in the workshop to conduct the maintenance procedure. For example, you must consider whether a rotating boom might collide with part of the workshop during machine testing – or whether some other activated device might hit the ceiling or overhead power lines.

6. Keep your work area tidy. Use drain trays under hydraulic equipment and, if any oil spillage occurs, clean it up immediately. Remember that one quality of oil is reduction of friction – and oil on the floor will reduce the friction between your footwear and the ground, which could lead to an accident.

7. Never service a hydraulic system while the motor, pump or actuators are operating – unless *absolutely* necessary.

8. To ensure control of the unit, keep the hydraulics in proper adjustment.

9. When washing parts, use a non-volatile cleaning solvent that is compatible with the hydraulic system.

10. When using test equipment coupled to flexible hoses, tie down the hoses and/or the equipment. As flexible hoses are pressurised, they stiffen and tend to straighten out. Unless restrained, any test equipment attached to the end will lift up in the air and then, when pressure is released, crash down again, potentially damaging itself.

11. Make sure that all line connections are tight and that lines are not damaged. Oil escaping under pressure is a fire hazard and can cause personal injury.

12. Be aware that, although manipulating hydraulic control valves may bleed down a system, pressure may still be trapped in a system which has counterbalance and pilot-operated check valves incorporated. This is because hydraulic pressure is required to operate these valves. You should therefore make yourself familiar with a system and its components before starting work on it.

13. Pinhole leaks in hydraulic hoses are a hazard and can be difficult to detect. Never use your hands to detect leaks, as oil can be injected into your bloodstream causing serious injury. When checking for pinhole leaks, a card or piece of cardboard should be used.

Hydraulic maintenance principles

System maintenance

A hydraulic system is easy to maintain, because the oil provides a very effective lubrication medium, while the system control valves protect the machine from mechanical overload.

Like any other mechanism, however, it must be operated and maintained correctly. Hydraulic systems can be damaged by excessive speeds and pressures, by fluid contamination and by high operating temperatures.

By using a regular maintenance program (preventative maintenance) to care for a hydraulic system, you can eliminate common problems and anticipate special ones. Problems can be corrected or averted before a breakdown occurs.

The following are the key problems that commonly need to be addressed in servicing hydraulic systems:

- contaminated oil
- poor fluid filtration
- incorrect fluid selection
- low fluid level
- high fluid temperature
- loose supply lines
- faulty seals.

The importance of cleanliness

Cleanliness is of supreme importance in servicing hydraulic systems. Keep dirt and other contaminants out of the system. Small particles can score valves, cause seizing of pumps and clog

orifices – resulting in expensive repair jobs.

When servicing a hydraulic system, always make sure you do the following.

- Keep the oil clean.
- Keep the system clean.
- Keep your work area clean.
- Be careful when you change or add oil.

Strive to keep oil clean from the minute it is delivered to you. This entails a number of things. Choose a clean location for storing oil. When oil is taken out of storage, use only clean containers with lids for carrying it from storage to the point of use. Use a clean funnel fitted with a fine-mesh screen when pouring oil from the container into the reservoir.

Keep an adequate supply of clean strainers, funnels and oil containers. Store them in a clean, dust-free environment. Use a clean, lint-free cloth to wipe the dipstick when checking oil levels.

Ask machine operators and service technicians to do everything possible to prevent dirt getting into the oil during the operation and servicing of a machine.

Fluid contamination and filtration

Fluid contamination

Contamination of fluids is by far the greatest source of trouble in hydraulic systems. Contamination may occur in several ways – ranging from unsatisfactory storage and careless handling of fluid to ineffective filtration and inadequate cleaning of the system.

System cleanliness and filtration are important factors in the long-term performance and effectiveness of hydraulic oil. Removal of contaminants is beneficial to both its lubrication properties and working life, since foreign matter is likely to be abrasive and also to act as a catalyst in encouraging chemical degradation. Moreover, the performance of a system is upset when silting prevents valves from moving freely through their full travel.

Oil that's contaminated by fine, hard particles can lead to severe wear, both in narrow clearances and where sudden changes of direction occur. This problem is particularly serious where the essential *sharp* edges of control valves are rounded off by erosion in high rates of flow; the result is that fine working clearances (magnified in Figures 3–6) are widened to a degree that seriously affects the accuracy of control.

Effect of erosion

In modern hydraulic systems, the close tolerances and high precision of components make it essential to keep fluids as free as possible from contamination by dirt, deposits and other foreign matter. Freedom from trouble cannot be guaranteed, even when clean fluid straight from the supplier is put into a new system. Various internal sources can put foreign matter into circulation long after the system has been commissioned – matter such as pipe scale, rust, thread-sealing compound, casting sand, flakes of paint, trapped swarf and weld spatter. Dirt and dust from the atmosphere may also be drawn into the system if the reservoir tanks are not properly fitted with filtered vents. Also fine metal particles are continuously created by the normal wear of moving parts. Rust caused by water contamination can be a further source of trouble. Rusted parts do not operate smoothly and rust particles can score moving parts.

Filtration

Filtration is undoubtedly the most effective way of removing solid contaminants from hydraulic fluids and virtually all hydraulic systems today incorporate efficient filters. Ideally, a filtration unit should satisfy several requirements. It should:

- remove solid contaminants efficiently
- remove all particles larger than a critical size, determined by the characteristics of the system's hydraulic components
- be sited where it can be easily cleaned
- give some indication of loss of efficiency – for example, through a gauge which indicates when cleaning is required.

Importance of oil and filter changes

You can't get peak performance from a hydraulic system that isn't clean.

Whatever precautions you take when working with a hydraulic system, some contaminants will get into the system anyway. Good hydraulic oils will hold these contaminants in suspension and the filters will collect them as the oil passes through. Good hydraulic oil contains many additives which work to keep contaminants from damaging or plugging the system. However, these additives lose their effectiveness after a certain period or amount of use.

Therefore, you should change oil at the recommended intervals – to ensure you maintain an active oil.

A system's filters can absorb only a limited amount of dirt and other contaminants from the oil. Filters stop working once they reach their limit.

Before this point is reached, you should clean the filters or replace them with new ones so an active filtration process is maintained. Filters that have been removed should be inspected – the amount and type of contamination they have trapped will provide an insight to the health of the system.

A filter is only as good as the maintenance it receives.

Filter service

Frequency of cleaning is one of the most important considerations in utilising any filtration system – and maintenance staff need to adhere to strict cleaning schedules. Some filter units incorporate indicators that tell operators when the pressure drop across the element is approaching a level where cleaning or replacement is required.

The effects of contamination on hydraulic components

Hydraulic component manufacturers agree that dirt is the cause of most malfunctions and unsatisfactory component performance. The effects of dirt on the various components of hydraulic systems are discussed below.

Pumps

In hydraulic pumps, dirt can:

- destroy working tolerances within the pump

- cause vanes to stick, thereby creating erratic action

- cause vanes to wear out the cam ring

- wear out rotor slots

- increase shaft journal and bearing wear

- increase gear wear, resulting in inefficiency

- increase piston and cylinder wear, resulting in inefficiency.

   Dirt in compensator controls on variable-volume pumps causes sticking, slow response and erratic delivery, which affects the performance of the entire system, resulting in excessive heat and inefficient power use.

Relief valves

Dirt in relief valves can cause:

- valve chatter

- seat wear within the valve

- valve failure, causing pressure to become erratic – which affects the function of the entire system.

   The diagram below shows areas within a relief valve that are commonly affected by contamination.

Valve unseated by dirt
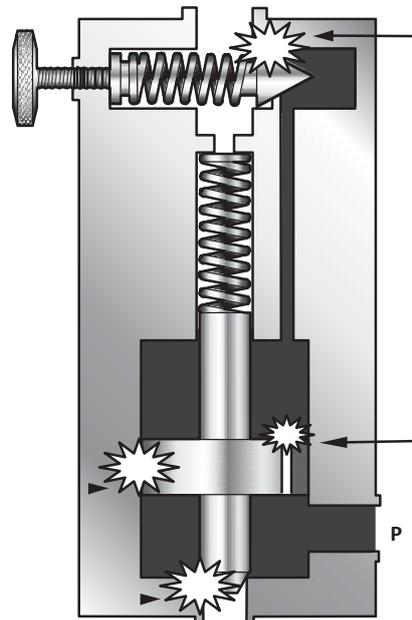
Orifice blocked by dirt

Sticking spool

P

Valve unseated by dirt

T

Figure 3: compound relief valve – common contamination sites

Directional valves

Dirt contamination in directional control valves can cause:

- blocked orifices
- wear to spool and body lands, which creates excess internal leakage
- spools to stick, which can result in solenoid failure
- valves to stick and cause excessive shock loads with damage to hose, piping, fittings and various other components.

Wear on spool and body lands

Seal wear and sticking valves
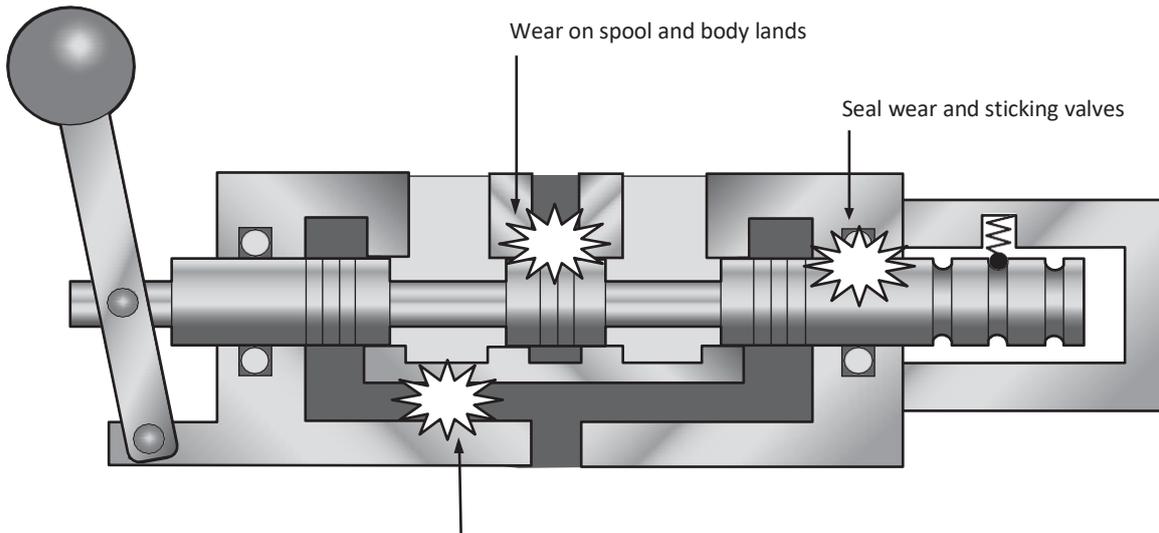
Port blockage

Figure 4: effects of contamination on directional control valves

Check valves

Check valves are designed to allow fluid flow in one direction. Dirt in these valves can:

- cause wear on the poppet seats, creating leakage
- permit fluid to bypass the check (reverse flow), as illustrated below.
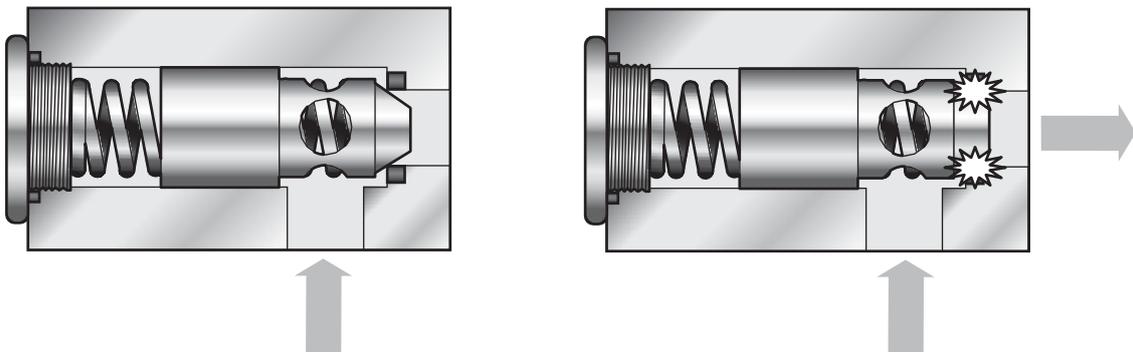
No flow

Reverse flow caused

by contamination under valve seat

Figure 5: check valve malfunction

Flow-control valves

In flow-control valves, dirt can cause erosion at the orifices, which will change the valve's flow characteristics.

Servo valves

Servo valves require a high level of filtration to maintain their accuracy. Contamination in these valves can result in the erosion of sharp edges, which will affect metering. Dirt can also result in the blockage of nozzles, because of their very small size.

Cylinders

Contamination in linear actuators can result in:

- excessive wear of the cylinder rod, packing and bore
- malfunction of the cushions
- cylinder drift or creep
- The cylinder losing its capacity to hold a load.
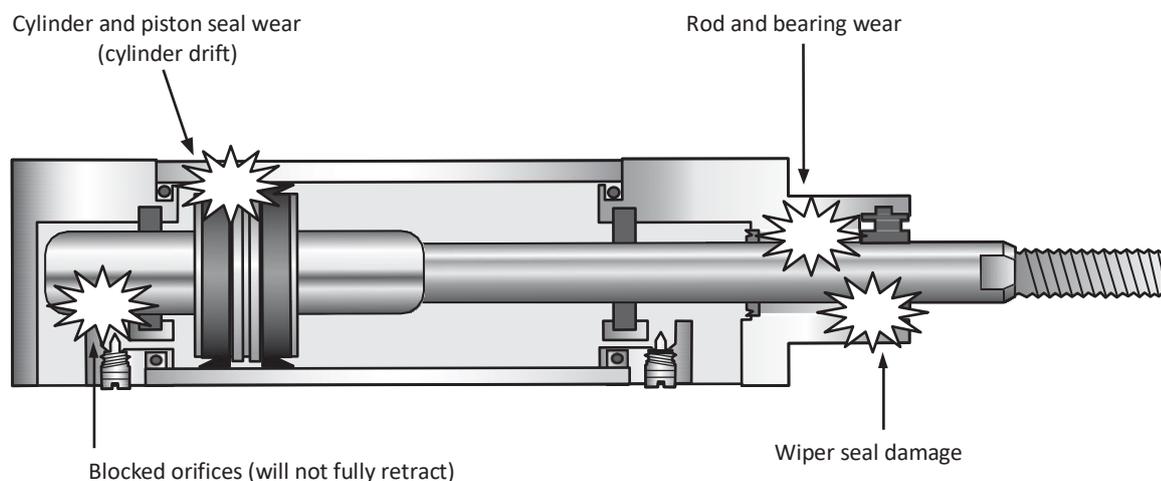
Figure 6: cylinder damage

Fluid motors

In hydraulic motors, the effects of contamination are generally similar to those exhibited by pump wear and result in reduced motor efficiency.

Fluids and fluid terminology

You should understand the following terms:

- **viscosity** – the degree to which a fluid resists flow. As temperature increases, viscosity decreases.

Honey, for example, has a high viscosity but flows increasingly easily as temperature increases.

- **viscosity index** – a measure of a fluid's resistance to, or rate of, viscosity change with change in temperature; the higher the index number, the less viscosity
will change with heating. *Ideally*, in hydraulics, a fluid's viscosity would remain constant at different temperatures.

- **demulsification** – the prevention or breaking down of liquid–liquid emulsions.
A fluid's demulsification properties will determine the degree to which it resists mixing with water. Demulsifiers allow the rapid separation of water from a hydraulic fluid.

Dirt in a hydraulic fluid:

- acts as a catalyst in breaking down molecular structure, causing gummy residual 'varnish'

- attacks the oil additives and changes the composition of the fluid.

Proper maintenance of hydraulic systems should keep troubles to a minimum. Experience has shown that proper and efficient running of hydraulic equipment is almost entirely in the hands of the user. For example, an analysis of a manufacturer's call-outs to customers' plants showed that 70 per cent of typical service calls were the result of improper condition of the oil concerned; dirty oil; incorrect oil type; water in the oil (rust); lacquer, varnish and sludge formation; or lint and/or other contaminants in the oil. Oil with good demulsification properties will not only resist mixing with water but allow rapid separation of oil and water mixtures.

Oxidation in a hydraulic fluid occurs when oxygen combines with the original hydrocarbon molecules and produces a chain reaction. Traces (even a few parts per million) of certain metals – particularly copper, iron, zinc and lead – and water act as catalysts and markedly increase the rate of oxidation.

Oxidation produces soluble as well as insoluble products and these may form sticky substances which may be deposited as gum or sludge in oil passages, various pump parts, valve spools and ports etc. This may result in blocking and the restriction of oil flow, thereby making the machine run sluggishly.

High operating temperatures severely stress hydraulic oil and, when it overheats, lacquers are formed. As lacquer deposits build up, friction between moving components increases – causing further temperature rise and escalation of the problem.

Varnish deposits in hydraulic oil are a result of oxygen in the oil and frequent draining of a hydraulic system will help to reduce the formation of gum and lacquer.

Contaminants

Typical contaminants that may be found in a hydraulic system include:

- dirt and dust

- grease from cleaning rags

- metal chips

- metal particles resulting from normal wear of moving parts

- packing and gasket fragments

- paint flakes

- pipe scale

- pipe-thread compounds

- rust particles

- water
- weld spatter
- incorrect hydraulic oil.

Maintenance suggestions

- Set up a filter maintenance schedule and follow it diligently.
- Inspect filter elements that have been removed from the system for signs of failure, which may indicate that the service interval should be shortened or that there are impending system problems.
- Do not return to the system any fluid that has leaked out.
- Make certain that fluid used is of a type recommended by the manufacturer for the system or component. That is, ensure that the fluid is compatible with the system.
- When checking oil level or adding oil to the system, make sure you clean the areas around the dipstick and filler cap before removing them.
- Before adding oil, be sure that the existing oil in the system is clean. If it's not, drain the oil and refill the system completely with new oil that will give good performance under prevailing conditions.
- Use clean containers, hoses and funnels when filling the reservoir. Using a filter cart when adding oil is highly recommended.
- Make sure that all clean-out holes, filler caps and breather cap filters on the reservoir are properly fastened.
- Do not run the system unless all normally provided filtration devices are in place.
- Use common-sense precautions to prevent dirt entering components that have been temporarily removed from the circuit.

Service tips

- Clean the machine areas before removing hydraulic components.

  Note: When steam cleaning or using water to clean a machine, make sure that filler openings, breather caps etc are protected from possible entry of water into the system.

- Use clean plastic plugs to cover the ends of disconnected lines or to plug openings when you are working on a hydraulic system.
- A clean workbench is an absolute 'must' when servicing components. An industrial-type vacuum cleaner is a valuable aid in removing dust, dirt and tiny metal particles from the work area.
- Check the condition of your tools – they should be clean. Always use hammers with heads made of plastic or leather, so there's no danger of metal chips getting into components.
- When removing parts for service, clean them and then store them in plastic bags or other clean containers until they are installed again.
- Thoroughly rinse the cleaned parts and dry them using clean, dry compressed air. Protect the parts immediately with a coating of rust-preventive oil.
- When cleaning, use extreme care to prevent damage to closely fitted, finely finished parts. Use gum solvents or chemical cleaners to clean metal parts only. Do not allow these cleaners and solvents to come into contact with seals or gaskets.

- Blank off all disconnected lines, hoses and openings.

Hydraulicsystemtesting and diagnosis

System performance

System performance depends upon several factors which require careful consideration during the application, design, installation and site location stages. All these parameters should be analysed if the hydraulic system is to operate effectively and efficiently. Loss of system efficiency through pressure and/or flow-rate drop is very costly in terms of machine downtime and lost production. Hydraulic problems that affect system flow and pressure are not always easy to locate. This section provides a clear and concise guide to system testing and troubleshooting. The troubleshooting charts towards the end of the section are designed to make the fault-finding process easier and faster. However, if the problem is not readily solved and inadequate flow rate and/or pressure continues, a portable hydraulic tester should be used.

Before any test procedures are carried out, the manufacturer's specifications must be obtained and studied to determine whether the hydraulic components are operating within design specifications – or are having impossible system demands placed upon them.

Effects of a drop in system flow rate

Reduced flow rate will affect the speed and cycle time of the hydraulic machine; actuators will not extend, retract or rotate at the required speed. Actuator control will become jerky with inconsistencies in flow as cylinders and motors are supplied at different rates. In many complex hydraulic systems, the sequencing and positioning of component operations will be affected as cycle times become thrown out of programmed control. The quickest method of checking a system's performance is to check the cycle time with a stopwatch.

The pump's flow rate should be checked first to ensure that the drop in flow is not a result of internal leakage or incorrectly set pump controls. A high temperature at the pump is often a sign of excessive leakage as a result of internal wear within the pump.

Flow rate drops linked to hydraulic motors, control valves and leaking seals may only be detected through using a portable hydraulic tester.

Effects of drop in pressure

Pressure drop is essentially a change in hydraulic energy. Resistance to flow caused by friction converts pressure to heat energy. A drop in pressure affects the work capability of a hydraulic machine. The result is a reduction in the amount of work, such as force and torque, that the system produces. Machines lose efficiency, as the
cylinders can no longer operate effectively at set pressure and force requirements. The torque capabilities of hydraulic motors are seriously impaired. Some motor designs require high initial pressure to start the motor – so pressure drop will not only affect the motor's running torque but also

start-up torque.

Hydraulic components are dependent upon precise pressure settings and will become erratic in operation or will not fulfil their circuit function if pressure drops below pre-set limits. Systems that depend upon a constant pressure to operate should be designed with a back-up accumulator to overcome safety problems which might arise through sudden pressure drops.

The major causes of pressure drop include:

- pipework restrictions, for example incorrect sizing
- fitting restrictions and sharp corners
- fluid temperature rises
- incompatible hydraulic fluid
- incorrect pressure settings
- sudden enlargement in fluid conductors
- long lengths of fluid conductors
- component leakage (internal and external)
- broken valve springs
- blocked pressure filters
- valves not sealing correctly because of contaminants
- some combination of the above causes.

A combined drop in flow rate and pressure will affect the power requirements of a hydraulic machine, especially in mobile applications, where the speed of the prime mover will have to increase to meet system demand. Pumps powered by electric motors cannot increase their revolutions to provide greater flow rate. Hydraulic motor performance is affected in terms of a drop in power (torque and speed capabilities).

Actuators convert hydraulic energy back into mechanical energy. It is here that lack of flow and pressure instigates the fault-finding process. Jerky cylinder and motor movements are unacceptable and the combination of these hydraulic faults results in a machine's power performance dropping. The problem must be solved to ensure efficient operation.

System testing procedures

Hydraulic systems, like all machines, require routine maintenance to ensure reliability. However, there are still times when problems occur and must be located quickly and efficiently, especially in production applications. A step-by-step method has been devised as a way of finding solutions to hydraulic problems quickly.

These steps are as follows.

Step 1 – Know the system

Study the machine's technical specifications to obtain an understanding of how the system operates and the function of the machine's components. Obtain a circuit drawing and check the system through. Check the machine's maintenance records and commissioning test results, if they are available.

Step 2 – Ask the operator

Determine the symptoms of the problem by asking the operator for a detailed description of the

machine's normal operating performance.

Step 3 – Inspect the machine

Use your senses (sight, smell, hearing and touch) to locate problems or damage such as high oil temperatures, milky or foaming oil, oil leaks, malfunctioning components and damaged fluid lines.

Step 4 – Operate the machine

Operate the machine at its correct operating temperature. Check that the machine's gauges are reading 'normal' and that there are no unusual noises. The operation of the machine's controls should not be 'sticky' or 'spongy'. The machine's performance should not be slow, erratic – nor non-existent.

Step 5 – List the possible causes

Once the fault has been located and recognised, list the possible causes – starting with the simplest.

Step 6 – Reach a conclusion

Use a troubleshooting chart to check the list of possible causes; then decide which is the most probable cause.

(A troubleshooting guide has been included towards the end of this section – for both study and reference purposes.)

Step 7 – Test the conclusion

Before starting any repairs to the system, test the conclusion on the cause of the problem. It may be necessary to use a portable hydraulic tester to substantiate the conclusion.

Possible causes

Symptom 1 – overheating of fluid

Action to locate cause:

- Check oil level.
- Check sufficient water is circulating in heat exchanger.
- Check that cooler's oil and water space is clear and metal surfaces clean.
- Check to ensure system is not overloaded.
- Check to ensure fluid has not been contaminated with incorrect fluid.
- Check for leakage due to worn pump or valve parts.

Symptom 2 – slow operation

Action to locate cause:

- Check actual operation pressure.
- Check fluid level for loss.
- Check suction filter.
- Check breather filter on reservoir.
- Check for contamination with incorrect fluid.

- Check relief valves.
- Check for internal leaks.

Symptom 3 – erratic action

Action to locate cause:
- Check suction filter.
- Check breather filter on reservoir.
- Check for air in system.
- Check for contaminative solids in system.
- Check for contamination of fluid by incorrect fluid.
- Check for wear in pumps and valves.

Symptom 4 – air in the system

Action to locate cause:
- Check fluid level.
- Check that correct grade of fluid is being used.
- Check method of topping up fluid.
- Check for leaks in suction line.
- Check for leaks in delivery lines.
- Check to ensure return vent is submerged in fluid.
- Check to ensure fluid is not pouring over baffle in reservoir.
- Check whether a vortex is forming at suction inlet.

System temperature

Heat causes hydraulic oil to break down faster and lose its effectiveness sooner. This is why cooling of the oil is needed.

In many systems, enough heat is dissipated through the lines, components and reservoir to keep the oil fairly cool. But on high-pressure, high-speed circuits, oil coolers are needed to dissipate the extra heat.

Overheating

Overheating a system can:
- break down the oil
- damage the seals
- cause coating of parts with varnish deposits
- cause extra leakage past working parts
- reduce the output of the system.

The oil in your hydraulic system was designed for operation within a specified temperature range. You may be able to run it at hotter temperatures for short periods intermittently, without bad effects.

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But if you operate continuously with oil that's too hot, your equipment will perform poorly – and eventually key components will fail and halt your machine.

How hot is 'too hot'?

Hot oil is a relative term. In most cases 50–55 °C at the reservoir is considered an ideal operating temperature. Always take the temperature of oil at the reservoir, not at a component or in any of the piping.

Some hydraulic systems are designed to operate at 55 °C or higher. If you don't know the maximum operating temperature for your equipment, check the operator's manual or ask your equipment supplier.

Measuring oil temperature

There are several ways to check the temperature of hydraulic oil. The best and most accurate method is by means of a thermometer. On some machines, one of these is mounted on the reservoir. Make a habit of checking the thermometer periodically, once the equipment has been running for more than an hour.

Isolating trouble spots

To determine which components are running hot and overheating the oil, feel the outlet fittings and lines at the valves, pumps and motors. If oil is at normal temperature when entering a component but hot on leaving, that component could be a trouble spot.

A sticking valve can cause excessive heat. If a spool does not return promptly to the neutral position, the pump flow will be dumped continuously. This builds up heat rapidly.

If a relief valve is set too low, part of the oil will be dumped across the valve on every cycle. This too, generates excessive heat. Even when all valves are set properly, they may not be operating well because of worn orifices or seals.

Look, smell and feel

Checking oil temperature periodically is good preventive maintenance. So, too, is the practice of periodically siphoning an oil sample from the reservoir and comparing it with a sample of clean, new oil.

Oil that's been running too hot will look darker and feel thinner than new oil. It will also smell 'burned'. It will probably contain more contaminants, because hot oil leads to accelerated wear of component parts.

Preventative measures

You can help keep your equipment's hydraulic system from running too hot by adhering to the following preventative measures.

- Set up a regular schedule for checking the level, temperature, appearance, smell and feel of the oil. Change oil as recommended by the equipment manufacturer.
- Be prompt in removing, checking and repairing or replacing valves, pumps or other components that are in need of maintenance.
- If relief or flow-control valves are running hot, check and adjust their settings following the owner's manual.
- Break in new components gradually. New, close-fitting parts may expand at different rates and are especially prone to seize when they get too hot.
- Keep equipment clean. A thick layer of dirt acts as an insulator. It will prevent heat from dissipating.
- On hot days, and in hot climates, check/change the oil more frequently. Be sure to use oil recommended for hot-weather operation by the equipment manufacturer or oil supplier.

Hydraulic system leaks

There are hundreds of causes of leaks – but they fall into two general categories: internal and external.

Internal leakage does not result in actual loss of oil from the system – but it does reduce system efficiency. External leakage results in direct loss of oil – and can have other undesirable effects as well.

Internal leakage

Internal leakage as a thin oil film is 'built into' the working parts of a hydraulic system by design. This lubricates the mating surfaces of valve spools, cylinder pistons and other moving parts. Oil is not lost through this normal internal leakage, because it eventually returns to the system reservoir.

However, too much internal leakage will slow the operation of the system and waste power through generation of heat. In some cases, it may cause cylinders to creep or drift – or cause loss of oil control in the valves.

Internal leakage increases with the normal wear of parts. Leakage is accelerated by using oil which has too low a viscosity, because such oil thins faster at higher
temperatures. High pressures also force more oil out of leaking points in the system. This is one reason why excessive pressures can actually reduce the efficiency of a hydraulic system.

Internal leaks are hard to detect. All you can do is monitor the system for sluggish action or creeping and drifting. If these signs appear, it's time to test the system and pinpoint the trouble.

External leakage

External oil leaks not only look bad but also can be expensive and hazardous. A drop of oil every second from a leaking container can cost the operator a significant amount of money.

A small drip of oil can also be a sign of an impending hydraulic failure, such as a hose rupture, which might cause injury and/or put the machine out of operation.

Every joint in a hydraulic circuit is a potential point of leakage. This is why the number of connections in a system should be kept to a minimum.

Components can leak – but care in the assembly and use of new seals and gaskets during overhaul will help to reduce this problem.

The lines that connect the different parts of the system are the main sources of external leakage. Proper fitting and maintenance of hoses, tubes and pipes are important to reduce this problem.

The following are among key points to remember when checking for leakage.

- If the reservoir oil level is lower than normal, check all external oil lines for leaks.
- The rubber cover on flexible hoses may crack or split without actually leaking – but check very closely for internal damage. The depth of the crack is the deciding factor. Any oil dampness is a sign that the hose is leaking.
- Air leaks in suction lines are hard to locate. One way of finding them is to pour oil over the points where you suspect leaks. If the noise or bubbling in the system stops, you've located the leak.
- If line connections are leaking, tighten only until the leak stops. If the connection will not stay tightened, the threads are probably stripped and the connector must be replaced. If the connector will tighten but still leaks, check for a cracked line flare or a damaged seal. Remember, more damage has been done to line connectors by over-tightening than by any other cause.
- After stopping leaks in a system, remember to warm it up and cycle the equipment and check at the trouble spots to be *sure* leaks have stopped.
- Recheck the system oil level and replace any oil lost through leaks or broken connections.

Checking the system

Reservoir – Check for low oil level, milky oil and foaming oil and check temperature.**Oil lines –** Check for oil and air leaks, loose connections, proper support and pinched and dented lines.

Figure 7: system checks

After repairs

After repairs on a system, check the whole circuit for leaks, proper oil level, overheating etc. Do this before operating the system on the job.

For accurate checks, warm up the system and cycle the hydraulic equipment. Start the motor and run the machine for 15 minutes to warm up the hydraulic system. Then run the equipment through its working cycle at least four times, to bleed air from the system.

Add oil if necessary – and operate the machine until the equipment will function smoothly at its full rated capacity.

With the equipment at rest and the motor shut off, recheck the oil level. If necessary, add oil to bring it to the proper level.

Important: Always check the oil level after any repairs to a system. Also check the system periodically during operation. Follow the machine operator's manual to determine proper intervals.

Regular checks

Some checks that should be done regularly are outlined below.

Checking reservoir and oil

- Check the reservoir oil level and the condition of the oil frequently.
- At this time, also check for other malfunctions in the system. Look for:
a) air bubbles or foaming oil – which might indicate an air leak somewhere in the system.
b) change in oil level. If there's a noticeable change in the oil level from day to day, look for leaks or cracks in the external parts of the system.
c) milky oil – which would indicate water in the system or in the oil used. Make sure that oil is stored properly.
- Before removing the filler cap, wipe away all dirt and grime on and around it. If a dipstick is used for checking oil, wipe it with a clean, lint-free cloth.
- Before adding oil, make sure that the existing oil in the system is clean. If not, drain the oil and refill the system completely with new oil that will give good performance under prevailing conditions. However, if the drained oil contains sludge, sediment or gum and lacquer formations, the system should be cleaned and flushed before refilling.

Checking cooler, lines and connectors

- Clean the oil cooler periodically and check it for leaks. Keep the fins clean on air-to-oil coolers. Check for corrosion in water–oil types.
- Check oil lines, hoses and connectors at regular intervals. Look for:
a) pressure oil leaks. Oil leaks in the pressure side of the system can be located by examining the outside of lines and fittings.
b) air leaks. If the suction side of the system is drawing in air, the oil in the reservoir will bubble and foam.
c) pinched or dented lines – which can cause oil foaming, overheating and loss of hydraulic power.

   Replace damaged hoses or tubes at once. Wash lines inside and out with clean solvent before installing them.

- Tighten any loose lines or connections. Use two set spanners to avoid twisting hose or tubes. Replace any connectors that continue to leak.

  Important: Tighten loose connectors *only* until the leak stops. Don't use excessive force to stop fluid leakage; otherwise the component body may be distorted or cracked.

Checking valves

Dirt will cause valves to stick or work erratically. Also, after long use, valve spools may become worn, allowing oil to leak past them. Check all valves for leaks periodically – and service them.

Checking cylinders

Check cylinders periodically for both external and internal leakage. Make sure cylinders are mounted properly. Make sure that the rods of exposed cylinders are *not* left extended when the machine is stored; otherwise, the rods will collect dirt and moisture, which might cause rusting or pitting of the rods. If the rods must be exposed, make sure they are coated with a heavy grease.

Checking motors

Never permit a hydraulic motor to overheat. If it is running hot, make sure the oil supply is adequate and also check the system oil cooler to make sure it is functioning properly. Also inspect for leaks at the motor hose connections, around the shaft, at the seals and at mating surfaces.

What is good maintenance?

Good maintenance involves good work habits, such as making sure you always do the following.

- Use common sense.
- Stop, look, touch and listen before picking up tools.
- Change oil and filters regularly.
- Maintain good records.

GOOD

- cleanliness
- high-quality oil
- proper filters
- tight seals
- normal operation

BAD

- dirt
- water
- air
- heat
- abuse

System testing methods

> **Recommended viewing**
>
> *Industrial Hydraulic Technology* video series: 'Flow meter hook-up'.

Tee testing

'Tee testing' checks system efficiency and enables faulty components to be isolated for repair or replacement. More than one 'tee test' may need to be performed to pinpoint a faulty component.

The three major system checks for which 'tee testing' is used are:

- ensuring the pump is producing its recommended flow rate (test performed with connection to the control valve plugged)
- checking that the relief valve is operating at the correct pressure setting
- checking component leakage.

Pump test

Flow rate problems in hydraulic systems often originate at the pump as a result of internal wear or incorrect settings on pump controls. If the cause of a flow rate problem cannot be easily pinpointed, a portable hydraulic tester is used to measure the system's flow at various points in the circuit; the pump's flow rate is usually measured first.
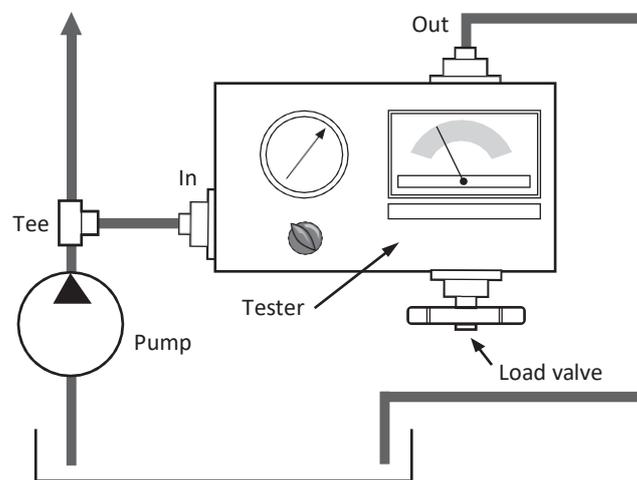
To relief valve or DCV

Figure 8: pump test

The manufacturer's specifications or pump-commissioning data provide a reference against which any future flow readings are compared. This comparison enables a pump's efficiency to be determined. (Refer to the discussion on leakage testing under *Hydraulic system leaks* earlier in this section.)

To evaluate a pump's output, the tester is installed in the circuit between the pump outlet and the inlet to the directional control valve or before the relief valve, as illustrated in Figure 8. The system is run until normal operating temperature is reached.

The tester's loading valve is fully opened to allow full flow at zero pressure. The valve is then progressively closed through a series of predetermined pressure 'steps' and the flow and pressure readings are recorded. The level of decrease in flow between the minimum and maximum pressure settings will indicate the pump's condition. A typically worn or damaged pump will lose 20–30 per cent flow capability. Low flow at both minimum and maximum pressure indicates inlet problems.

Relief valve test

To test a relief valve, the tester is installed in the circuit after the relief valve, with the outlet of the tester connected to the reservoir. When the loading valve on the tester is fully opened, the pump's flow passes through the tester and back to the reservoir, bypassing the control circuit. The loading valve is then slowly closed while pressure
and flow readings are observed. The pressure will increase until the relief valve opens and diverts the flow back to the reservoir via the relief valve. When the relief valve's operating pressure setting is reached, there should be a zero reading on the tester's flow meter.
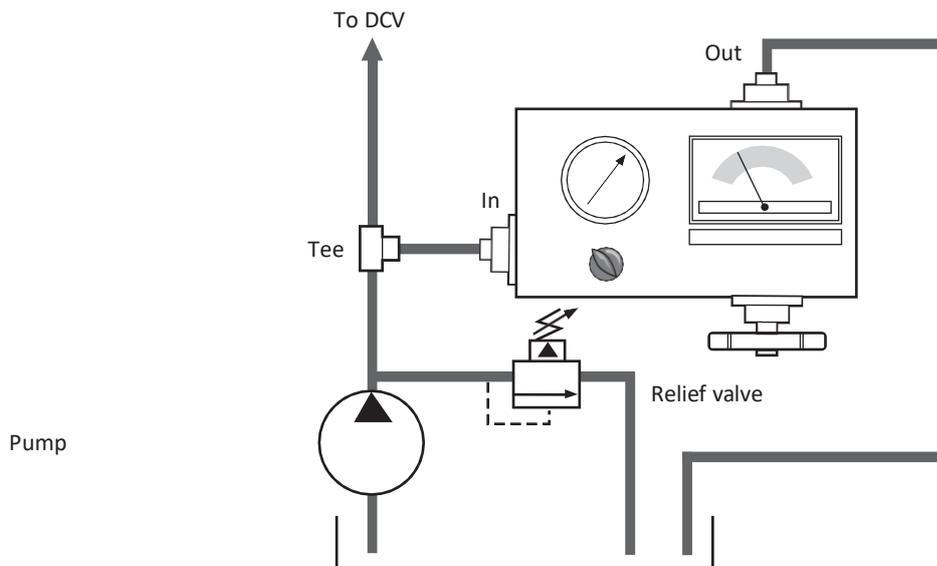

Figure 9: relief valve test

The pressure setting should be recorded and adjusted if it is incorrect. It is not unusual for a relief valve to start opening below the maximum pressure setting, causing considerable leakage and loss of machine performance. Direct-acting relief valves
are prone to this problem; pilot-operated relief valves are not – and are preferred. The cracking pressure can be checked by slowly increasing the pressure until the flow through the tester starts to fall away.

Tee testing for leakage in control valves and cylinders

The tester is inserted into the system between the pump and control valve, with its return line connected back to the reservoir. Start the system and warm the hydraulic oil to normal operating temperature. Extend the cylinder to the end of its stroke. On multiple-spool valves, only one spool should be in the 'power' position at any one time.

The leakage test for a directional control valve (DCV) is conducted by closing the tester's loading valve and monitoring the flow and pressure readings. Leakage is determined by subtracting flow readings on the tester from the system flow readings determined during the pump test. If the flow readings of the valve equal the pump test flow readings, the valve is in good condition. If all *valve leakage readings* are similar, the tests indicate the component is functioning correctly even if test readings are somewhat below the flow readings of the pump test. The manufacturer's recommendations and the application will determine whether any leakage can be tolerated.

The relief valve should be checked first if all the flow readings (leakage) from mullet- banked control valves are the same. If the 'tee test' does not pinpoint the leakage to either the control valve or cylinder, an additional test may be required.

By disconnecting the line to the cylinder and plugging the valve port, the control valve can be tested separately. Place the handle of the control valve in the position at which the greatest decrease in flow was noted in the previous test; then close the tester's loading valve and record the pressure and flow readings. If the decrease in flow is
the same as that in the first test, the control valve is at fault. But, if the flow readings are higher and comparable to those of the other control valve spools, the excessive leakage is due to a faulty cylinder.
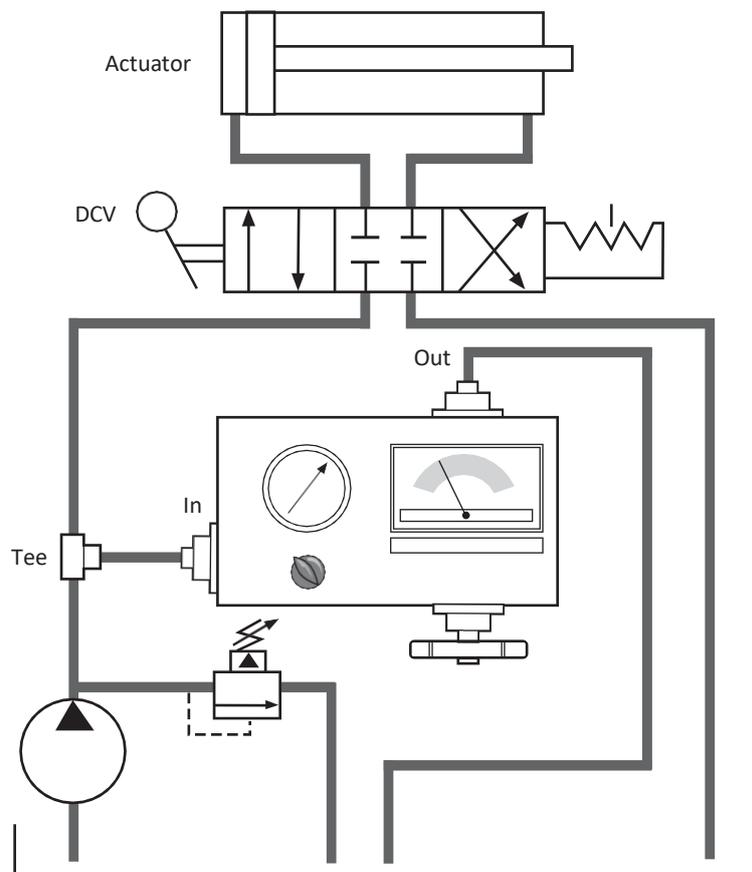
Figure 10: 'tee testing' control valves and cylinders

Motor in-line testing

The tester may be used in an in-line test to evaluate the condition of valves, motors, cylinders and pumps.

The performance of a hydraulic motor is checked by measuring the flow rate and comparing it to equivalent motor speed. The tester is installed in the line before the motor – which is determined by the motor's direction of rotation. The hydraulic system is run to reach operating temperature with the tester's loading valve fully open. The motor is run under normal load and flow and pressure readings are noted. If the flow rate is below the manufacturer's specifications or lower than that recorded in

the pump test, check the control valve. The motor's speed (revolutions per minute) should be

recorded when it is working at normal pressure. If the motor's speed is low and the inlet flow found to be correct, the motor's internal leakage is excessive and will not be acceptable.

Note: *If the motor does not have an external drain or cannot be back-pressure-loaded, the tester must also be connected on the other side of the motor to repeat the test in the opposite direction.*

An alternative method of motor testing is to disconnect the motor from the system and connect the tester in its place. By pressurising the flow through the tester, the flow rate can be compared to manufacturer's specifications and the pump test flow rate figures. If the motor test flow figures are lower, the directional control valve should be checked. But, if the flow is correct and the speed of the motor slow, the motor is defective.
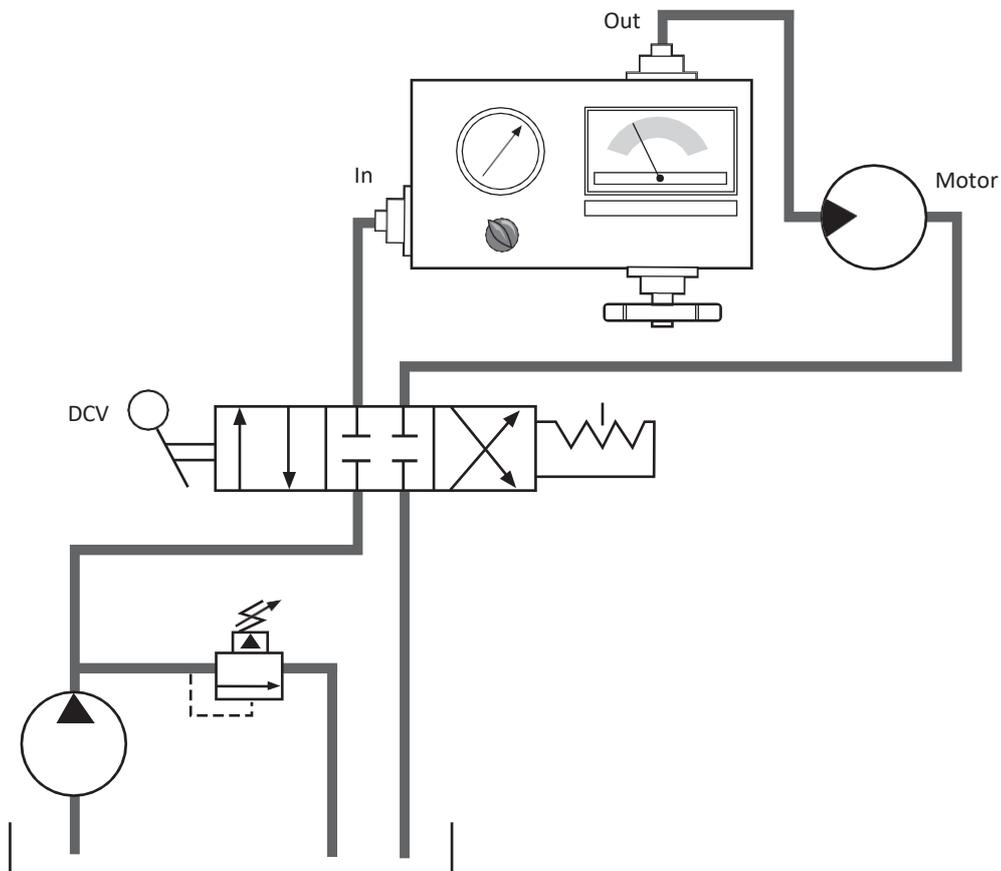
Figure 11: motor test

Hydraulic circuitry and components

The main parts that make up a hydraulic system are:

- the reservoir
- filters
- coolers
- the pump

- valves
- actuators
- pressure gauge.

Reservoirs

The main storage area for fluid in a hydraulic circuit is known as a reservoir. This is sometimes integrated into the hydraulic machine but, in other cases, is a separate container which is conveniently located in an external power pack. A typical reservoir is constructed as shown in the figure below but some reservoirs contain additional equipment to improve system performance. The reservoir not only stores oil but also helps to keep the system clean and free of air. It also reduces the oil's operating temperature.
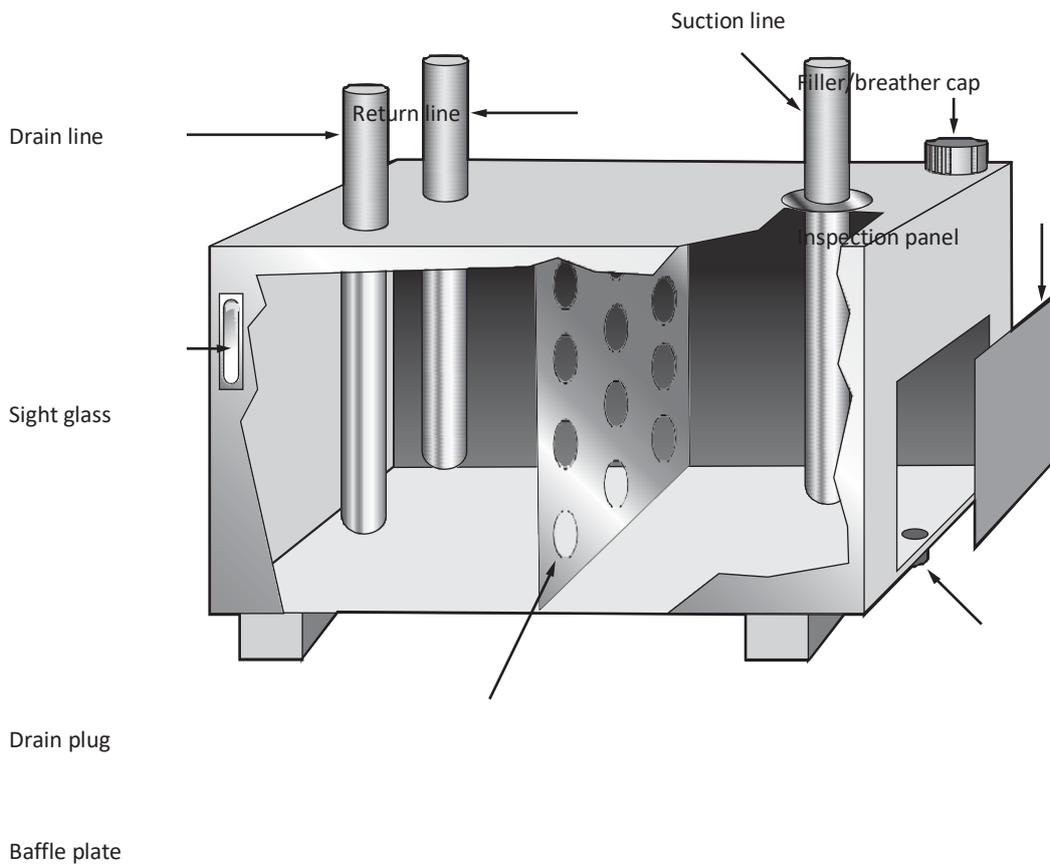
Figure 12: main components of a standard reservoir

Reservoir parts

Filler cap – This should be airtight when closed but usually contains an air vent with a filter to allow in atmospheric pressure for proper oil flow.

The filter must be kept clean in order to prevent blockage of air flow and the creation of a partial vacuum, which would restrict oil flow to the system.

Oil-level gauge – This indicates the oil level in the reservoir but a dipstick may be used in difficult locations.

Baffles – These prevent the hot return oil from mixing with cooler oil entering the pump. This separation also allows contaminants in the return oil to settle and any air to separate from the oil.

Outlet and return lines – These are designed to keep turbulence in the oil to a minimum. Their ends should be approximately 50 millimetres from the bottom of the tank and pointed at the wall.

Intake filter – This is usually a screen positioned in the pump inlet to prevent large particles from entering the system.

Drain plug – This allows all oil to be drained from the reservoir. Some drain plugs are magnetic so that they remove iron and steel particles from the oil.

Manhole – This access panel allows cleaning and inspection of the reservoir.

Servicing a reservoir

Manufacturers usually recommend certain time periods between hydraulic oil changes. If the system is working under extremely hot conditions or if the correct oil level is not maintained in the reservoir, the oil will overheat and start to chemically break down, necessitating servicing. This can be observed – because the oil will change colour. It may also lose its ability to lubricate the moving parts within the hydraulic equipment, which could cause an expensive breakdown. If the oil in the reservoir drops below
the low-level mark on the gauge, it must be replenished to the correct level. Mobile equipment must be on reasonably level ground when an oil level check is carried out.

If the reservoir oil is dirty or has a bad odour, it's time to have the oil checked by a qualified person. If necessary, the system should be flushed and the oil replaced.

Filters

Because hydraulic fluid not only transmits power but also acts as a lubricant for the moving parts in a hydraulic system, it is most important to prevent its contamination with dust, metal particles or other contaminants.

Contaminated oil can jam a precisely fitted valve spool. Its abrasive action can ruin the close tolerance required for satisfactory sealing of a valve. Even a grain of sand in a tiny orifice can put a whole machine out of operation. Very small particles of foreign material cause wear as they pass through the small orifices of hydraulic equipment
and may lodge between moving valves and housings, causing permanent scratches on hard surfaces.

The air surrounding hydraulic equipment is often the major source of contamination. Another source is the normal wearing of components – which produces metal particles – during operation of the system.

Filter applications

Three kinds of filter are used to perform different jobs in a hydraulic system.

Air vent filters

These prevent contamination of the hydraulic fluid by polluted air surrounding the system.

Filler cap and filter

Air flow

Screen

Circuit symbol for filter
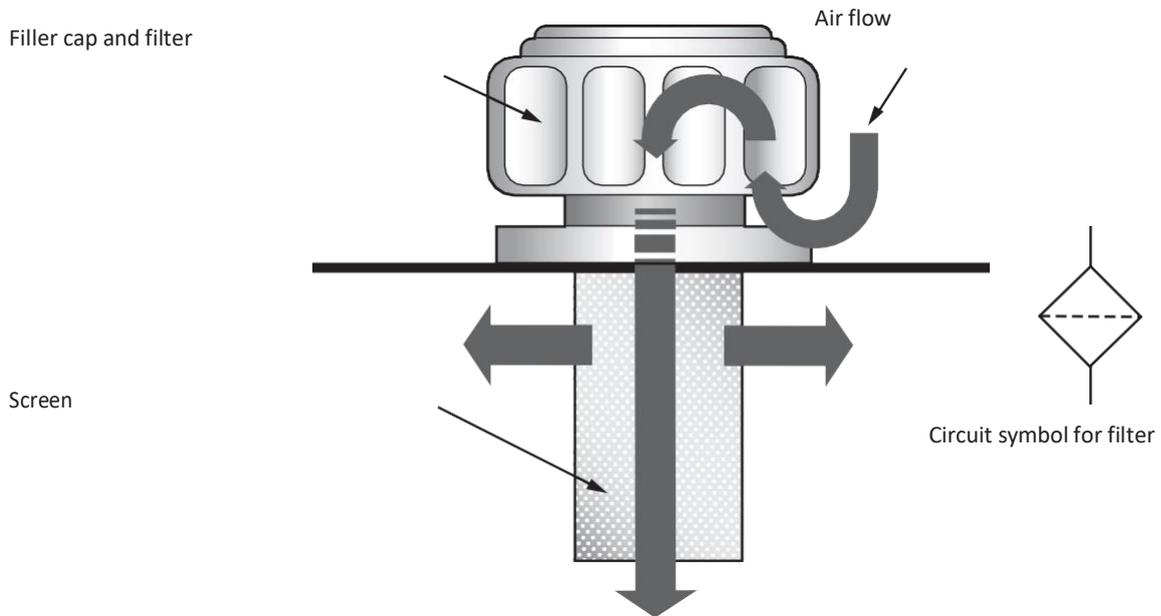
Figure 13: operation of air vent filter

Inlet strainers

These filters are positioned in the reservoir and connected to the inlet line of the hydraulic pump. They remove some of the larger impurities from the oil before it reaches the pump.

Flow in

Flow out
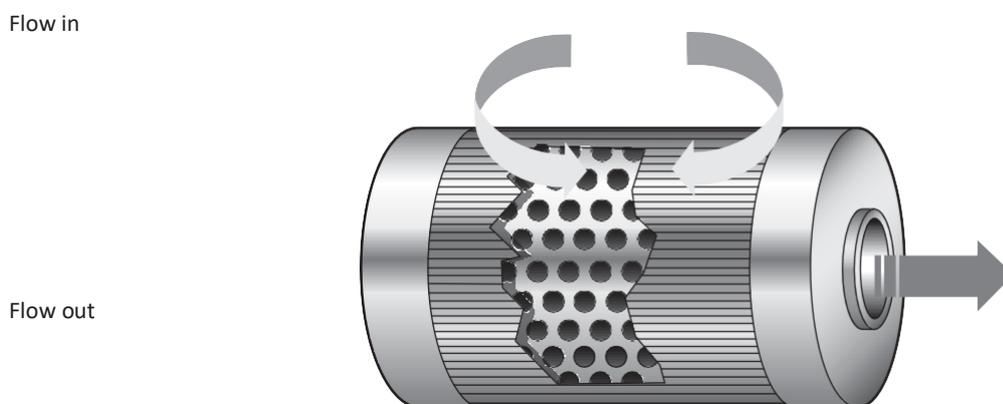
Figure 14: inlet strainer

Oil filters

Oil filters are used to prevent contamination of the fluid in a hydraulic system by collecting wear debris and contamination such as dirt particles. Some filters have a bypass valve that will allow the passage of oil should the filter become blocked. Others may have pressure indicators to monitor the condition of the filter.

Filter pressure indicator

Bypass valve

Filter element

Filter bowl
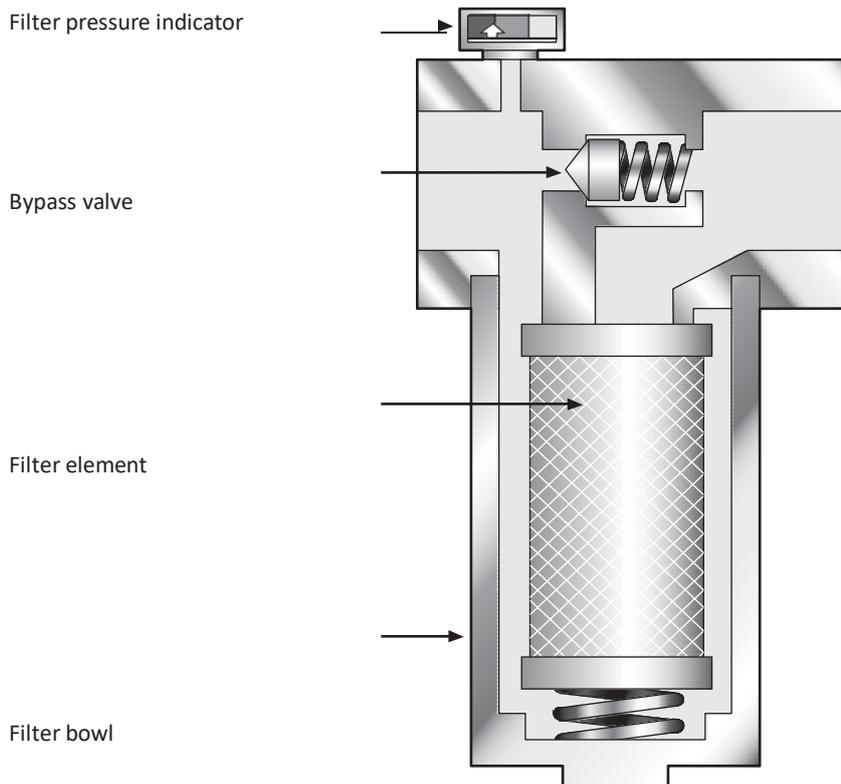
Figure 15: return line bypass oil filter

Filter construction, rating and maintenance

All three kinds of filter (described above) consist mainly of fine, porous material which allows only clean air or oil to pass through and so prevents the fluid being contaminated by solid contaminants. Filters belong to one of two basic groups according to design. They are:

- the *depth* type, which filters the fluid through a series of layers of material such as long strands of synthetic or metal fibres – or even paper
- the *surface* type, which traps contaminants on the surface of a woven mesh.

Hydraulic filters are rated as *absolute*, *nominal* or *beta* – according to the size of particle removed and their efficiency.

Regular maintenance is 'a must' for filtration units. Poor servicing will render them useless for filtering

out contaminants. A highly contaminated or blocked filter will cause an increase in pressure resulting in the hydraulic fluid bypassing the filter via an
internal check valve. If a strainer becomes blocked with impurities, only a small quantity of oil will reach the pump. A high-pitched scream will be emitted from the inlet side of the oil-starved pump. The imbalance between the demand and supply of oil causes *cavitation*, which is one of the major causes of permanent pump failure – with resulting expensive repair work.

Cavitation results when the pressure at the pump inlet is less than the vapour pressure of the fluid being pumped. If a liquid's temperature rises enough or pressure is substantially reduced, vapour bubbles will form within it. This phenomenon is called cavitation and, in the broad sense, includes the formation of bubbles when water is boiled. In the case of a hydraulic pump, as the pressure increases at the pump's outlet, vapour bubbles caused by cavitation will implode or collapse, producing a shock wave which will damage the pump's internal components. This is usually identified by pitting and the removal of metal from pump components.

If the reservoir oil level is low, air will be induced into the pump and aeration of the oil will take place, causing it to froth and reducing lubrication of the pump. This will also cause rapid wear of pump assemblies and the hydraulic system will have a 'spongy' feel to the controls.

Oil coolers

In modern hydraulic systems, cooling the oil can be a significant problem. The normal circulation of the oil around the system, through the reservoir, will no longer do the job in many cases. For this reason, oil coolers are becoming common on modern equipment. The two types of coolers widely used are *air-to-oil* coolers and *water-to-oil* coolers.

An air-to-oil cooler uses moving air to dissipate heat from the oil. The cooler has fins that direct air over oil tubes, which cool the oil.

A water-to-oil cooler uses moving water to remove heat from the oil. The water flows through a series of tubes and the oil circulates around these tubes. On mobile machinery, water from the engine radiator is often used for cooling.

Pumps

The pump is the heart of a hydraulic system. It converts mechanical or electrical power, supplied from the prime mover, into hydraulic power. The mechanical operation of the pump moves the fluid from the reservoir into the system. The major function of the pump is to produce fluid flow; any resistance to this flow will produce pressure in the system.

All modern hydraulic systems use positive displacement pumps. Such pumps have a mechanical seal between the inlet and outlet ports, causing a predetermined volume of oil to be pumped every cycle. The seal prevents system pressure causing leakage across the pumping chamber and back to the reservoir.

Non-positive displacement pumps do not have a seal across the pumping chamber, so some fluid can leak back across from the outlet port to the inlet port. An example is the centrifugal pump commonly used for pumping water at low pressure.

Principle of the hydraulic pump

Hydraulic pumps are designed on the following principle. A partial vacuum is created at the inlet port, allowing atmospheric pressure to force fluid into the inlet side of the pump from the reservoir. The pump's mechanical action forces the fluid to and through the outlet port.

The essential requirements in any hydraulic pump are:

- a low-pressure inlet port supplied with fluid from the reservoir
- a high-pressure outlet or delivery port connected to the system
- a pumping chamber, which allows the fluid to be moved from the inlet to the delivery port
- internal pumping components (for example, piston, vanes or gears) to positively move the fluid from the inlet to the delivery port
- an internal seal to prevent oil leakage across the pumping chamber
- an external seal on the pump to prevent fluid leakage to atmosphere
- connection of the pumping chamber to a drive unit.

Maintenance notes

All pumps must be operated at the speeds and pressures recommended by the manufacturer; any deviation from these specifications may reduce a pump's working life or result in pump failure.

Cleanliness is essential when working on pumps. Any small pieces of foreign material which find their way into small clearances of pump assemblies will cause excessive wear – which will be expensive to rectify.

The amount of internal leakage from a pump's outlet to inlet is known as *slippage* and must be kept to a minimum. Excess slippage causes heat generation.

Valves

The fluid flow generated by the pump through a hydraulic system has to be directed and controlled at all times. If the fluid pressure and flow is not controlled, the system might not be used effectively by the operator or the machine may even self-destruct.

One of the advantages of a hydraulic system is that the energy can be controlled with relative ease by using a selection of the following control valves: directional control valves, pressure-control (relief) valves and flow-control valves.

Directional control valves

A directional control valve controls the direction of fluid flow. It consists of a valve body and a moving part which selectively directs or prevents fluid flow to a specified channel.

Do not neglect a small leak in a hydraulic circuit, because pressure will soon enlarge a small score mark in a seal.

Relief valves

A relief valve provides a hydraulic system with protection from overload. This is achieved by setting a maximum pressure for the system and diverting all or part of the pump output to the reservoir when the maximum pressure is reached.

Relief valves will activate to provide overload protection if:

- an actuator stalls due to excessive load
- a cylinder bottoms out at the end of its stroke
- a cylinder is in a force-holding position during a pressure cycle (nil flow required)
- the system's flow demand is less than the pump's delivery – for example, if the pump outlet flow is 30 litres per minute and the system demand is five litres per minute.

All hydraulic systems using positive displacement pumps are fitted with a relief valve for system protection; otherwise system pressure would build up until permanent damage was done to the pump or a hydraulic line, which might burst and cause injury.

The simplest form of relief valve comprises just a valve body and spring-loaded poppet. Such a valve is known as a *direct-operated* relief valve. The valve is normally in closed position, held shut by the preloaded spring. When system pressure exceeds the spring tension at the base of the poppet, the poppet lifts, allowing fluid to pass the poppet and

flow to the reservoir. When pressure drops, the spring forces the poppet downwards and the pressure port is closed. When pressure builds up again, the valve opens again. In this way, continuous operation is maintained.

Maintenance notes

Any excessive noise from a relief valve should be investigated, because, under normal conditions, relief valves should be reasonably quiet in operation.

Once a relief valve has been set, it is often a good idea to remove the handle of the adjustment screw to prevent inexperienced operators from 'over-adjusting' the valve and thus creating a safety hazard.

If difficulty is experienced in shifting loads with a machine, the relief valve should be checked because too much oil might be returning to the reservoir, leaving insufficient pressure for the main hydraulic system to do the work.

When servicing a pilot-operated valve, cleanliness is essential at all times. This is because the operating clearance of the piston is very small, so even small pieces of foreign matter in the oil will cause damage.

Flow-control valves

A flow-control valve consists of a valve body with inlet and outlet ports. An adjustment orifice within the valve body can be used to restrict the valve's output flow. The function of a flow-control valve is to reduce the flow of oil from the pump to the actuator.

With fixed-displacement pumps, increased fluid back-pressure increases pump operating pressure, which, once maximum allowable system pressure is reached, in turn opens the circuit relief valve, to return the excess fluid flow to the reservoir.
It must be remembered that, if pump flow is severely restricted, excessive relief valve operation will cause overheating of oil, resulting in costly repairs.

Actuators

The function of an actuator is to convert hydraulic energy to mechanical energy.

An actuator may be linear or rotary. A linear actuator (cylinder or ram) produces force and motion in a straight line, while a rotary actuator (motor) produces torque and rotational motion.

Linear actuators

These are more commonly called hydraulic cylinders or rams. They are used for clamping and lifting and for traverse and feed motions.

Cylinder cushions are often installed at one or both ends of a cylinder to slow movement down near the end of the stroke and prevent the piston from hammering against the end cap.

A *cylinder stop tube* is a spacer placed on the cylinder rod next to the piston in a cylinder with long strokes. The stop tube provides increased side-loading support to the rod, thus minimising the chance of rod or bearing failure.

Maintenance notes

When cylinders are dismantled for inspection, the work area must be perfectly clean. A sheet of

paper over a bench will assist in keeping parts clean.

Carefully dismantle the actuator, taking care that parts are not damaged. Inspect all parts for abnormal wear. Any parts showing abnormal wear should be put aside for a qualified opinion.

Inspect the inside of the cylinder, looking for score marks and at the condition of the surface finish. The cylinder may be free of score marks but may be distorted, which would cause the ram to flex as it extended from the cylinder.

If a small leakage of oil is noted on the ram shaft, the cylinder end plate seals may be suspect.

Carefully inspect piston seals for wear, because it is these that prevent oil leakage around the piston.

When assembling an actuator, it is important that all seals be given a coating of oil before installation. Also, care must be taken that the shafts or cylinders slide smoothly through the seals; otherwise small slivers of seal material may be peeled off, causing premature failure of the assembly.

Situations may arise in which circuit pressure is correct but the cylinder will not deliver a force. This is the result of oil leakage from the high-pressure side of the actuator to the low-pressure side. Some operators may mistakenly blame the pressure relief valve or pump – but the cause is piston seal leakage.

Under no circumstances should attachments be welded or fitted to cylinders, because this causes distortion and resultant rapid deterioration of the actuator assembly.

Rotary actuators

The motor is designed much like the pump. Both use the same basic type of construction – that being gear, vane or piston. Often parts from one can be substituted in the other.

The major difference is that a hydraulic motor works 'in reverse' to a pump. The pump drives the fluid, while the motor is driven by the fluid. A pump draws in fluid and pushes it out, converting mechanical force into fluid force. In the case of a hydraulic motor, fluid is forced in, converting fluid force into mechanical force. The work output of the motor is called *torque*. It is the rotary force applied by the motor to the drive shaft.

The ratio between the speed and torque output of a motor depends upon the volume of fluid it displaces with each cycle.

Maintenance notes

Hydraulic motors are manufactured to very fine engineering tolerance and therefore are very expensive.

Regular inspection of motors should be carried out in order to determine whether oil leakage is taking place.

If dampness is noticed at the output shaft seal, this should be reported before high-pressure flow of oil takes place.

Internal leakage or slippage may be checked on models fixed with external drains by measuring the amount of leakage oil returned to the reservoir in a given time – with the system at operating temperature.

Connections of hydraulic tubes or flexible hoses should be inspected. If leakage is noticed at a threaded connection, the fitting should be checked for tightness, care

being taken not to over-tighten or strip threads. Sealing tapes or chemicals may also be used to eliminate leaks from threaded connections.

Do not subject a motor to 'shock loading' by rapid operation of the direction valve, because this would set up a high-pressure pulsation in the motor, causing damage to some of the components.

Fluid connectors

Pipes and tubes

A pipe is recognised by its inside diameter and a tube by its outside diameter.

It is usual to have piping between the reservoir and pump inlet – and tubing after the pump, where high pressure is developed.

Piping connections are threaded and are now described according to size in metric terms. Any leakage at these connections is unacceptable, so Teflon® tape should be wound around the thread, in the same direction as the thread, before a connector is finally tightened.

It is important to remember that Teflon® tape lubricates the thread as it seals, so care must be taken not to over-tighten. Teflon® tape should not be used on flares – only on threads.

Tubing is usually sealed at connections by a standard flare and nut – or a bite-type fitting.

Vibration may cause fracture of hydraulic tubing at the point where it enters a component. So regular inspection of hydraulic tubing may avoid trouble by revealing a minor leakage before a major breakdown occurs.

Note: *If excessive force is used to tighten tapered fittings into hydraulic components, they will distort or crack the body.*

Flexible hoses

Hoses are the best form of hydraulic plumbing for most uses. Not only do hoses allow for motion but they also absorb vibrations and noise, withstand pressure surges and are easy to route and connect.

A hydraulic hose is made up of three basic parts: an inner tube, reinforcement layers in the middle and an outer cover.

The inner tube is a synthetic rubber layer which is oil-resistant. It must be smooth, flexible and able to resist heat and corrosion and must be compatible with the fluids being pumped through the system.

The reinforcement layers vary with hose type. They provide resistance to burst pressure. These layers (or plies) are made of natural or synthetic fibres, braided wire or a combination of these. The strength of the overall layer depends upon the
pressure requirements for which the hose is designed. As the number of braids or plies increases, the hose's pressure rating increases and its flexibility decreases.

The outer cover protects the reinforcement layers. It is usually made of a special rubber which resists the effects of weather, dirt, oil and abrasion.

Pressure gauge

The pressure gauge informs the operator of circuit pressure.

If the pressure tends to fall below that set by the pressure relief valve, the operator will know there's a malfunction in the circuit.

As the operation of a pressure gauge is partly mechanical, circuit pulsations may rapidly cause damage.

Sometimes an isolator valve is positioned in the circuit before the gauge – and opened only when circuit pressure is to be checked.

Accumulators

An accumulator stores hydraulic pressure and may be used in a circuit as either or both of the following:

- a safety device, in case of temporary failure of the main power source or system leakage during a holding cycle
- a shock absorber, to absorb high-pressure pulsations that would normally cause pressure-related breakdowns in the circuit.

The bladder type of accumulator contains nitrogen compressed to circuit pressure. If a high-pressure pulsation occurs in the system's oil, the nitrogen compresses and absorbs the pulsation which might otherwise cause leakage.

In the case of a temporary circuit failure, the nitrogen expands and oil in the accumulator is forced into the failing circuit to keep it operating.

A poppet valve at the base of the accumulator prevents the bag from extruding through the outlet.

Maintenance notes

Never dismantle any connection from an accumulator even if the engine is stopped, because oil will still be under pressure and injury may result.

If nitrogen leaks from an accumulator, it must be recharged by a qualified person. Do not attempt to put air into a leaking accumulator, because the result may be an explosion when pressure is developed.

A drop of soapy water, placed on the nitrogen valve, will indicate whether there is any gas leakage to the exterior.

If you suspect an internal leak, check for foaming oil in the system reservoir and/or inaction of the accumulator. These signs usually indicate a faulty bladder or faulty piston seals inside the accumulator.

If an accumulator appears to be in good condition but nevertheless is slow or inactive, pre-charge it as necessary.

Troubleshooting in hydraulic systems

Troubleshooting is the 'tracking down' and elimination of the cause of a problem in a system. It requires the ability to analyse a hydraulic system and a logical approach to identifying the problem area. It is bad practice to begin removing components from a hydraulic circuit without having a logical plan. *Whenever there is doubt, call in someone who is qualified.* It will save time and probably money.

To undertake troubleshooting on a hydraulic system, you need to:

- understand how the circuit works
- understand how the components in the circuit affect each other
- read 'telltale' signs presented by the circuit
- test components within the circuit and relate the results to the problem.

Knowing the system

Probably the greatest help in troubleshooting is confidence in knowing the system. Every component has a purpose in the system. The construction and operating characteristics of each one should be understood.

You should:

- know the *capabilities of the system.* Each component in the system has a maximum rated speed, torque or pressure. Loading the system beyond the specifications simply increases the possibility of failure.
- know the *correct operating pressure.* Always set and check pressures with a gauge. How else can you know if the operating pressure is above the maximum rating of the components?

  Sometimes there may be a question over the correct operating pressure. If it isn't correctly specified on the hydraulic circuit drawings, apply the following rule. Take the correct operating pressure as the lowest pressure which will allow adequate system function while remaining below the maximum pressure rating of the components and machine. Once correct pressures have been established, note them on the hydraulic schematic for future reference.
- know the *proper signal and feedback levels and dither and gain settings* in servo-control systems. If they aren't specified, check them when the system is functioning correctly and mark them on the schematic for future reference.

Recognising indications of trouble

The ability to recognise indications of trouble in a specific system is usually acquired with experience. However, a few general indicators can be discussed.

Excessive heat

Excessive heat means trouble. A misaligned coupling places an excessive load on bearings and can be readily identified by the heat generated. A warmer-than-normal return line from a relief valve to a tank indicates the valve is operating at its relief setting. Hydraulic fluids which have a low viscosity will increase the internal leakage of components, resulting in a heat rise. Cavitation and slippage in a pump will also generate heat.

Excessive noise

Excessive noise could indicate wear, cavitation or that there's air in the fluid. Contaminated fluid can cause a relief valve to stick and chatter. Unusual noises may be the result of dirty filters or fluid, high fluid viscosity, excessive drive speed, low reservoir level, loose intake lines or worn couplings.

Developing schematic procedures

Analyse the system and develop a logical sequence of setting valves, mechanical stops, interlocks and mechanical controls. Tracing of flow paths can often be accomplished by listening for flow in the lines or feeling them for warmth. Develop a cause-and-effect troubleshooting guide similar to the fault charts shown later in this section. The initial time spent on such a project can save hours of system downtime