JANSONS INSTITUTE OF TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

ME 3492 – HYDRAULICS AND PNEUMATICS

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ME3492 HYDRAULICS AND PNEUMATICS

UNIT I - FLUID POWER PRINICIPLES AND HYDRAULIC PUMPS

1.1**Introduction to Fluid power**

Fluid power is energy transmitted and controlled by means of a pressurized fluid, either liquid or gas. The term fluid power applies to both hydraulics and pneumatics. Hydraulics uses pressurized liquid, for example, oil or water; pneumatics uses compressed air or other neutral gases. Fluid power can be effectively combined with other technologies through the use of sensors, transducers and microprocessors.

Fluid power is the use of **fluids** under pressure to generate, control, and transmit **power**. **Fluid power** is subdivided into hydraulics using a **liquid** such as mineral oil or water, and pneumatics using a gas such as air or other gases.

1.2**Advantages and Applications**

The advantages of fluid power

Fluid power systems provide many benefits to users including:

- **Multiplication and variation of force-**Linear or rotary force can be multiplied from a fraction of an ounce to several hundred tons of output.
- **Easy, accurate control-**You can start, stop, accelerate, decelerate, reverse or position large forces with great accuracy. Analog (infinitely variable) and digital (on/off) control are possible. Instantly reversible motion-within less than half a revolution-can be achieved.
- **Multi-function control-**A single hydraulic pump or air compressor can provide power and control for numerous machines or machine functions when combined with fluid power manifolds and valves.
- **High horsepower, low weight ratio-**Pneumatic components are compact and lightweight. You can hold a five horsepower hydraulic motor in the palm of your hand.
- **Low speed torque-**Unlike electric motors, air or hydraulic motors can produce large amounts of torque (twisting force) while operating at low speeds. Some hydraulic and air motors can even maintain torque at zero speed without overheating.
- **Constant force or torque-**This is a unique fluid power attribute.
- **Safety in hazardous environments-**Fluid power can be used in mines, chemical plants, near explosives and in paint applications because it is inherently spark-free and can tolerate high temperatures.
- **Established standards and engineering-**The fluid power industry has established design and performance standards for hydraulic and pneumatic products through NFPA, the National Fluid Power Association and ISO, the International Organization for Standardization.

Fluid power applications

 Mobile: Here fluid power is used to transport, excavate and lift materials as well as control or power mobile equipment. End use industries include construction, agriculture, marine and the military. Applications include backhoes, graders, tractors, truck brakes and suspensions, spreaders and highway maintenance vehicles.

 Industrial: Here fluid power is used to provide power transmission and motion control for the machines of industry. End use industries range from plastics working to paper production. Applications include metalworking equipment, controllers, automated manipulators, material handling and assembly equipment.

 Aerospace: Fluid power is used for both commercial and military aircraft, spacecraft and related support equipment. Applications include landing gear, brakes, flight controls, motor controls and cargo loading equipment.

More applications of fluid power

ulture	rs; farm equipment such as mowers, ploughs, cal and water sprayers, fertilizer spreaders, harvesters
ation	ated transfer lines, robotics
obiles	steering, power brakes, suspension systems, static transmission
on	power equipment such as landing wheels in aircraft. pters, aircraft trolleys, aircraft test beds, luggage loading and unloadi s, ailerons, aircraft servicing, flight simulators
ruction ry/equipment	etering and mixing of concrete rudders, excavators, ucket loaders, crawlers, post-hole diggers, road graders, road cleaners, ro nce vehicles, tippers
se	e-launching systems, navigation controls
ainment	ement park entertainment rides such as roller coasters
ation industry	tools such as pneumatic drills, grinders, borers, g machines, nut runners
and beverage	pes of food processing equipment, wrapping, bottling,
ry	nd semi-automatic molding machines, tilting of es, die-casting machines
industry	m suction cups for handling
dous gaseous areas	ulic fracturing technologies: It involves pumping volumes of water and sand into a well at high pressure to fracture shale a

	tight formations, allowing hazardous oil and gas to flow into the we ver, hydraulic fracturing has serious environmental and water polluti d issues.
mentation	to create/operate complex instruments in space s, gas turbines, nuclear power plants, industrial labs
nd fixtures	holding devices, clamps, stoppers, indexers
ine tools	ated machine tools, numerically controlled(NC) ne tools
ials handling	hoists, cranes, forklifts, conveyor systems
al	al equipment such as breathing assistors, heart assist s, cardiac compression machines, dental drives and human patient simulato
s	al-effect equipment use fluid power; movies such as ic park, Jaws, Anaconda, Titanic
g	drills, excavating equipment, ore conveyors, loaders
papers and periodicals	trimming, stapling, pressing, bundle wrapping
dustry	ore oil rigs
and packaging	ss control systems, special-purpose machines for g and packing
aceuticals	ss control systems such as bottle filling, tablet placement, packaging
c industry	atic injection molding machines, raw materia
tools	duty presses for bulk metal formation such as sheet forging, bending, punching, etc.
ng industry	per feeding, packaging
s	power operated robots, pneumatic systems
	izing systems, unloading and loading unit, gyroscopic ments, movement of flat forms, lifters, subsea inspection equipment
es	ensioning devices, trolleys, process controllers
portation	ulic elevators, winches, overhead trams
sea	arines, under sea research vehicles, marine drives and control of ships
working	hearers, handling huge logs, feeding clamping and perations

1.3 **Fluid power system**

Fluid power systems are made up of component groups containing parts designed to perform specific tasks. These component groups acts together to perform the work desired by the system designer. The work may involve simple or complex tasks, but the component groups perform specific system functions that are basic to all fluid power systems. There are five functions that are basic to system operation of any fluid power system.

■ Energy conversion.

■ Fluid distribution.

■ Fluid control.

■ Work performance.

■ Fluid conditioning.

Each of these functions must be performed by a fluid power system if the system is to operate efficiently and provide a reasonable service life. The operating environment, power output, and complexity of the system establish the number of components required to perform a particular function.

Energy Conversion:

Fluid power systems do not generate energy, but transform it into a form that can be used to complete a task. The process begins with a prime mover pressurizing a fluid. It ends with an actuator using the energy stored in the pressurized fluid to perform work.

Fluid Distribution:

The operation of fluid power systems requires the distribution of fluid to the components in the system. Various types of lines are involved in this function. Valves and other components also serve to assist in fluid distribution.

Fluid Control:

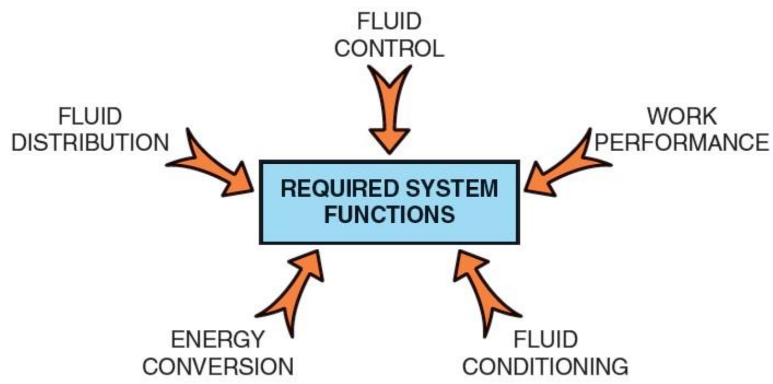
Fluid power systems require the control and regulation of the fluid in the system to perform the tasks desired by the system designer. A number of different components are used to control fluid flow rate, direction, and pressure in a system. Control of these three elements allow the system to provide the desired operating characteristics.

Work Performance:

Using the energy stored in the pressurized fluid of the system is the primary function of a fluid power system. This process involves actuators that convert the energy stored in the fluid to linear or rotary motion to perform the desired work.

Fluid Conditioning:

Fluid power system performance and service life require a fluid that is clean and provides lubrication to system components. This function involves storing fluid, removing dirt and other contaminants, and maintaining proper system operating temperature.



The basic functions of a fluid power system.

Classification of Fluid Power Systems

The fluid power system can be categorized as follows:

1. **Based on the control system**

Open-loop system: There is no feedback in the open system and performance is based on the characteristics of the individual components of the system. The open- loop system is not accurate and error can be reduced by proper calibration and control.

Closed-loop system: This system uses feedback. The output of the system is fed back to a comparator by a measuring element. The comparator compares the actual output to the desired output and gives an error signal to the control element. The error is used to change the actual output and bring it closer to the desired value. A simple closed-loop system uses servo valves and an advanced system uses digital electronics.

2. Based on the type of control

Fluid logic control: This type of system is controlled by hydraulic oil or air. The system employs fluid logic devices such as AND, NAND, OR, NOR, etc. Two types of fluid logic systems are available:

(a) *Moving part logic (MPL):* These devices are miniature fluid elements using moving parts such as diaphragms, disks and poppets to implement various logic gates.

(b) *Fluidics:* Fluid devices contain no moving parts and depend solely on interacting fluid jets to implement various logic gates.

Electrical control: This type of system is controlled by electrical devices. Four basic electrical devices are used for controlling the fluid power systems: switches, relays, timers and solenoids. These devices help to control the starting, stopping, sequencing, speed, positioning, timing and reversing of actuating cylinders and fluid motors. Electrical control and fluid power work well together where remote control is essential.

Electronic control: This type of system is controlled by microelectronic devices. The electronic brain is used to control the fluid power muscles for doing work. This system uses the most advanced type of electronic hardware including programmable logic control (PLC) or microprocessor (P). In the electrical control, a change in system operation results in a cumbersome process of redoing hardware connections.

The difficulty is overcome by programmable electronic control. The program can be modified or a new program can be fed to meet the change of operations. A number of such programs can be stored in these devices, which makes the systems more flexible.

1.4 Types of fluids

Depending on the behavior of fluids, fluids are divided into two types. They are

- Newtonian Fluid
- Non-Newtonian Fluid

Below about the types of fluids are discussed in brief.

Newtonian Fluid:

Fluids that obey Newton law of viscosity are known as Newtonian Fluids. Newton law of viscosity states that the shear stress on a fluid element layer is directly proportional to the rate of shear strain.

Examples of Newtonian fluids: water, air, kerosene.

Non-Newtonian Fluid:

Fluids that doesn’t obey Newton law of viscosity are known as Non-Newtonian fluids. These fluids are the opposite of Newtonian fluids.

Examples of Non-Newtonian fluids : colloids, thick slurry, emulsions.

1.5 PROPERTIES OF FLUID:

Understanding the **properties of fluids is essential to analyse their behavior in working conditions**. In this post we have written the fluid properties namely mass density, specific weight, specific volume, specific gravity, viscosity, vapor pressure, compressibility and surface tension.

Mass Density:

Mass Density (ρ) is the property of a fluid is the mass per unit volume.

Specific Weight:

Specific Weight (w) of a fluid is the weight per unit volume.

Specific Volume:

Specific Volume (v) of a fluid is the volume of the fluid per unit mass.

Specific Gravity or Relative Density:

Specific Gravity(s) of a fluid is the ratio of the mass density of a fluid to the mass density of a standard fluid.

Viscosity:

Viscosity is property by virtue of which it offers resistance to the movement of one layer of fluid over the adjacent layer.

Vapor Pressure:

When a liquid is confined in a closed vessel, the ejected vapor molecules accumulated in the space between free liquid pressure and top of the vessel exert a partial pressure on the liquid surface. This pressure in liquid is known as vapor pressure.

Compressibility:

The normal compressive stress of any fluid element at rest is known as hydro static pressure which arises as a result of innumerable molecular collisions in the entire fluid. The degree of compressibility of a substance is characterized by *bulk modulus of elasticity (B)*.

Surface Tension:

Surface is a measure of fluid tendency to take a spherical shape, caused by mutual attraction of the liquid molecules.

1.6 Basics of Hydraulics

Hydraulics is the transmission and control of forces and motions through the medium of fluids. Short and simple. Hydraulic systems and equipment have wide-spread application throughout industry.

For example: - machine tool manufacturing - press manufacturing - plant construction - vehicle manufacturing - aircraft manufacturing - shipbuilding - injection molding machines

Basic Components of a Hydraulic System : Hydraulic systems are power-transmitting assemblies employing pressurized liquid as a fluid for transmitting energy from an energy-generating source to an energy-using point to accomplish useful work. Figure 1.1 shows a simple circuit of a hydraulic system with basic components.

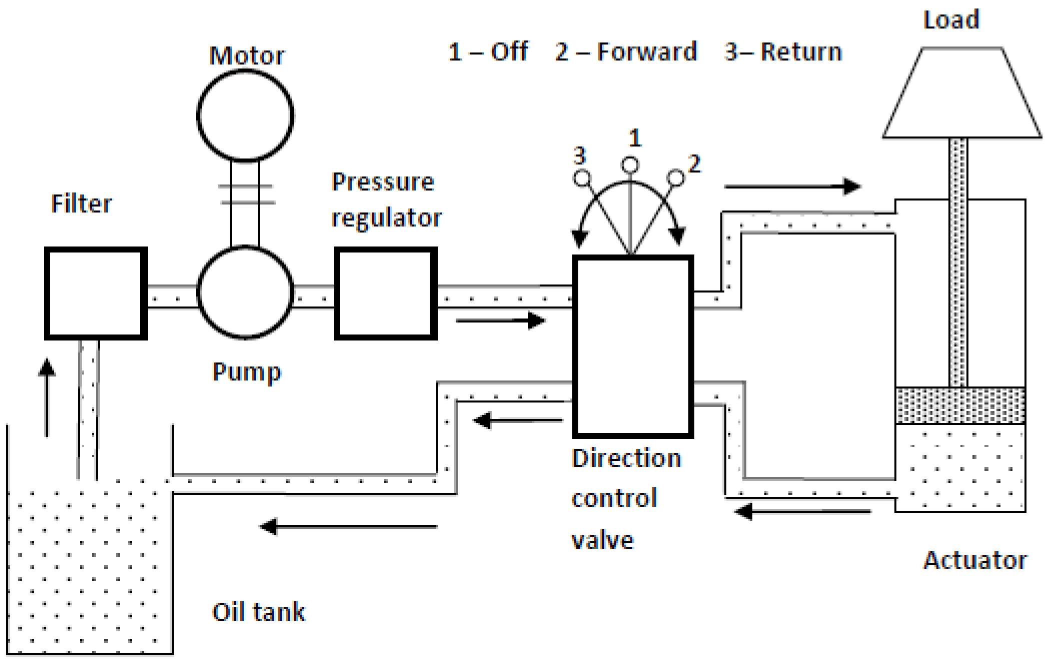


Figure Components of a hydraulic system

Functions of the components shown in Fig. are as follows:

1. The hydraulic actuator is a device used to convert the fluid power into mechanical power to do useful work. The actuator may be of the linear type (e.g., hydraulic cylinder) or rotary type(e.g., hydraulic motor) to provide linear or rotary motion, respectively.

2. The hydraulic pump is used to force the fluid from the reservoir to rest of the hydraulic circuit by converting mechanical energy into hydraulic energy.

3. Valves are used to control the direction, pressure and flow rate of a fluid flowing through the circuit.

4. External power supply (motor) is required to drive the pump.

5. Reservoir is used to hold the hydraulic liquid, usually hydraulic oil.

6. Piping system carries the hydraulic oil from one place to another.

7. Filters are used to remove any foreign particles so as keep the fluid system clean and efficient, as well as avoid damage to the actuator and valves.

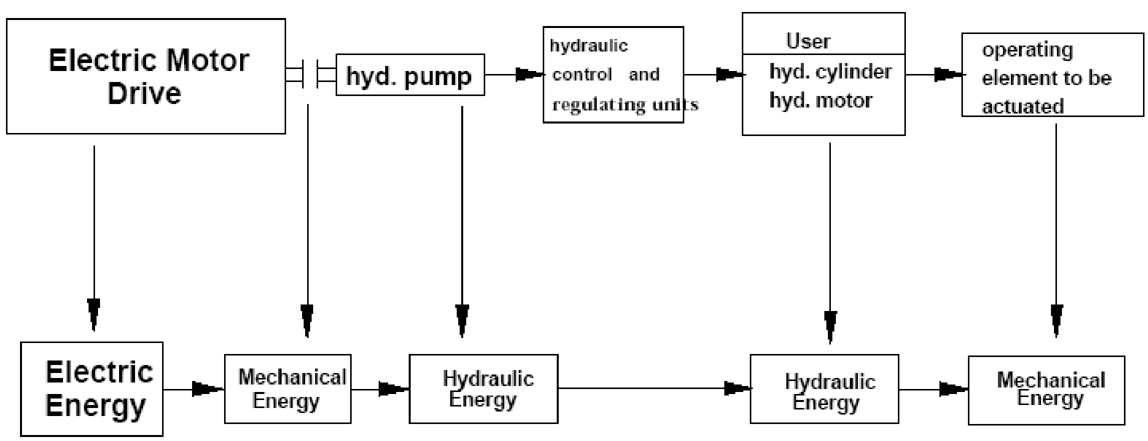
8. Pressure regulator regulates (i.e., maintains) the required level of pressure in the hydraulic fluid.

Hydraulic to Electrical Analogy:

Hydraulics and electrics are analogous, because they both deal with flow, pressure and load. The components in each type of circuit perform similar functions and therefore can be related, a few examples are listed below:

Hydraulic Pump	⟷	Generator
Hydraulic Motor	⟷	Electric Motor
Directional Control Valve	⟷	Switches
Hoses	⟷	Wire
Cylinder	⟷	Solenoid
Check Valve	⟷	Diode
Relief Valve	⟷	Circuit Breaker
Accumulator	⟷	Capacitor
Booster	⟷	Transformer

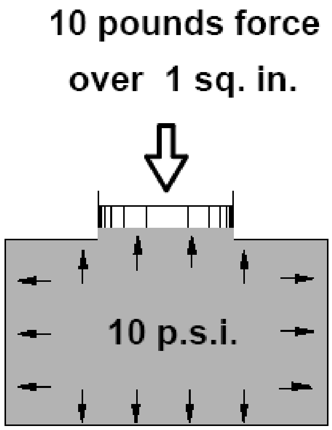
Conversion of Energy in Hydraulics

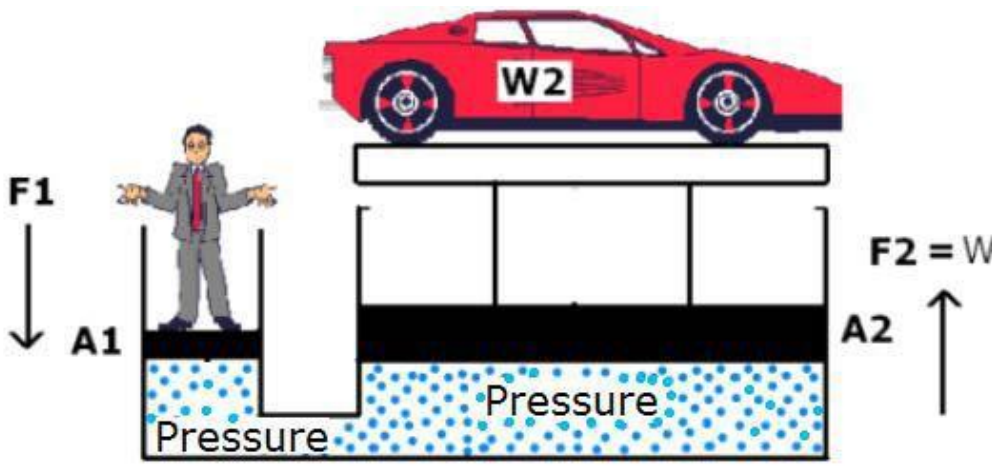


Various forms of energy are converted to accomplish mechanical movement in the injection molding machine. Electrical energy is converted to mechanical energy, which in turn is converted to hydraulic energy to operate and control the moving components of the machine. The hydraulic energy is converted to mechanical energy to achieve the final desired result, which may be "mold clamping pressure" or "material injection".

1.7 Pascal’s Law

Pascal's Law states that the pressure acting on a confined fluid is transmitted equally and undiminished in all directions. In the figure below, a 10 pound force acting on a 1 square inch area generates a pressure of 10 pounds per square inch (psi) throughout the container acting equally on all surfaces.





Fluid pressure is measured in terms of the force exerted per unit area.

$$P = \frac{F}{A}$$

$$P_1 = \frac{F_1}{A_1}$$

$$P_2 = \frac{F_2}{A_2}$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

The values F1, A2 can be calculated using the following formula:

$$F_1 = \frac{A_1 \times F_2}{A_2}, \text{ and } A_2 = \frac{A_1 \times F_2}{F_1}$$

1.8 Work, Power and Torque

Work refers to an activity involving a force and movement in the directon of the force. A force of 20 newtons pushing an object 5 meters in the direction of the force does 100 joules of work.

Power is the rate of doing work or the rate of using energy, which are numerically the same. If you do 100 joules of work in one second (using 100 joules of energy), the power is 100 watts.

Torque is defined as a twisting force that tends to cause rotation. We call the point where the object rotates the axis of rotation. You apply torque three times when you simply open a locked door. Turning the key, turning the doorknob, and pushing the door open so it swings on its hinges are all methods of applying a torque.

1.9 Properties of air

The following is a list of the properties of air;

Air has weight.

Air is under pressure.

Air has temperature.

Air has a volume.

Air usually contains some water vapour.

Air usually has some velocity (speed).

1.10 Perfect Gas Laws

A law that describes the relationships between measurable properties of an ideal gas. The law states that P × V = n × (R) × T, where P is pressure, V is volume, n is the number of moles of molecules, T is the absolute temperature, and R is the gas constant (8.314 joules per degree Kelvin or 1.985 calories per degree Celsius). A consequence of this law is that, under constant pressure and temperature conditions, the volume of a gas depends solely on the number of moles of its molecules, not on the type of gas. Also called *universal gas law*.

UNIT 2

HYDRAULIC ACTUATORS AND CONTROL COMPONENTS

UNIT 2 HYDRAULIC SYSTEM AND COMPONENTS

Sources of Hydraulic power: Pumping Theory – Pump Classification- Construction, Working, Design, Advantages, Disadvantages, Performance, Selection criterion of Linear, Rotary- Fixed and Variable displacement pumps, Hydraulic Actuators: Cylinders – Types and construction, Hydraulic motors Control Components: Direction control, Flow control and Pressure control valves- Types, Construction and Operation- Applications – Types of actuation. Accessories: Reservoirs, Accumulators, Intensifiers, Pressure Switches- Applications- Fluid Power ANSI Symbol.

2.1 SOURCES OF HYDRAULIC POWER

Pumping Theory:

Pumps operate on the principle whereby a partial vacuum is created at the pump inlet due to the internal operation of pump. This allows atmospheric pressure to push the fluid out of the oil tank (reservoir) and into pump intake. The pump then mechanically pushes the fluid out the discharge line.

This type of operation can be visualized by referring to the simple piston pump figure. Note that this pump contains two ball check valves, which are described as follow:

- Check valve 1 is connected to the pump inlet line and allows the fluid to enter the pump only at this location.
- Check valve 2 is connected to the pump discharge line and allows the fluid to leave the pump only at this location.

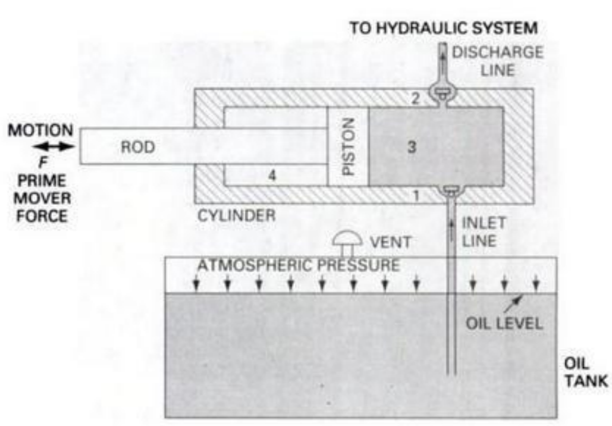


Figure Pumping action of a simple piston pump.

As the piston is pulled to the left, a partial vacuum is generated in pump cavity 3, because the close tolerance between the piston and cylinder (or the use of piston ring seals) prevents air inside cavity 4 from traveling into cavity 3. This flow of air, if allowed to occur, would destroy the vacuum. This vacuum holds the ball of check valve 2 against its seat (lower position) and allows atmospheric pressure to push fluid from the reservoir into the pump via check valve 1. This inlet flow occurs because the force of the fluid pushes the ball of check valve 1 off its seat.

When the piston is pushed to the right, the fluid movement closes inlet valve 1 and opens outlet valve 2. The quantity of fluid, displaced by the piston, is forcibly ejected out the discharge line leading to the hydraulic system. The volume of oil displaced by the piston during the discharge stroke is called the *displacement volume* of the pump.

2.2 CLASSIFICATION OF PUMPS:

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

Pumps are used to transfer and distribute liquids in various industries. Pumps convert mechanical energy into hydraulic energy. Electrical energy is generally used to operate the various types of pumps.

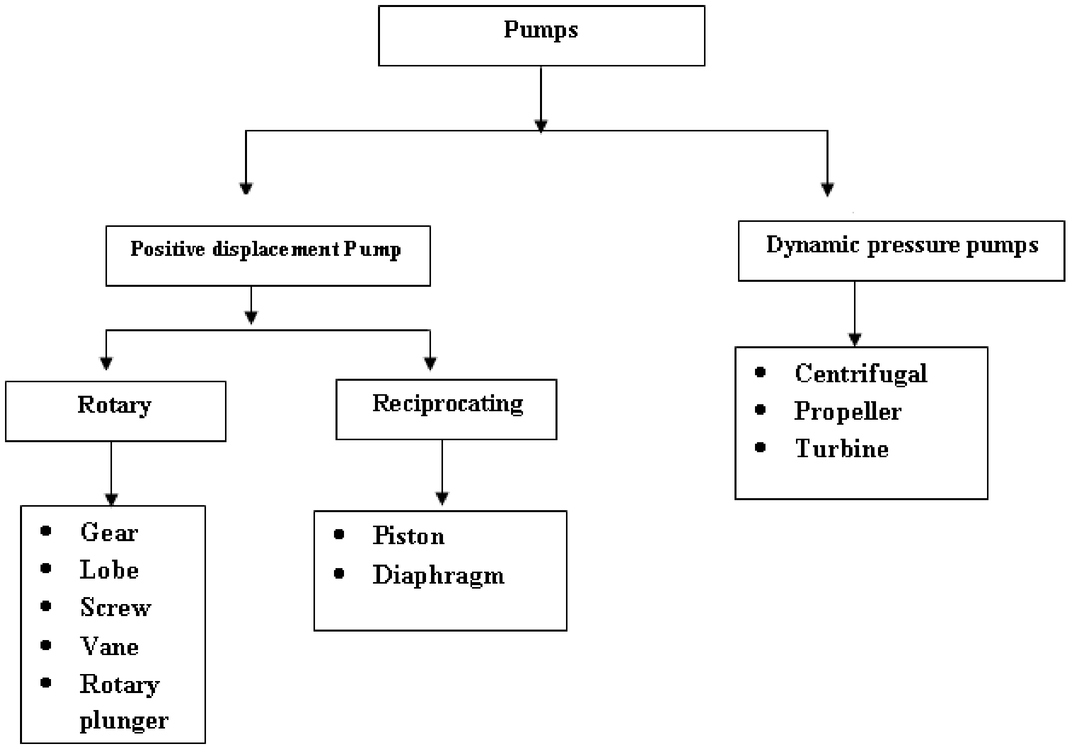
Pumps have two main purposes.

- Transfer of liquid from one place to another place (e.g. water from an underground into a water storage tank).
- Circulate liquid around a system (e.g. cooling water or lubricants through machines and equipment).

Components of a Pumping System

- Pump casing and impellers
- Prime movers: electric motors, diesel engines or air system
- Piping used to carry the fluid
- Valves, used to control the flow in the system
- other fittings, controls and instrumentation
- End-use equipment, which have different requirements (e.g. pressure, flow) and therefore determine the pumping system components and configuration. Examples include heat exchangers, tanks and hydraulic machines.

Classification:



There exist a wide variety of pumps that are designed for various specific applications. However, most of them can be broadly classified into two categories as mentioned below.

i. Dynamic pressure pumps (Non positive displacement pump)

ii. Positive displacement pumps

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

2. Positive displacement pumps. This type is universally used for fluid power systems. As the name implies, a positive displacement pump ejects a fixed amount of fluid into the hydraulic system per revolution of pump shaft rotation. Such a pump is capable of overcoming the pressure resulting from the mechanical loads on the system as well as the resistance to flow due to friction. These are two features that are desired of fluid power pumps. These pumps have the following advantages over nonpositive displacement pumps:

a. High-pressure capability (up to 12,000 psi)
b. Small, compact size
c. High volumetric efficiency
d. Small changes in efficiency throughout the design pressure range
e. Great flexibility of performance (can operate over a wide range of pressure requirements and speed ranges)

POSITIVE DISPLACEMENT PUMPS

Positive displacement pump can be classified by the types of motion of the internal elements. The motion may be either rotary or reciprocating. Although these pumps comi in wide variety of designs, there are essentially three basic types:

1. GEAR PUMPS:
   - External Gear pump
   - Internal Gear pump
   - Lobe pump
   - Screw Pump
2. Vane pump
   - Balanced Vane pump
   - Unbalanced Vane pump
3. Piston pump
   - Axial Design
   - Radial Design

GEAR PUMPS:

EXTERNAL GEAR PUMP

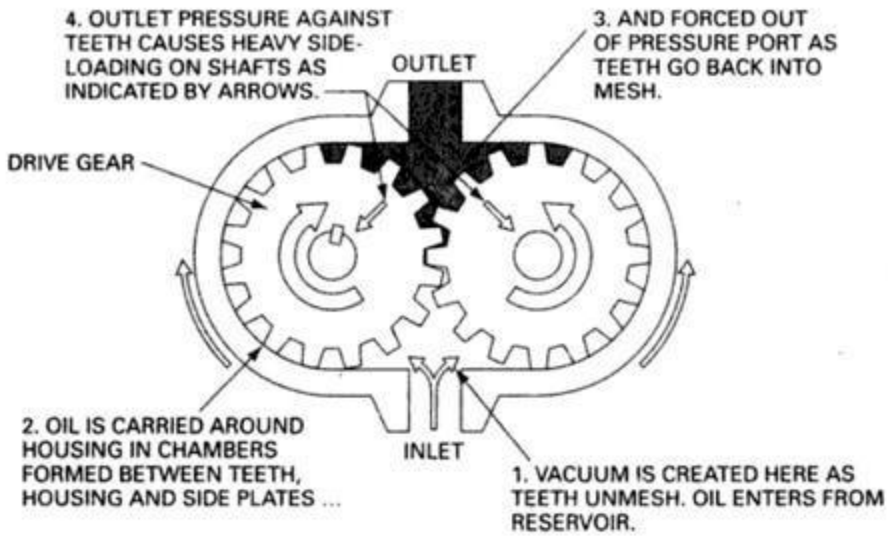
External gear pumps are used in industrial and mobile (e.g. log splitters, lifts) hydraulic applications. Typical applications are lubrication pumps in machine tools, fluid power transfer units and oil pumps in engines. These pumps have some unique features:

- Low weight
- Relatively high working pressures
- Wide range of speeds
- Wide temperature and viscosity range (i.e. flexibility)
- Low cost

In an external gear pump, only one of the gear wheels is connected to the drive. The other gear wheel rotates in the opposite direction so that the teeth of the rotating gear wheels interlock. With use of a bearing block, the gear wheels are positioned in such a way that they interlock with the minimum clearance. Volume is created between the gear tooth profiles, housing walls and surfaces of the bearing blocks.

Typical parameters are:

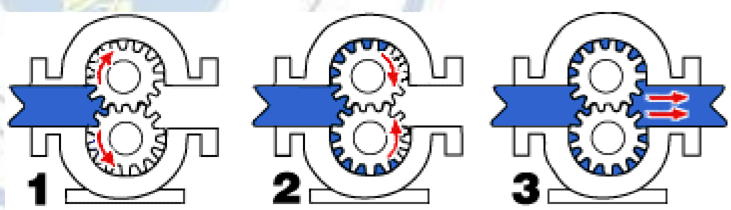
- Displacement volume: 0.2 to 200 cc
- Maximum pressure: up to 300 bar (size dependent)
- Speed range: 500 to 6,000 rpm



External gear pump operation. *(Courtesy of Sperry Vickers, Sperry Rand Corp., Troy, Michigan.)*

How External Gear Pumps Work

External gear pumps are similar in pumping action to internal gear pumps in that two gears come into and out of mesh to produce flow. However, the external gear pump uses two identical gears rotating against each other -- one gear is driven by a motor and it in turn drives the other gear. Each gear is supported by a shaft with bearings on both sides of the gear.



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1. As the gears come out of mesh, they create expanding volume on the inlet side of the pump. Liquid flows into the cavity and is trapped by the gear teeth as they rotate.

2. Liquid travels around the interior of the casing in the pockets between the teeth and the casing -- it does not pass between the gears.

3. Finally, the meshing of the gears forces liquid through the outlet port under pressure.

Because the gears are supported on both sides, external gear pumps are quiet-running and are routinely used for high-pressure applications such as hydraulic applications. With no overhung bearing loads, the rotor shaft can't deflect and cause premature wear.

Volumetric Displacement and Theoretical Flow Rate

The following analysis permits us to evaluate the theoretical flow-rate of a gear pump using specified nomenclature:

D_o = outside diameter of gear teeth (in, m)

D_i = inside diameter of gear teeth (in, m)

L = width of gear teeth (in, m)

V_D = displacement volume of pump (in^3/rev, m^3/rev)

N = rpm of pump

Q_T = theoretical pump flow-rate

$$V_D = \frac{\pi}{D}(D_o^2 - D_i^2)L$$

The theoretical flow-rate (in English units) is determined next:

$$Q_T(\text{in}^3/\text{min}) = V_D(\text{in}^3/\text{rev}) \times N(\text{rev/min})$$

Since 1 gal = 231 in^3, we have

$$Q_T(\text{gpm}) = \frac{V_D(\text{in}^3/\text{rev}) \times N(\text{rev/min})}{231}$$

Using metric units, we have

$$Q_T(\text{m}^3/\text{min}) = V_D(\text{m}^3/\text{rev}) \times N(\text{rev/min})$$

Volumetric Efficiency

$$\eta_v = \frac{Q_A}{Q_T}$$

ages	***antages***	***ations***
peed ressure rhung bearing loads ely quiet operation accommodates wide variety of ls	shings in liquid area ds allowed nd Clearances	on external gear pump applications include not limited to: s fuel oils and lube oils l additive and polymer metering l mixing and blending (double pump) ial and mobile hydraulic applications (log s, lifts, etc.) nd caustic (stainless steel or composite ction) lume transfer or application

A gear pump has a 3-in outside diameter, a 2-in inside diameter, and a 1-in width. If the actual pump flow at 1800 rpm and rated pressure is 28 gpm, what is the volumetric efficiency?

Solution Find the displacement volume using Eq. (5-1):

$$V_D = \frac{\pi}{4}[(3)^2 - (2)^2](1) = 3.93 \text{ in}^3$$

Next, use Eq. (5-2) to find the theoretical flow-rate:

$$Q_T = \frac{V_D N}{231} = \frac{(3.93)(1800)}{231} = 30.6 \text{ gpm}$$

The volumetric efficiency is then found using Eg. (5-3):

$$\eta_v = \frac{28}{30.6} = 0.913 = 91.3\%$$

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

Solution The volume displacement is

$$V_D = \frac{\pi}{4}[(0.075)^2 - (0.050)^2](0.025) = 0.0000614 \text{m}^3\text{/rev}$$

Since 1 L = 0.001 m^3, V_D = 0.0614 L.

Next, combine Eqs. (5-2M) and (5-3) to find the actual flow-rate:

$$Q_A = \eta_v Q_T = \eta_v V_D(\text{m}^3\text{/rev}) \times N(\text{rev/min})$$

$$= 0.90 \times 0.0000614 \times 1000 = 0.0553 \text{ m}^3\text{/min}$$

Since 1 L = 0.001 m^3, we have

$$Q_A = 55.3 \text{ Lpm}$$

INTERNAL GEAR PUMP:

Internal gear pumps are primarily used in non-mobile hydraulics (e.g. machines for plastics and machine tools, presses, etc.) and in vehicles that operate in an enclosed space (electric fork-lifts, etc.). The internal gear pump is exceptionally versatile and also capable of handling thick fluids. Key features are:

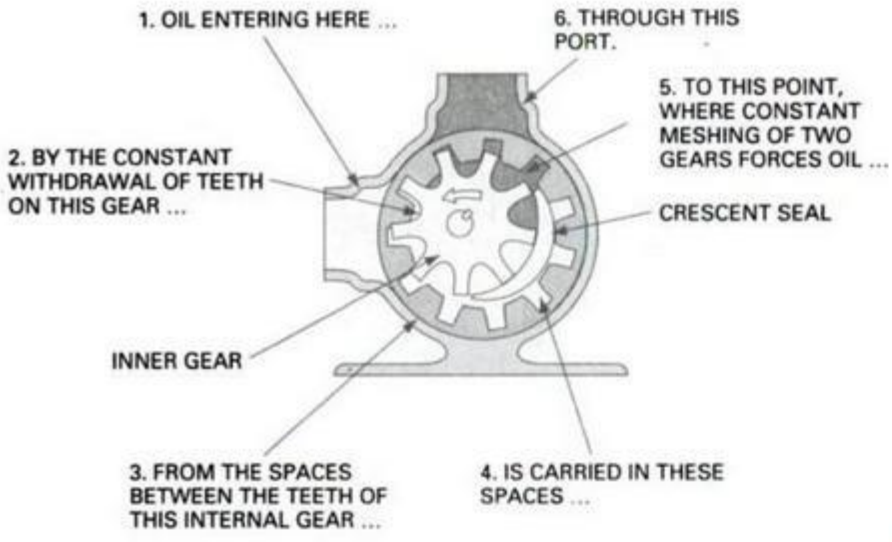
- Low flow pulsation
- Low operating noise
- High efficiency

In an internal gear pump, the gear rotor is connected to the drive. When the gear rotor and internal gear rotate, volume is created between the gear ring profiles, housing walls and filling piece. The space between the gear tooth profiles increases relatively slowly over an angle of about 120°. This causes operation to be exceptionally quiet with a constant flow.

Typical parameters are:

- Displacement volume: 0.5 to 500 cc
- Maximum pressure: up to 300 bar (dependent on nominal size)

- Speed range: 500 to 3,000 rpm (dependent on nominal size)



WORKING:

1. Liquid enters the suction port between the rotor (large exterior gear) and idler (small interior gear) teeth. The arrows indicate the direction of the pump and liquid.

2. Liquid travels through the pump between the teeth of the "gear-within-a-gear" principle. The crescent shape divides the liquid and acts as a seal between the suction and discharge ports.

3. The pump head is now nearly flooded, just prior to forcing the liquid out of the discharge port. Intermeshing gears of the idler and rotor form locked pockets for the liquid which assures volume control.

4. Rotor and idler teeth mesh completely to form a seal equidistant from the discharge and suction ports. This seal forces the liquid out of the discharge port.

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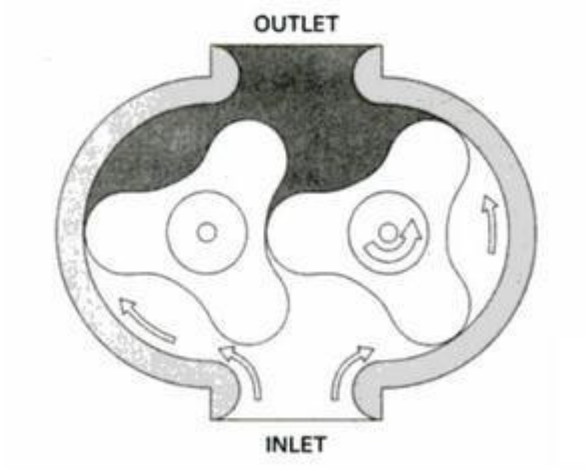
vo moving parts ne stuffing box lsating discharge nt for high-viscosity liquids nt and even discharge regardless of e conditions es well in either direction made to operate with one direction ith either rotation PSH required adjustable end clearance maintain e design offers application ization	requires moderate speeds n pressure limitations aring runs in the product pumpe ng load on shaft bearing	on internal gear pump applications , but are not limited to: ieties of fuel oil and lube oil and Polymers ls and solvents t, Bitumen, and Tar ethane foam (Isocyanate and polyol) roducts such as corn syrup, chocolate, butter nks, and pigments nd surfactants

LOBE PUMP:



The gear ring pump is primarily used as a pressure lubrication system for machines and combustion engines. They are also used in hydraulic power steering systems.

This pump is often assembled with a high pressure pump, e.g. radial piston pump. The rotors of the gear ring pump can be directly built into the housing of the high pressure pump, which makes it possible to build very compact units. Such small double-pumps are often used for rapid traverse on large presses and tensioning equipment.

The rotor has one tooth less than the inner stator. Planetary movement of the rotor results in compressing and decompressing of the displacement chambers within the housing.

WORKING:

Lobe pumps are similar to external gear pumps in operation in that fluid flows around the interior of the casing. Unlike external gear pumps, however, the lobes do not make contact. Lobe contact is prevented by external timing gears located in the gearbox. Pump shaft support bearings are located in the gearbox, and since the bearings are out of the pumped liquid, pressure is limited by bearing location and shaft deflection.

1. As the lobes come out of mesh, they create expanding volume on the inlet side of the pump. Liquid flows into the cavity and is trapped by the lobes as they rotate.

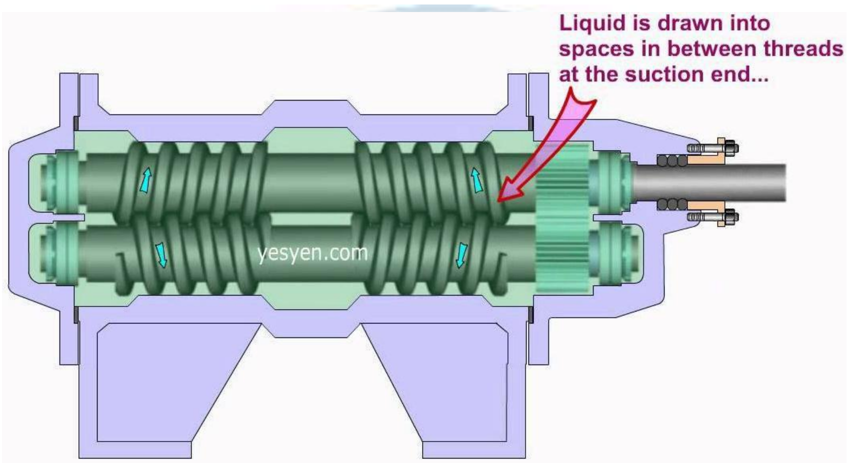
2. Liquid travels around the interior of the casing in the pockets between the lobes and the casing -- it does not pass between the lobes.

3. Finally, the meshing of the lobes forces liquid through the outlet port under pressure.

Lobe pumps are frequently used in food applications because they handle solids without damaging the product. Particle size pumped can be much larger in lobe pumps than in other PD types. Since the lobes do not make contact, and clearances are not as close as in other PD pumps, this design handles low viscosity liquids with diminished performance. Loading characteristics are not as good as other designs, and suction ability is low. High-viscosity liquids require reduced speeds to achieve satisfactory performance. Reductions of 25% of rated speed and lower are common with high-viscosity liquids.

tages	antages	ations
edium solids al-to-metal contact r CIP/SIP capabilities rm dry run (with lubrication to lsating discharge	es timing gears es two seals d lift with thin liquids	on rotary lobe pump applications , but are not limited to: rs oatings nd surfactants and dyes and adhesives ceuticals

SCREW SPINDLE PUMP



Similar to internal gear pumps, screw pumps possess an extremely low operating noise level. They are therefore used in hydraulic systems in such places as theatres and opera houses.

The displacement volume of the screw spindle pump is the largest of all gear pumps. Screw pumps contain 2 or 3 worm gears within the housing and therefore also referred to as worm gear pumps.

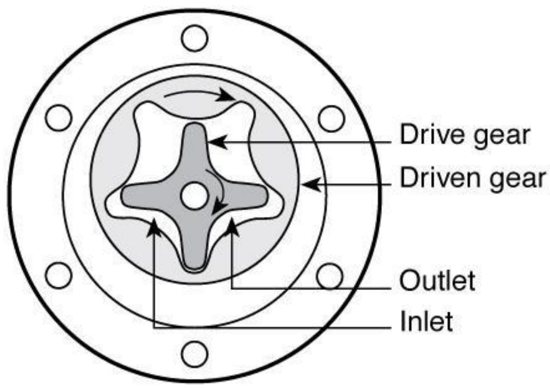
Typical parameters are:

- Displacement vol.: 15 to 3,500 cc
- Maximum pressure: up to 200 bar (dependent on nominal size)
- Speed range: 500 to 3,500 rpm (dependent on nominal size)

The worm gear that is connected to the drive has a clockwise thread. Rotary movement is transmitted to further worm gears, which have counter-clockwise threads. The displacement chamber is formed between the threads and the housing of the screw pump.

GEROTOR PUMP

The Gerotor pump, shown in Figure , operates very much like the internal gear pump. The inner gear rotor (Gerotor element) is power-driven and draws the outer gear rotor around as they mesh together. This forms inlet and discharge pumping chambers between the rotor lobes. The tips of the inner and outer rotors make contact to seal the pumping chambers from each other. The inner gear has one tooth less than the outer gear, and the volumetric displacement is determined by the space formed by the extra tooth in the outer rotor.



gerotor pump

WORKING

1. Liquid enters the suction port between the rotor (gray gear) and idler (orange gear) teeth.

2. Liquid travels through the pump between the teeth of the "gear-within-a-gear" principle. The close tolerance between the gears acts as a seal between the suction and discharge ports.

3. Rotor and idler teeth mesh completely to form a seal equidistant from the discharge and suction ports. This seal forces the liquid out of the discharge port.

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VANE PUMP

- ❖ **Balanced Vane pump**
- ❖ **Unbalanced Vane pump**

Figure illustrates the operation of a vane pump. The rotor, which contains radial slots, is splined to the drive shaft and rotates inside a cam ring. Each slot contains a vane designed to mate with the surface of the cam ring as the rotor turns. Centrifugal force keeps the vanes out against the surface of the cam ring. During one-half revolution of rotor rotation, the volume increases between the rotor and cam ring. The resulting volume expansion causes a reduction of pressure. This is the suction process, which causes fluid to flow through the inlet port and fill the void. As the rotor rotates through the second half revolution, the surface of the cam ring pushes the vanes back into their slots, and the trapped volume is reduced. This positively ejects the trapped fluid through the discharge port.

Key features of the vane pump:

- Low flow pulsation
- Very low noise levels
- Wide range of speeds
- Wide viscosity range

The operating pressure of vane pumps does not normally exceed 175 bar. However, in specially designed vane pumps the operating pressure may go over 200 bar and up to 300 bar. Hydraulic vane pumps are available as single chamber vane pumps or double chamber vane pumps.

Both types use the same parts, i.e. they comprise a rotor and vanes. The vanes may be radially moved within the rotor, and the centrifugal force of the rotor pushes the vanes out to touch the housing. The difference between the two types is in the shape of the stroke ring that limits the stroke movement of the vanes.

Typical parameters are:

- Displacement volume: 6 to 640 cc
- Maximum pressure: up to 200 bar

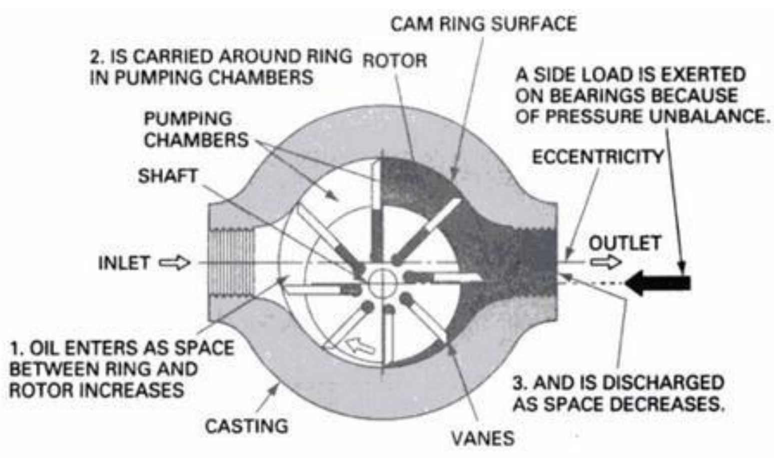


Figure Vane pump operation.

- Speed range: 500 to 3,000 rpm

VOLUMETRIC ANALYSIS OF VANE PUMP:

D_C = diameter of cam ring (in, m)

D_R = diameter of rotor (in, m)

L = width of rotor (in, m)

V_D = pump volumetric displacement (in^3, m^3)

e = eccentricity (in, m)

e_{max} = maximum possible eccentricity (in, m)

$V_{D_{max}}$ = maximum possible volumetric displacement (in^3, m^3)

From geometry, we can find the maximum possible eccentricity:

$$e_{max} = \frac{D_C - D_R}{2}$$

This maximum value of eccentricity produces a maximum volumetric displacement:

$$V_{D_{max}} = \frac{\pi}{4}(D_C^2 - D_R^2)L$$

Noting that we have the difference between two squared terms yields

$$V_{D_{max}} = \frac{\pi}{4}(D_C + D_R)(D_C - D_R)L$$

Substituting the expression for e_{max} yields

$$V_{D_{max}} = \frac{\pi}{4}(D_C + D_R)(2e_{max})L$$

The actual volumetric displacement occurs when $e_{max} = e$:

$$V_D = \frac{\pi}{2}(D_C + D_R)eL$$

PISTON PUMP

- **Axial Design**
- **Radial Design**

Hydraulic piston pumps can handle large flows at high hydraulic system pressures. Typical applications are mobile and construction equipment, marine auxiliary power, metal forming and stamping, machine tools and oil field equipment.

In these pumps, the pistons accurately slide back and forth inside the cylinders that are part of the hydraulic pump. The sealing properties of the pistons are excellent.

Key features of hydraulic piston pumps are:

- Compact size
- High power density
- Optimum efficiency and reliability
- High speed and torque
- High operating pressures

Hydraulic piston pumps operate at very high volumetric efficiency levels due to low fluid leakage. The plungers may consist of valves at the suction and pressure ports or with input and output channels. Piston pumps with valves at the ports are better suited to operate at higher system pressures due to better sealing characteristics

Axial Piston Pum p

Axial piston pumps are positive displacement pumps which converts rotary motion of the input shaft into an axial reciprocating motion of the pistons. These pumps have a number of pistons (usually an odd number) in a circular array within a housing which is commonly referred to as a cylinder block, rotor or barrel. These pumps are used in jet aircraft. They are also used in small earthmoving plants such as skid loader machines. Another use is to drive the screws of torpedoes. In general, these systems have a maximum operating temperature of about 120 °C. Therefore, the leakage between cylinder housing and body block is used for cooling and lubrication of the rotating parts. This cylinder block rotates by an integral shaft aligoed with the pistons. These pumps have sub-types as:

a. Bent axis piston pumps
b. Swash plate axial piston pump

A. Bent-Axis Piston Pum ps

Figure 5.3.5 shows the schematic of bent axis piston pump. In these pumps, the reciprocating action of the pistons is obtained by bending the axis of the cylinder block The cylinder block rotates at an angle which is inclined to the drive shaft. The cylinder block is turned by the drive shaft through a universal link. The cylinder block is set at an offset angle with the drive shaft. The cylinder block contains a number of pistons along its periphery. These piston rods are connected with the drive shaft flange by ball-and-socket joints. These pistons are forced in and out of their bores as the distance between the drive shaft flange and the cylinder block changes. A universal link connects the block to the drive shaft, to provide aligornent and a positive drive.

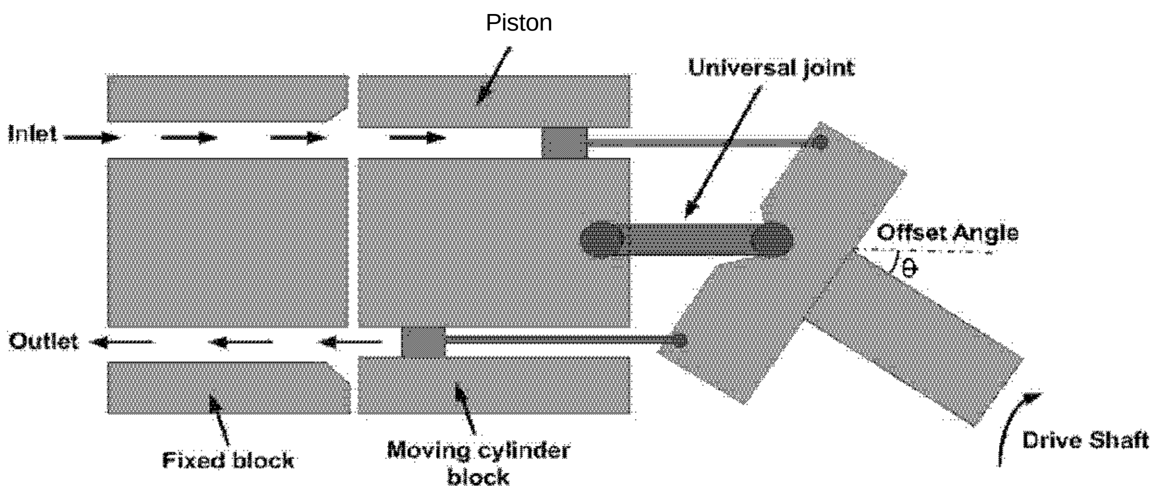


Figure 5.3.5 Bent axis piston pump

The volumetric displacement (discharge) of the pump is controlled by changing the offset angle. It makes the system simple and inexpensive. The discharge does not occur when the cylinder block is parallel to the drive shaft. The offset angle can vary from 0° to 40°. The fixed displacement units are usually provided with 23° or 30° offset angles while the variable displacement units are provided with a yoke and an external control mechanism to change the offset angle. Some designs have arrangement of moving the yoke over the center position to reverse the fluid flow direction. The flow rate of the pump varies with the offset angle *e.* There is no flow when the cylinder block centerline is parallel to the drive shaft centerline (offset angle is 0°). The total fluid flow per stroke can be given as:

$Vd \ nADtanB$

The flow rate of the pump can be given as:

$Vd \ nADN \ tanB$

here,tanB=s;D

where S is the piston stroke, D is piston diameter, n is the number of pistons, N is the speed of pump and A is the area of piston.

B. Swash Plate Axial Piston Pump

A swash plate is a device that translates the rotary motion of a shaft into the reciprocating motion. It consists of a disk attached to a shaft as shown in Figure 5.3.6. If the disk is aligned perpendicular to the shaft; the disk will tum along with the rotating shaft without any reciprocating effect. Similarly, the edge of the inclined shaft will appear to oscillate along the shaft's length. This apparent linear motion increases with increase in the angle between disk and the shaft {offset angle). The apparent linear motion can be converted into an actual reciprocating motion by means of a follower that does not tum with the swash plate.

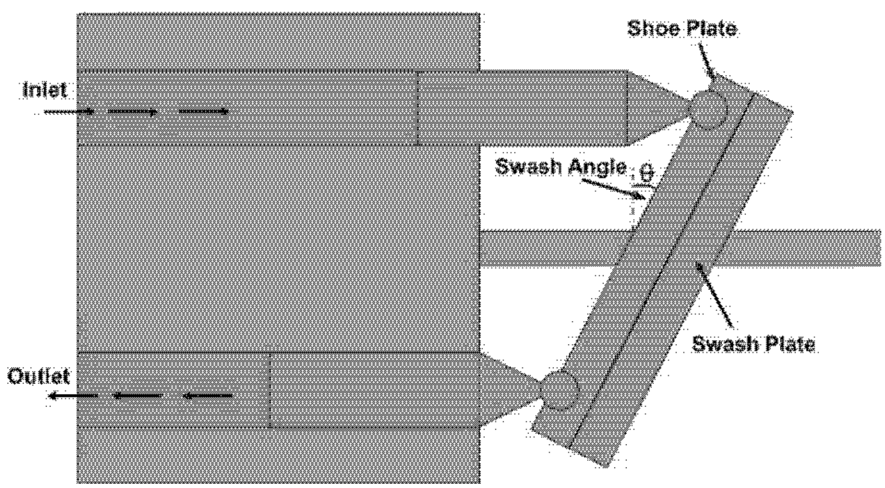


Figure 5.3.6 Swash plate piston pump

In swash plate axial piston pump a series of pistons are aligned coaxially with a shaft through a swash plate to pump a fluid. The schematic of swash plate piston pump is shown in Figure 5.3.6. The axial reciprocating motion of pistons is obtained by a swash plate that is either fixed or has variable degree of angle. As the piston barrel assembly rotates, the piston rotates around the shaft with the piston shoes in contact with the swash plate. The piston shoes follow the angled surface of the swash plate and the rotational motion of the shaft is converted into the reciprocating motion of the pistons. When the swash plate is perpendicular to the shaft; the reciprocating motion to the piston does not occur. As the swash plate angle increases, the piston follows the angle of the swash plate surface and hence it moves in and out of the barrel. The piston moves out of the cylinder barrel during one half of the cycle of rotation thereby generating an increasing volume, while during other half of the rotating cycle, the pistons move into the cylinder barrel generating a decreasing volume. This reciprocating motion of the piston results in the drawing in and pumping out of the fluid. Pump capacity can be controlled by varying the swash plate angle with the help of a separate hydraulic cylinder. The pump capacity (discharge) increases with increase in the swash plate angle and vice-versa. The cylinder block and the drive shaft in this pump are located on the same centreline. The pistons are connected through shoes and a shoe plate that bears against the swash plate. These pumps can be designed to have a variable displacement capability. It can be done by mounting the swash plate in a movable yoke. The swash plate angle can be changed by pivoting the yoke on pintles.

Radial Piston Pum p

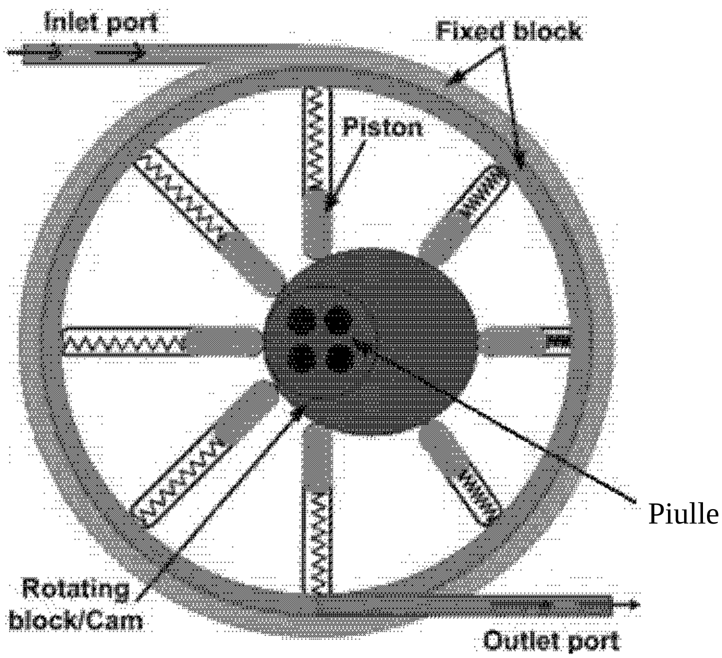


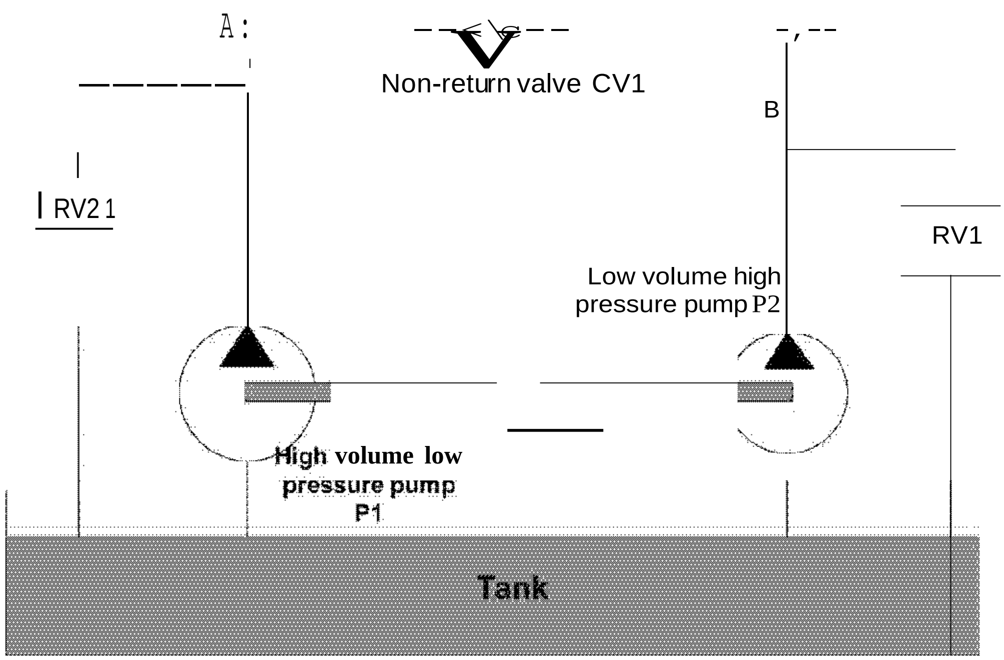
Figure 5.3.7 **Radial piston pump**

The typical construction ofradial piston pump is shown in Figure 5.3.7. The piston pump has pistons aligned radially in a cylindrical block. It consists of a pintle, a cylinder barrel with pistons and a rotor containing a reaction ring. The pintle directs the fluid in and out of the cylinder. Pistons are placed in radial bores around the rotor. The piston shoes ride on an eccentric ring which causes them to reciprocate as they rotate. The eccentricity determines the stroke of the pumping piston. Each piston is connected to inlet port when it starts extending while it is connected to the outlet port when start retracting. This connection to the inlet and outlet port is performed by the timed porting arrangement in the pintle. For initiating a pumping action, the reaction ring is moved eccentrically with respect to the pintle or shaft axis. As the cylinder barrel rotates, the pistons on one side travel outward. This draws the fluid in as the cylinder passes the suction port of the pintle. It is continued till the maximum eccentricity is reached. When the piston passes the maximum eccentricity, pintle is forced inwards by the reaction ring. This forces the fluid to flow out of the cylinder and enter in the discharge (outlet) port of the pintle.

The radial piston pump works on high pressure (up to 1000 bar). It is possible to use the pump with various hydraulic fluids like mineral oil, biodegradable oil, HFA (oil in water), HFC (water-glycol), HFD (synthetic ester) or cutting emulsion. This is because the parts are hydrostatically balanced. It makes the pump suitable for the many applications such as machine tools (displace of cutting emulsion, supply for hydraulic equipment like cylinders), high pressure units (overload protection of presses), test rigs, automotive sector (automatic transmission, hydraulic suspension control in upper-class cars), plastic (powder injection molding) and wind energy etc.

3. Combination Pump

There are two basic requirements for load lifting or load applying by a hydraulic ram. First, there is a need of large volume of fluid at a low pressure when the cylinder extends or retracts. The low pressure is required to overcome the frictional resistance. The second requirement is that a high pressure is needed, when the load is gripped.



Com bination **pump**

This type of requirements can be fulfilled by an arrangement as shown in figure. In this system two separate pumps are driven by a common electrical motor. Pump Pl is a high pressure low volume pump and pump P2 is a high volume low pressure pump. The hydraulic system is associated with relief valves RV1 and RV2 and a one-way check valve CV1. This kind of arrangement allows the fluid flow from left to right, but blocks in the reverse direction.

The pressure relief valve RV1 is a normal high pressure valve. The pressure relief valve RV2 is not operated by the pressure at point A, however, it is remotely operated by the pressure at point B. This can be achieved with the balanced piston valve. In low pressure mode both relief valves are closed and both pumps Pl and P2 deliver fluid to the load but the majority comes from the pump P2 as its capacity is higher.

When the load is in the holding mode, the pressure at B rises and relief valve RV2 opens. It results in all the fluid from pump P2 to return straight to the tank directly and the pressure at A to fall to a low value. The check valve CV 1 stops the fluid from pump Pl pass it back to the tank via relief valve RV2, consequently pressure at B rises to the level set by relief valve RV1.

This kind of arrangement saves energy as the large volume of fluid from pump P2 is returned to the tank at a very low pressure, and only a small volume of fluid from pump P1 is returned at a high pressure.

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

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

2.3 HYDRAULIC ACTUATORS: CYLINDERS – TYPES AND CONSTRUCTION

Hydraulic systems are used to control and transmit power. A pump driven by a prime mover such as an electric motor creates a flow of fluid, in which the pressure, direction and rate of flow are controlled by valves. An actuator is used to convert the energy of fluid back into the mechanical power. The amount of output power developed depends upon the flow rate, the pressure drop across the actuator and its overall efficiency. Thus, hydraulic actuators are devices used to convert pressure energy of the fluid into mechanical energy.

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

1. Linear actuator: For linear actuation (hydraulic cylinders).
2. Rotary actuator: For rotary actuation (hydraulic motor).
3. Semi-rotary actuator: For limited angle of actuation (semi-rotary actuator).

Hydraulic linear actuators, as their name implies, provide motion in a straight line. The total movement is a finite amount determined by the construction of the unit. They are usually referred to as cylinders, rams and jacks. All these items are synonymous in general use, although ram is sometimes intended to mean a single-acting cylinder and jack often refers to a cylinder used for lifting. The function of hydraulic cylinder is to convert hydraulic power into linear mechanical force or motion. Hydraulic cylinders extend and retract a piston rod to provide a push or pull force to drive the external load along a straight-line path.

Continuous angular movement is achieved by rotary actuators, more generally known as a hydraulic motor. Semi-rotary actuators are capable of limited angular movements that can be several complete revolutions but 360o or less is more usual.

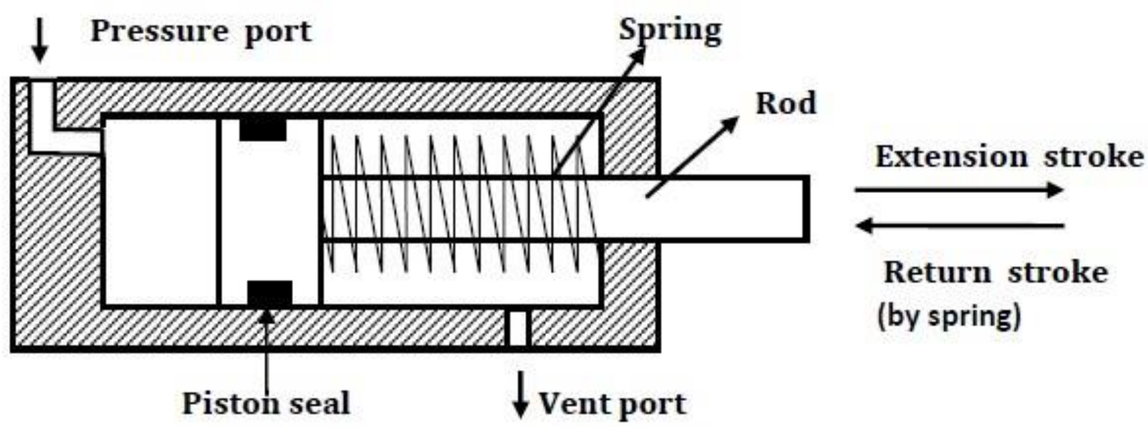
2.3.1 Types of Hydraulic Cylinders

Hydraulic cylinders are of the following types:

- Single-acting cylinders.
- Double-acting cylinders.
- Telescopic cylinders.
- Tandem cylinders.

A. Single-Acting Cylinders

A single-acting cylinder is simplest in design and is shown schematically in Fig.1.1. It consists of a piston inside a cylindrical housing called barrel. On one end of the piston there is a rod, which can reciprocate**.** At the opposite end, there is a port for the entrance and exit of oil. Single-acting cylinders produce force in one direction by hydraulic pressure acting on the piston. (Single-acting cylinders can exert a force in the extending direction only.) The return of the piston is not done hydraulically. In single-acting cylinders, retraction is done either by gravity or by a spring.



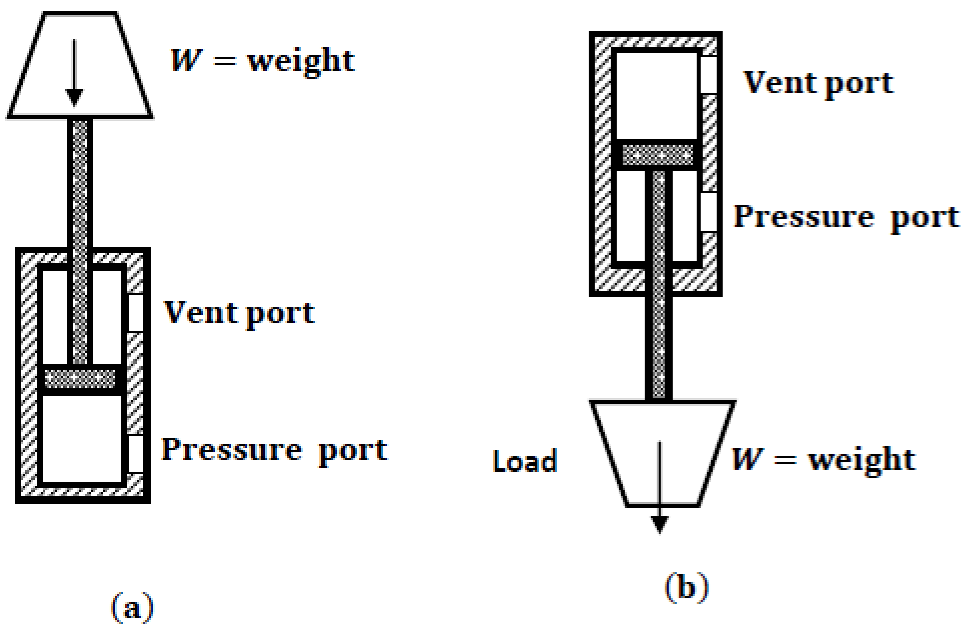
Single-acting cylinders

According to the type of return, single-acting cylinders are classified as follows:

- Gravity-return single-acting cylinder.
- Spring-return single-acting cylinder.

Gravity-Return Single-Acting Cylinder

Figure shows gravity-return-type single-acting cylinders. In the push type [Fig. 1.2(a)], the cylinder extends to lift a weight against the force of gravity by applying oil pressure at the blank end. The oil is passed through the blank-end port or pressure port. The rod-end port or vent port is open to atmosphere so that air can flow freely in and out of the rod end of the cylinder. To retract the cylinder, the pressure is simply removed from the piston by connecting the pressure port to the tank. This allows the weight of the load to push the fluid out of the cylinder back to the tank. In pull-type gravity-return-type single-acting cylinder, the cylinder [Fig. 1.2(b)] lifts the weight by retracting. The blank-end port is the pressure port and blind-end port is now the vent port. This cylinder automatically extends whenever the pressure port is connected to the tank.

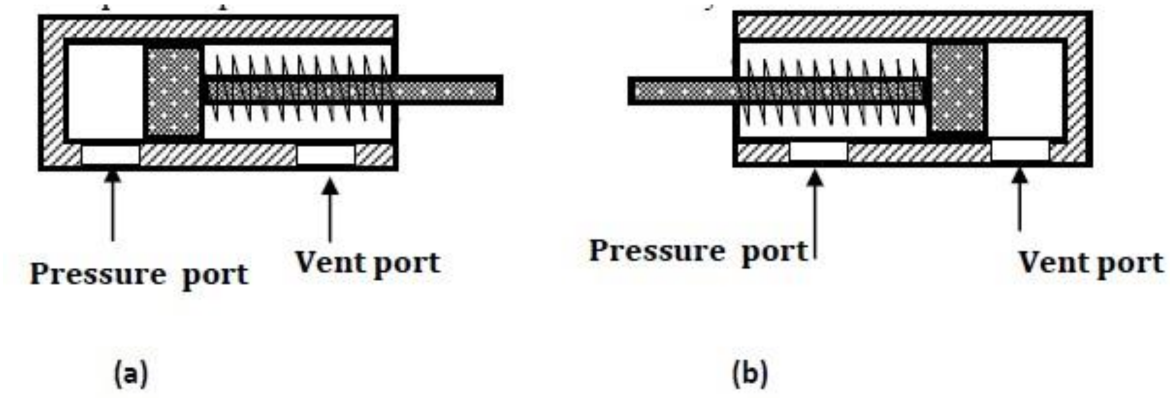


Gravity-return single-acting cylinder: (a) Push type; (b) pull type

Spring-Return Single-Acting Cylinder

A spring-return single-acting cylinder is shown in Fig. A & B.In push type [Fig. (a)], the pressure is sent through the pressure port situated at the blank end of the cylinder. When the pressure is released, the spring automatically returns the cylinder to the fully retracted position. The vent port is open to atmosphere so that air can flow freely in and out of the rod end of the cylinder.

Figure (b) shows a spring-return single-acting cylinder. In this design, the cylinder retracts when the pressure port is connected to the pump flow and extends whenever the pressure port is connected to the tank. Here the pressure port is situated at the rod end of the cylinder.



(a) Push- and (b) pull-type single-acting cylinders

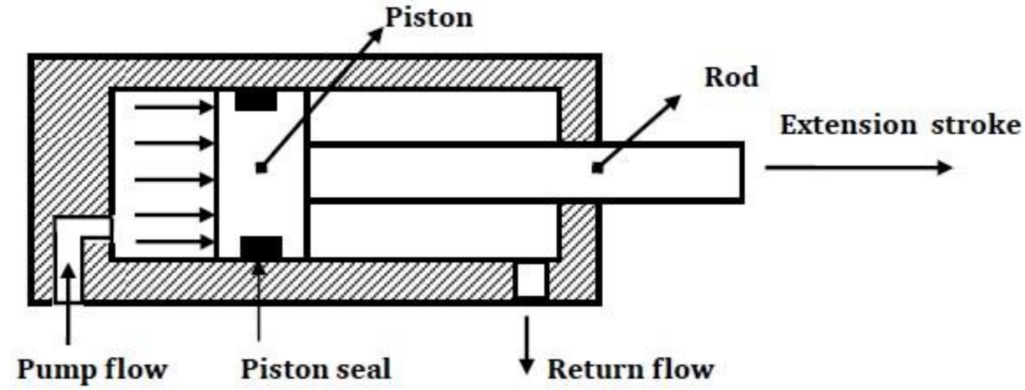
B. Double-Acting Cylinder

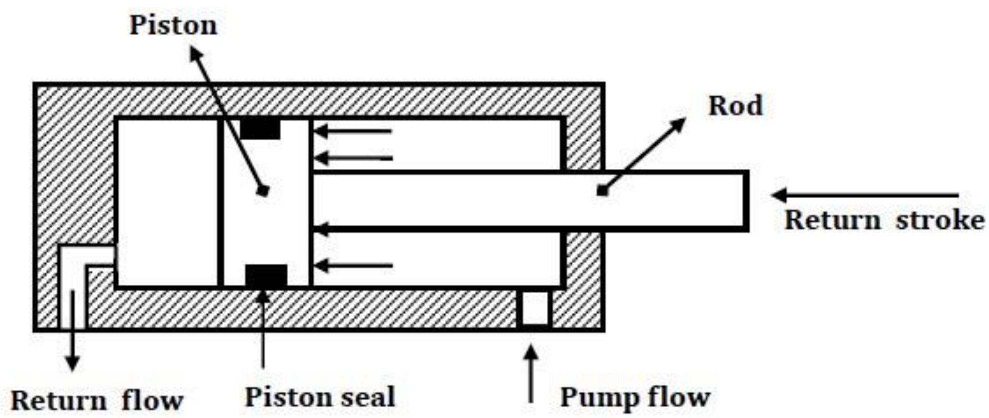
There are two types of double-acting cylinders:

- Double-acting cylinder with a piston rod on one side.
- Double-acting cylinder with a piston rod on both sides.

Double-Acting Cylinder with a Piston Rod on One Side

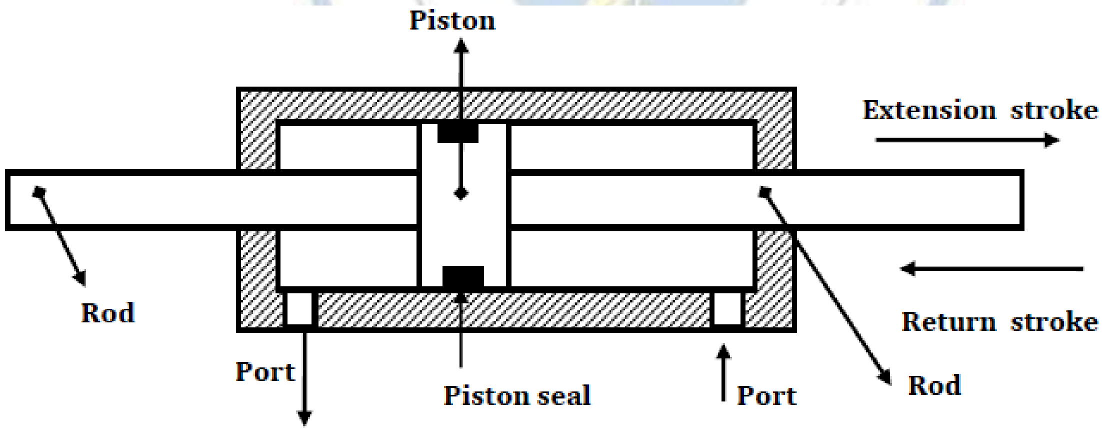
Figure 1.4 shows the operation of a double-acting cylinder with a piston rod on one side. To extend the cylinder, the pump flow is sent to the blank-end port as in Fig. (a). The fluid from the rod-end port returns to the reservoir. To retract the cylinder, the pump flow is sent to the rod-end port and the fluid from the blank-end port returns to the tank as in Fig (b).





Double-acting cylinder with a piston rod on one side

Double-Acting Cylinder with a Piston Rod on Both Sides



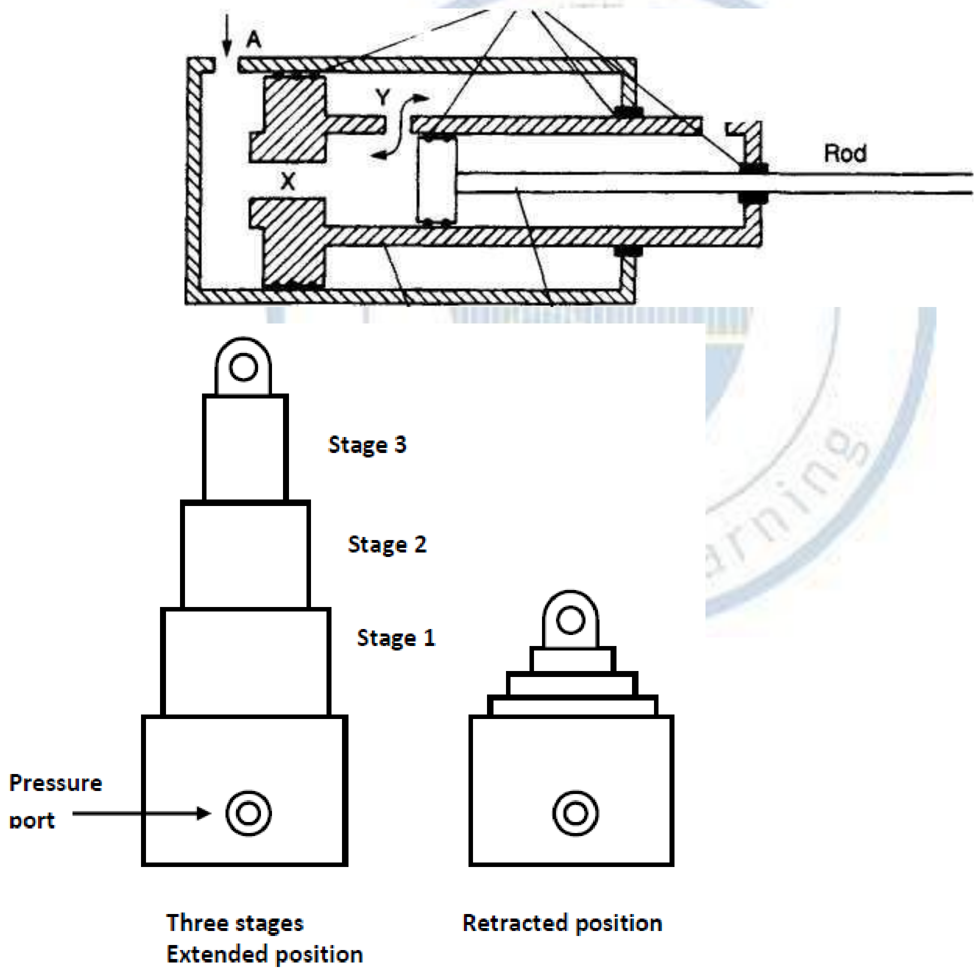
Double-acting cylinder with a piston rod on one side

A double-acting cylinder with a piston rod on both sides (Fig.1.5)is a cylinder with a rod extending from both ends. This cylinder can be used in an application where work can be done by both ends of the cylinder, thereby making the cylinder more productive. Double-rod cylinders can withstand higher side loads because they have an extra bearing, one on each rod, to withstand the loading.

C. Telescopic Cylinder

A telescopic cylinder is used when a long stroke length and a short retracted length are required. The telescopic cylinder extends in stages, each stage consisting of a sleeve that fits inside the previous stage. One application for this type of cylinder is raising a dump truck bed. Telescopic cylinders are available in both single-acting and double-acting models. They are more expensive than standard cylinders due to their more complex construction.

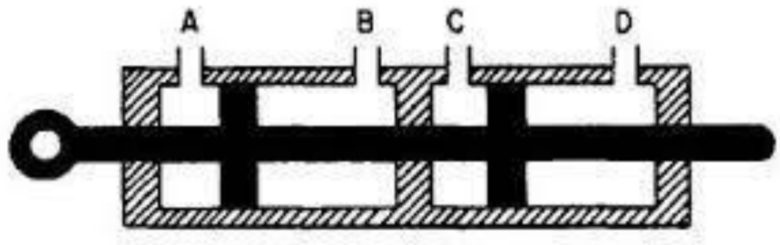
They generally consist of a nest of tubes and operate on the displacement principle. The tubes are supported by bearing rings, the innermost (rear) set of which have grooves or channels to allow fluid flow. The front bearing assembly on each section includes seals and wiper rings. Stop rings limit the movement of each section, thus preventing separation. When the cylinder extends, all the sections move together until the outer section is prevented from further extension by its stop ring. The remaining sections continue out-stroking until the second outermost section reaches the limit of its stroke; this process continues until all sections are extended, the innermost one being the last of all.



Telescopic cylinder

For a given input flow rate, the speed of operation increases in steps as each successive section reaches the end of its stroke. Similarly, for a specific pressure, the load-lifting capacity decreases for each successive section.

D. Tandem Cylinder



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

Through-Rod Cylinders

These are similar in construction to the standard double-acting cylinders, but have a cylinder rod extending through both cylinder end caps. Although it is possible to have both the piston rods with different diameters at each end of the cylinder, generally the rods have the same diameters. The main applications of through-rod cylinders are as follows: the same speed is required in both the directions, both ends of the rod can be utilized to do work and the non-working end is used to indicate or signal the position of the load. In some applications, the rod is fixed at both the ends and the cylinder body carrying the load moves on the rod.
A major problem in the manufacture of through-rod cylinders is achieving the correct alignment and concentricity of cylinder bore, piston, end caps and rods. Any misalignment can result in excessive seal wear and premature cylinder failure.

Displacement Cylinders

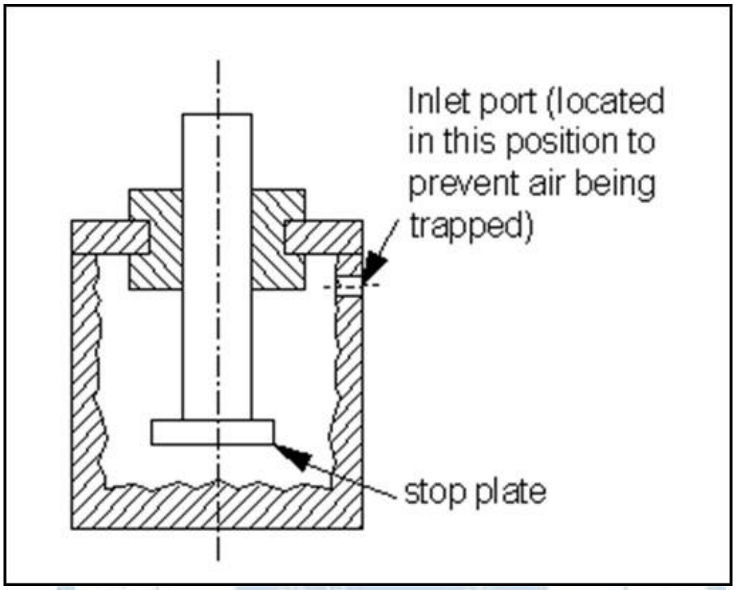
A displacement-type hydraulic cylinder shown in Fig. 1.8 consists of a rod that is displaced from inside a tube by pumping hydraulic fluid into the tube. The volume of the rod leaving the tube is equal to the volume of fluid entering the tube, hence the name “displacement cylinder.” The rod of the displacement cylinder is guided by bearings in the nose or neck of the cylinder body. A collar on the end of the rod prevents it from being ejected and limits the stroke of the cylinder. Elastomer seals in the neck prevent any leakage of fluid along the outside of the rod. This design is a single-acting “push” or extension cylinder, which has to be retracted by gravity, a spring or some external force. The bore of the cylinder body does not require machining other than that for the neck bearing and the inlet port; the manufacturing cost is, therefore, low when compared with other types or hydraulic cylinders.

The maximum thrust exerted by a displacement cylinder is given by

$$\text{Maximum thrust} = \text{Pressure} \times \text{Rod area} = p \times \frac{\pi d^2}{4}$$

where d is the diameter of the rod. The extending speed of the rod is given by

$$\text{Rod speed} = \frac{\text{Flow rate of fluid entering the cylinder}}{\text{Area of cylinder rod}}$$



Displacement cylinder

2.4 CONTROL COMPONENTS: DIRECTION CONTROL, FLOW CONTROL AND PRESSURE CONTROL VALVES:

One of the most important functions in any fluid power system is control. If control components are not properly selected, the entire system will fail to deliver the required output. Elements for the control of energy and other control in fluid power system are generally called **"Valves".** It is important to know the primary function and operation of the various types of control components. This type of knowledge is not only required for a good functioning system, but it also leads to the discovery of innovative ways to improve a fluid power system for a given application The selection of these control components not only involves the type, but also the size, the actuating method and remote control capability. There are 3 basic types of valves.

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

Directional control valves are essentially used for distribution of energy in a fluid power system. They establish the path through which a fluid traverses a given circuit. For example they control the direction of motion of a hydraulic cylinder or motor.

These valves are used to control the start, stop and change in direction of flow of pressurized fluid. Pressure may gradually buildup due to decrease in fluid demand or due to sudden surge as valves opens or closes**. Pressure control valves protect the system against such overpressure**. Pressure relief valve, pressure reducing, sequence, unloading and counterbalance valve are different types of pressure control valves. In addition, fluid flow rate must be controlled in various lines of a hydraulic circuit. For example, the control of actuator speeds depends on flow rates. This type of control is accomplished through the use of flow control valves.

1. DIRECTIONAL CONTROL VALVES

A valve is a device that receives an external signal (mechanical, fluid pilot signal, electrical or electronics) to release, stop or redirect the fluid that flows through it. The function of a DCV is to control the direction of fluid flow in any hydraulic system. A DCV does this by changing the position of internal movable parts. To be more specific, a DCV is mainly required for the following purposes:

- To start, stop, accelerate, decelerate and change the direction of motion of a hydraulic actuator.
- To permit the free flow from the pump to the reservoir at low pressure when the pump's delivery is not needed into the system.
- To vent the relief valve by either electrical or mechanical control.
- To isolate certain branch of a circuit.

Any valve contains ports that are external openings through which a fluid can enter and exit via connecting pipelines. The number of ports on a DCV is identified using the term "way." Thus, a valve with four ports is a four-way valve A DCV consists of a valve body or valve housing and a valve mechanism usually mounted on a sub-plate. The ports of a sub-plate are threaded to hold the tube fittings which connect the valve to the fluid conductor lines. The valve mechanism directs the fluid to selected output ports or stops the fluid from passing through the valve. DCVs can be classified based on fluid path, design characteristics, control methods and construction.

Classification of DCVs

1. According to type of construction:
• Poppet valves
• Spool valves
2. According to number of working ports (way):
• Two- way valves
• Three – way valves

- Four- way valves.

3. According to number of switching position:

- Two – position
- Three – position

4. Based on fluid path, DCVs can be classified as follows:

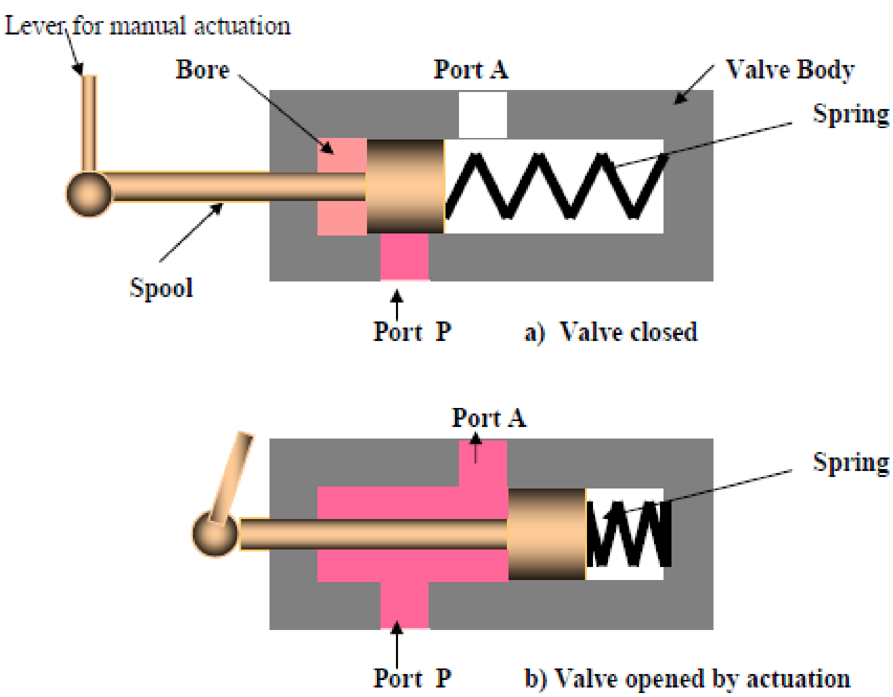
- Check valves.
- Shuttle valves.
- Two-way valves.
- Three-way valves.
- Four-way valves.

5. According to actuating mechanism:

- Manual actuation
- Mechanical actuation
- Solenoid (Electrical) actuation
- Hydraulic (Pilot) actuation
- Pneumatic actuation
- Indirect actuation.

2.4.1 Number of ports

A. Two way valves



Two way valves have only two ports as shown in Figure. These valves are also known as on-off valves because they allow the fluid flow only in direction. Normally, the valve is closed. These valves are available as normally open and normally closed function. These are the simplest type of spool valves. When actuating force is not applied to the right, the port P is not connected with port A as shown in figure. Therefore, the actuation does not take place. Similarly, Figure shows the two-way spool valve in the open condition. Here, the pressure port P is connected with the actuator port A.

B. Three way valves

When a valve has one pressure port, one tank port and one actuating port as shown in Figures, it is known as three way valve. In this valve, the pressure port pressurizes one port and exhausts another one. As shown in figures, only one actuator port is opened at a time. In some cases a neutral position is also available when both the ports are blocked. Generally, these valves are used to operate single acting cylinders.

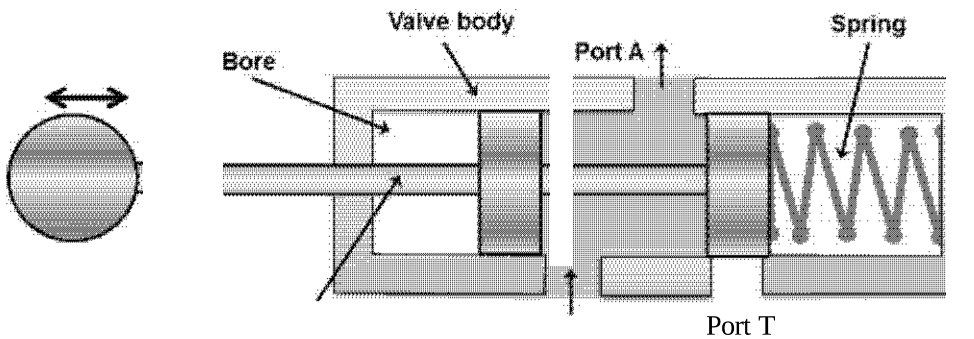


Figure A Three way valve: Pto A connected and T is blocked

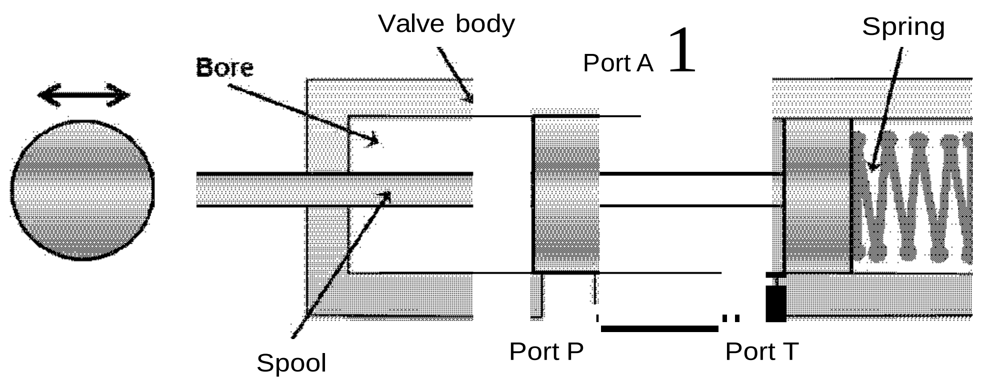


Figure B Three way valve in closed position

Four way valves

Figure shows a four-way valve. It is generally used to operate the cylinders and fluid motors in both the directions. The four ways are: pump port P, tank port T, and two working ports A and B connected to the actuator. The primary function of a four way valve is to pressurize and exhaust two working ports A and B alternatively.

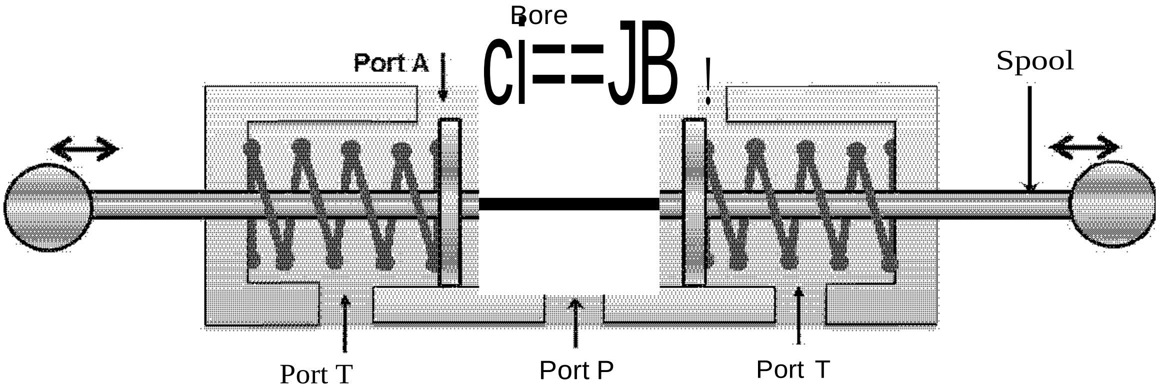
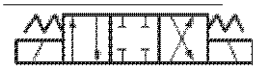
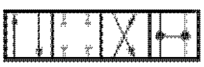
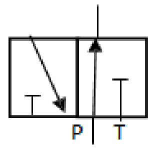
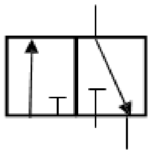
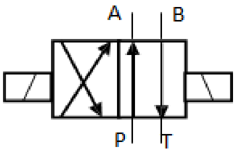
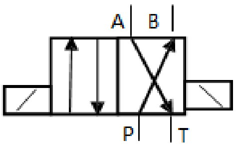


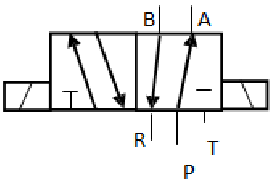
Figure Three position four way valve in open center mode

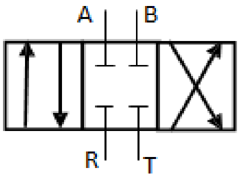
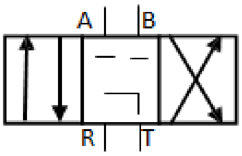
Tw<> Ports	CID	This valve has two ports to open/close a hydraulic line,
Three Ports		Tl1is valve has lhree ports for from he pump to two ways only
Four Ports	[X]]J]	This valve has four for a wide of pu11bses. mc•utlmg mr>Virtg the actualm forward and barkw:ird or stopping it
Ports	1:x,: 1;1 11:11	This valve has five or more for special purposes.
Two	N[illJ:s:J	This valve has two positions.
Tl1™0 Po,;ition:s		This valve has three positions.
l'osffions		This valve four or more por>iticrns for sp,,ri;al purpose<.

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

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

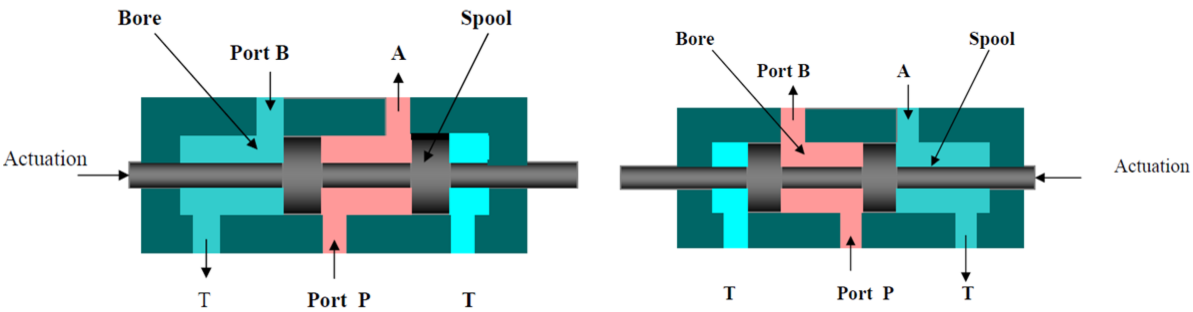
4/2-way valve – 4-port and 2-position DCV	
	P is connected to A B is connected to T
	Position 2: P is connected to B A is connected to T

5/2-way valve – 5-port and 2-position DCV	
	Normal position: P is connected to B A is connected to R

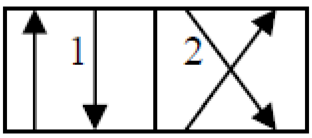
4/3-way valve – 4-port and 3-position DCV	
	P, T, A, B
	Mid-position pump reticulating: P to T, A and B closed

Two- position, Four – way DCV:

These valves are also used to operate double acting cylinder. These valves are also called as impulse valve as 2 / 4 DCV has only two switching positions, i.e it has no mid position. These valves are used to reciprocate or hold and actuating cylinder in one position. They are used on machines where fast reciprocation cycles are needed. Since the valve actuator moves such a short distance to operate the valve from one position to the other, this design is used for punching, stamping and for other machines needing fast action. Fig 4.15 a and b shows the two position of 2 / 4 DCV.



a. 1 Position : P to A and B to T   b. 2 Positon, P to B and A to T



Symbol

2.4.2 BASED ON THE TYPE OF ACTUATING MECHANISM:

Direction control valves may be actuated by a variety of methods. Actuation is the method of moving the valve element from one position to another. There are four basic methods of actuation: Manual, mechanical, solenoid-operated and pilot-operated. Several combinations of actuation are possible using these four basic methods.

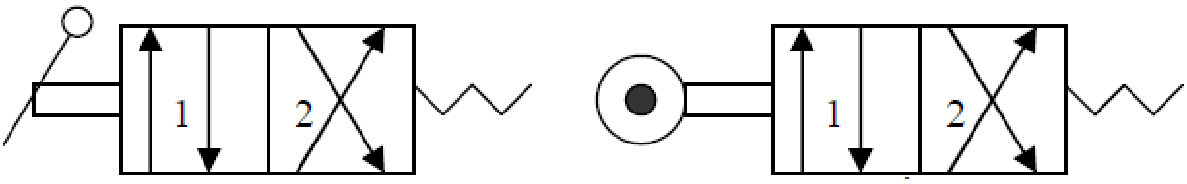
Manually operated: In manually operated DCVs, the spool is shifted manually by moving a handle pushing a button or stepping on a foot pedal. When the handle is not operated, the spool returns to its original position by means of a spring.

Mechanically operated: The spool is shifted by mechanical linkages such as cam and rollers.

Solenoid operated: When an electric coil or a solenoid is energized, it creates a magnetic force that pulls the armature into the coil. This causes the armature to push the spool of the valve.

Pilot operated: A DCV can also be shifted by applying a pilot signal (either hydraulic or pneumatic) against a piston at either end of the valve spool. When pilot pressure is introduced, it pushes the piston to shift the spool.

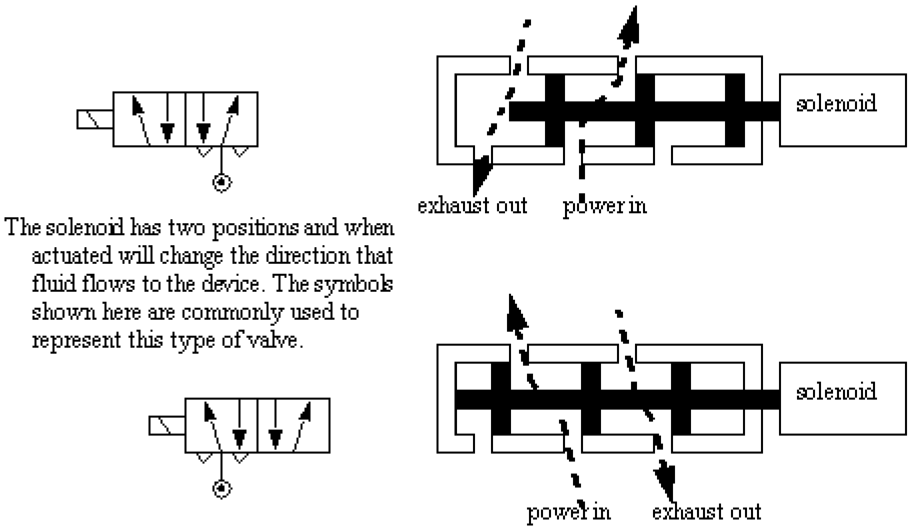
1. Manually – actuated Valve: A manually actuated DCV uses muscle power to actuate the spool. Manual actuators are hand lever , push button, pedals . The following symbols shows the DCV actuated manually

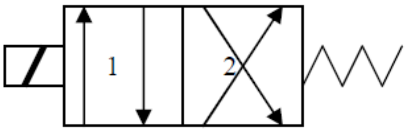


The symbol of 2 / 4 DCV with manually operated by hand lever to 1 and spring return to 2. In the above two symbols the DCV spool is returned by springs which push the spool back to its initial position once the operating force has stopped e.g, letting go of the hand lever.

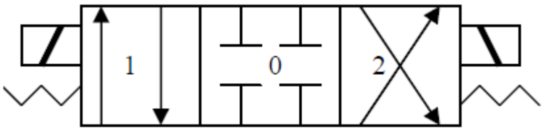
2. Mechanical Actuation: The DCV spool can be actuated mechanically, by roller and cam, roller and plunger. The spool end contains the roller and the plunger or cam can be attached to the actuator (cylinder).. When the cylinder reaches a specific position the DCV is actuated. The roller tappet connected to the spool is pushed in by a cam or plunger and presses on the spool to shift it either to right or left reversing the direction of flow to the cylinder. A spring is often used to bring the valve to its center configuration when de-actuated.

3. **Solenoid-actuated DCV** : A very common way to actuate a spool valve is by using a solenoid is illustrated in Fig. When the electric coil (solenoid) is energized, it creates a magnetic force that pulls the armature into the coil. This caused the armature to push on the spool rod to move the spool of the valve.. The advantage of a solenoid lies within its less switching time.



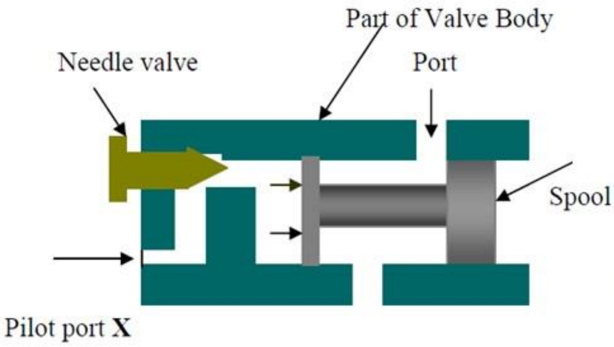


a) Symbol for Single solenoid-actuated , 2- Position, 4-way spring centered DCV

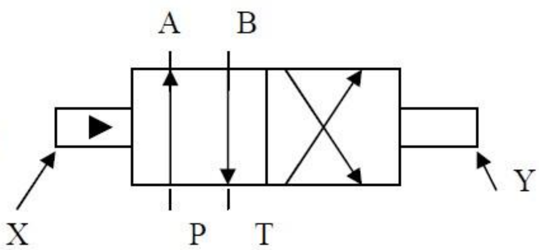


b) Symbol for Solenoid actuated, 3- position, 4- way spring centered DCV

4. Pilot-actuation: This type actuation is usually known as pilot- actuated valve. The hydraulic pressure or pneumatic pressure may directly used on the end face of the spool. The pilot ports are located on the valve ends. Figure shows a directional valve where the rate of shifting the spool from one side to another can be controlled by a needle valve. Fluid entering the pilot pressure port on the X end flows through the check valve and operates against the piston. This forces the spool to move towards the opposite position. Fluid in the Y end (right end ,not shown in the figure) is passed through the adjustable needle valve and exhausted back to tank. The amount of fluid bled through the needle valve controls how fast the valve will shift.



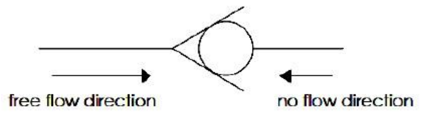
Pilot actuated DCV



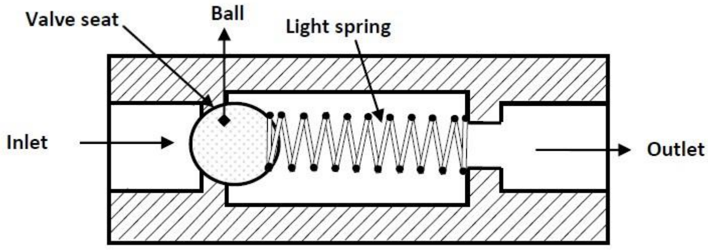
Symbol for pilot actuated 2 /4 DCV

2.4.3 Check Valve

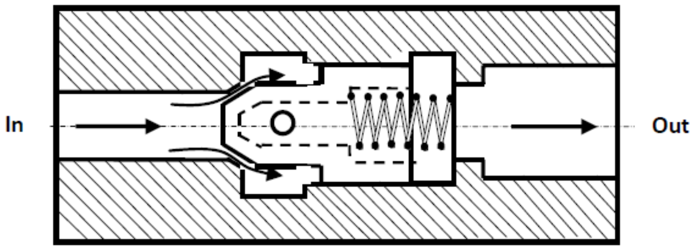
The simplest DCV is a check valve. A check valve allows flow in one direction, but blocks the flow in the opposite direction. It is a two-way valve because it contains two ports. Figure shows the graphical symbol of a check valve along with its no-flow and free-flow directions.



Graphical symbol of a check valve.



In above figure, a light spring holds the ball against the valve seat. Flow coming into the inlet pushes the ball off the seat against the light force of the spring and continues to the outlet. A very low pressure is required to hold the valve open in this direction. If the flow tries to enter from the opposite direction, the pressure pushes the ball against the seat and the flow cannot pass through.

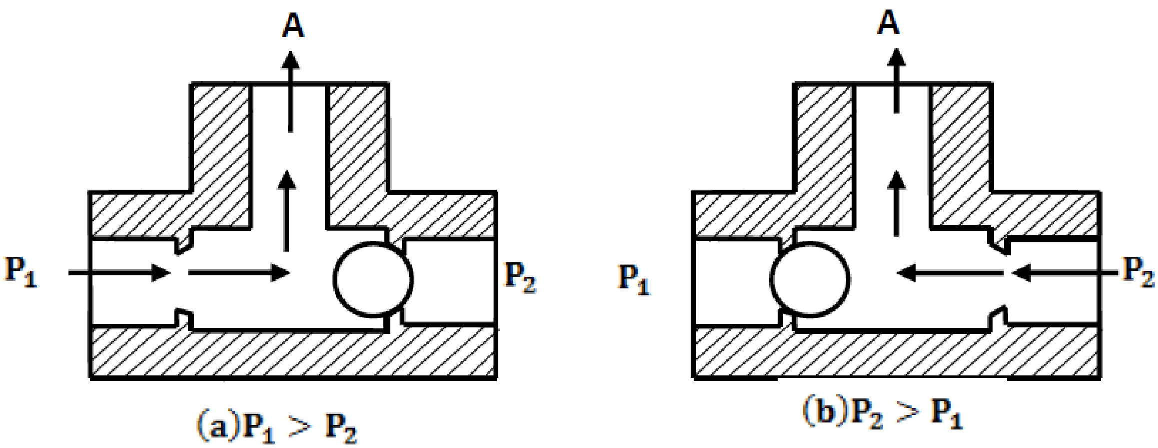


Poppet check valve

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

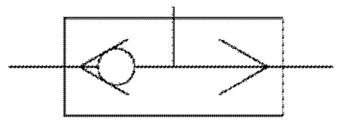
2.4.5 SHUTTLE VALVE

A shuttle valve allows two alternate flow sources to be connected in a one-branch circuit. The valve has two inlets P1 and P2 and one outlet A. Outlet A receives flow from an inlet that is at a higher pressure. Figure 1.5 shows the operation of a shuttle valve. If the pressure at P1 is greater than that at P2, the ball slides to the right and allows P1 to send flow to outlet A. If the pressure at P2 is greater than that at P1, the ball slides to the left and P2 supplies flow to outlet A.



Shuttle valve: (a) Flow from left to outlet and (b) flow from right to outlet

Graphical symbol



2.4.6 FLOW CONTROL VALVES

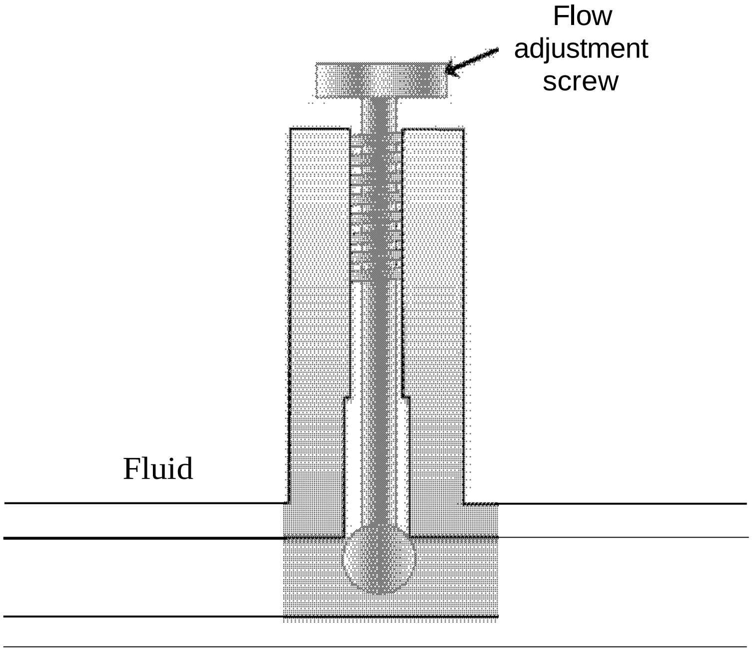


Figure Flow Control Valve

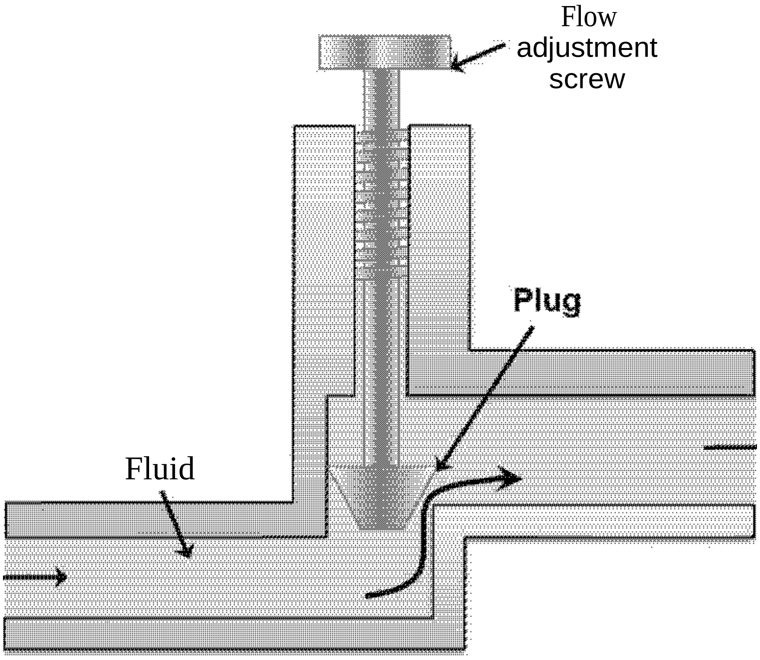
In practice, the speed of actuator is very important in terms of the desired output and needs to be controlled. The speed of actuator can be controlled by regulating the fluid flow. A flow control valve can regulate the flow or pressure of the fluid. The fluid flow is controlled by varying area of the valve opening through which fluid passes. The fluid flow can be decreased by reducing the area of the valve opening and it can be increased by increasing the area of the valve opening. A very common example to the fluid flow control valve is the household tap. Figure shows the schematic diagram of a flow control valve. The pressure adjustment screw varies the fluid flow area in the pipe to control the discharge rate.

The pressure drop across the valve may keep on fluctuating. In general, the hydraulic systems have a pressure compensating pump. The inlet pressure remains almost constant but the outlet pressure keeps on fluctuating depending on the external load. It creates fluctuating pressure drop. Thus, the ordinary flow control valve will not be able to maintain a constant fluid flow. A pressure compensated flow control valve maintains the constant flow throughout the movement of a spool, which shifts its position depending on the pressure. Flow control valves can also be affected by temperature changes. It is because the viscosity of the fluid changes with temperature. Therefore, the advanced flow control valves often have the temperature compensation. The temperature compensation is achieved by the thermal expansion of a rod, which compensates for the increased coefficient of discharge due to decreasing viscosity with temperature.

Types of Flow Control Valves

The flow control valves work on applying a variable restriction in the flow path. Based on the construction; there are mainly four types viz. plug valve, butterfly valve, ball valve and balanced valve.

A Plu g or glove valve

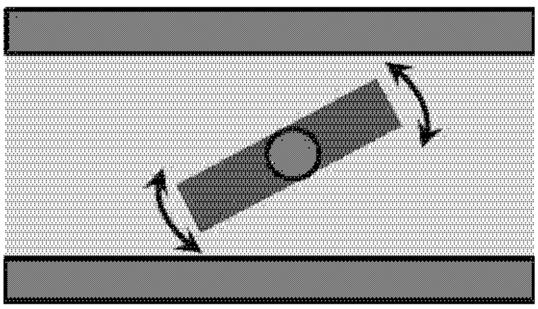


Plu g or glove valve

The plug valve is quite commonly used valve. It is also termed as glove valve. This valve has a plug which can be adjusted in vertical direction by setting flow adjustment screw. The adjustment of plug alters the orifice size between plug and valve seat. Thus the adjustment of plug controls the fluid flow in the pipeline. The characteristics of these valves can be accurately predetermined by machining the taper of the plug. The typical example of plug valve is stopcock that is used in laboratory glassware. The valve body is made of glass or teflon. The plug can be made of plastic or glass. Special glass stopcocks are made for vacuum applications. Stopcock grease is used in high vacuum applications to make the stopcock air-tight.

B Butterfly valve

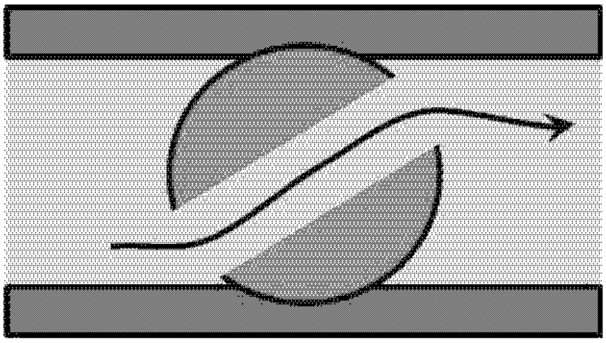
It consists of a disc which can rotate inside the pipe. The angle of disc determines the restriction. Butterfly valve can be made to any size and is widely used to control the flow of gas. These valves have many types which have for different pressure ranges and applications. The resilient butterfly valve uses the flexibility of rubber and has the lowest pressure rating. The high performance butterfly valves have a slight offset in the way the disc is positioned. It increases its sealing ability and decreases the wear. For high-pressure systems, the triple offset butterfly valve is suitable which makes use of a metal seat and is therefore able to withstand high pressure. Ithas higher risk of leakage on the shut-off position and suffer from the dynamic torque effect. Butterfly valves are favored because of their lower cost and lighter weight. The disc is always present in the flow therefore a pressure drop is induced regardless of the valve position.



Butterfly valve

C Ball Valve

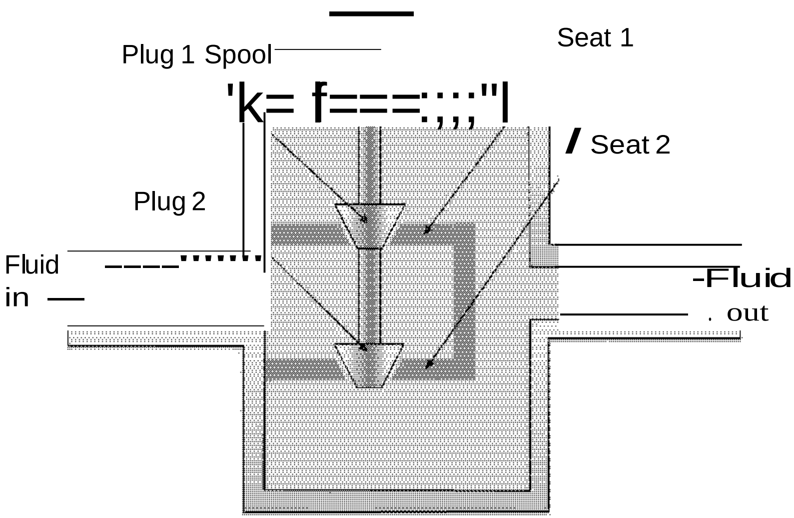
The ball valve is shown in Figure 5.5.14. This type of flow control valve uses a ball rotated inside a machined seat. The ball has a through hole as shown in Figure. It has very less leakage in its shut -off condition. These valves are durable and usually work perfectly for many years. They are excellent choice for shutoff applications. They do not offer fine control which may be necessary in throttling applications. These valves are widely used in industries because of their versatility, high supporting pressures (up to 1000 bar) and temperatures (up to 250°C). They are easy to repair and operate.



Ball valve

D Balanced valve

Schematic of a balanced valve is shown in figure. It comprises of two plugs and two seats. The opposite flow gives little dynamic reaction onto the actuator shaft Itresults illthe negligible dynamic torque effect. However, the leakage is more in these kind of valves because the manufacturing tolerance can cause one plug to seat before the other. The pressure-balanced valves are used in the houses. They provide water at nearly constant temperature to a shower or bathtub despite of pressure fluctuations in either the hot or cold supply lines.

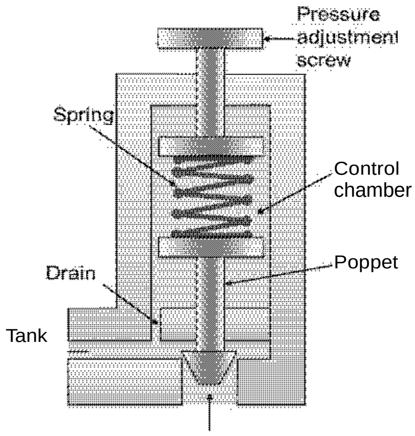


Balanced valve

2.4.6 Pressure relief valves

The pressure relief valves are used to protect the hydraulic components from excessive pressure. This is one of the most important components of a hydraulic system and is essentially required for safe operation of the system. Its primary function is to limit the system pressure within a specified range. It is normally a closed type and it opens when the pressure exceeds a specified maximum value by diverting pump flow back to the tank. The simplest type valve contains a poppet held in a seat against the spring force as shown in Figure. The fluid enters from the opposite side of the poppet. When the system pressure exceeds the preset value, the poppet lifts and the fluid is escaped through the orifice to the storage tank directly. It reduces the system pressure and as the pressure reduces to the set limit again the valve closes. This valve does not provide a flat cut-off pressure limit with flow rate because the spring must be deflected more when the flow rate is higher. Various types of pressure control valves are discussed in the following sections:

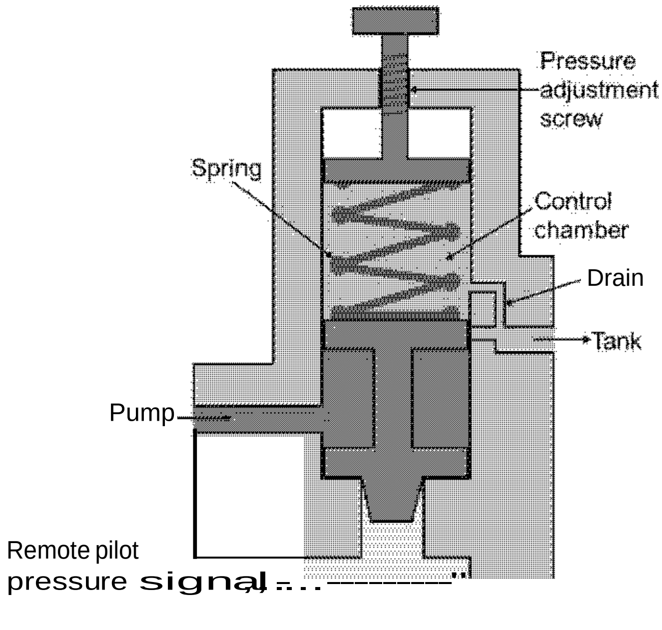
1. Direct type of relief valve



Pressure Relief Valve

Schematic of direct pressure relief valve is shown in ffgifre. This type of valves has two ports; one of which is connected to the pump and another is connected to the tank. It consists of a spring chamber where poppet is placed with a spring force. Generally, the spring is adjustable to set the maximum pressure limit of the system. The poppet is held in position by combined effect of spring force and dead weight of spool. As the pressure exceeds this combined force, the poppet raises and excess fluid bypassed to the reservoir (tank). The poppet again reseats as the pressure drops below the pre-set value. A drain is also provided in the control chamber. It sends the fluid collected due to small leakage to the tank and thereby prevents the failure of the valve.

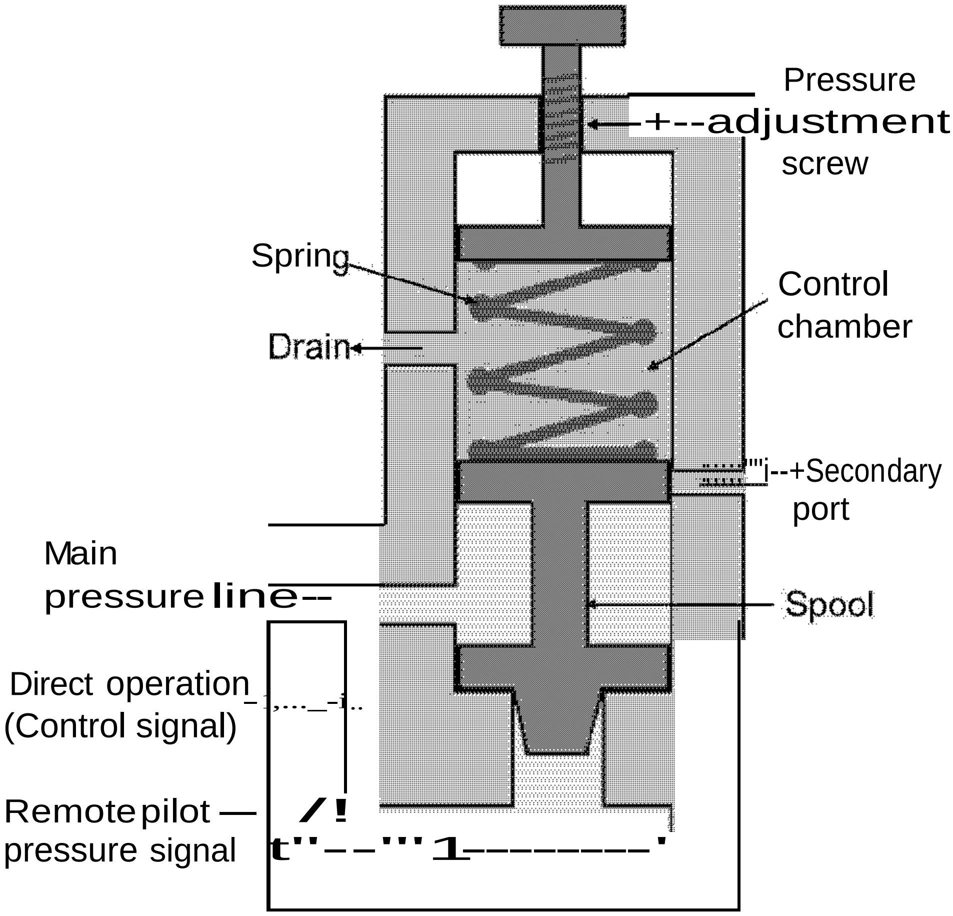
2. Unloading Valve



Unloading Valve

This valve consists of a control chamber with an adjustable spring which pushes the spool down. The valve has two ports: one is connected to the tank and another is connected to the pump. The valve is operated by movement of the spool. Normally, the valve is closed and the tank port is also closed. These valves are used to permit a pump to operate at the minimum load. It works on the same principle as direct control valve that the pump delivery is diverted to the tank when sufficient pilot pressure is applied to move the spool. The pilot pressure maintains a static pressure to hold the valve opened. The pilot pressure holds the valve until the pump delivery is needed in the system. As the pressure is needed in the hydraulic circuit; the pilot pressure is relaxed and the spool moves down due to the self-weight and the spring force. Now, the flow is diverted to the hydraulic circuit. The drain is provided to remove the leaked oil collected in the control chamber to prevent the valve failure. The unloading valve reduces the heat buildup due to fluid discharge at a preset pressure value.

3. Sequence valve



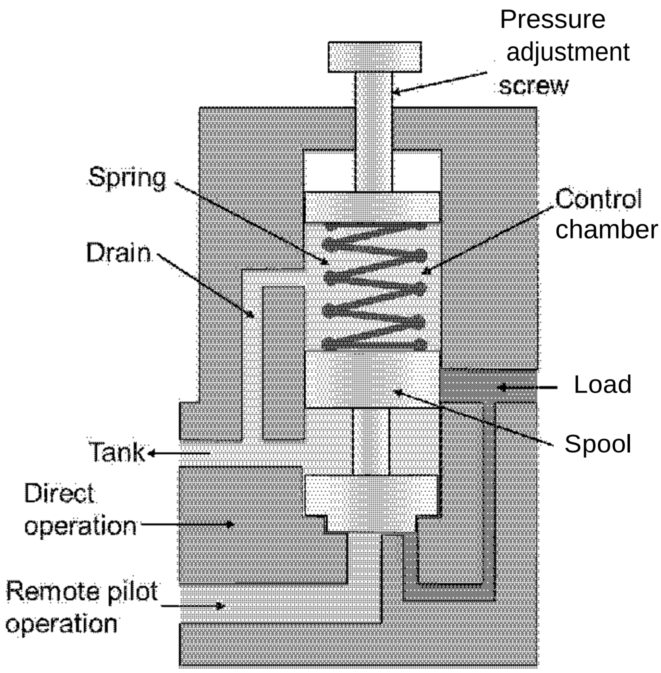
Sequence valve

The primary function of this type of valve is to divert flow in a predetermined sequence. It is used to operate the cycle of a machine automatically. A sequence valve may be of direct-pilot or remote-pilot operated type.

Schematic of the sequence valve is shown in Figure. Its construction is similar to the direct relief valve. It consists of the two ports; one main port connecting the main pressure line and another port (secondary port) is connected to the secondary circuit. The secondary port is usually closed by the spool. The pressure on the spool works against the spring force. When the pressure exceeds the preset value of the spring; the spool lifts and the fluid flows from the primary port to the secondary port. For remote operation; the passage used for the direct operation is closed and a separate pressure source for the spool operation is provided in the remote operation mode.

4. Counterbalance Valve

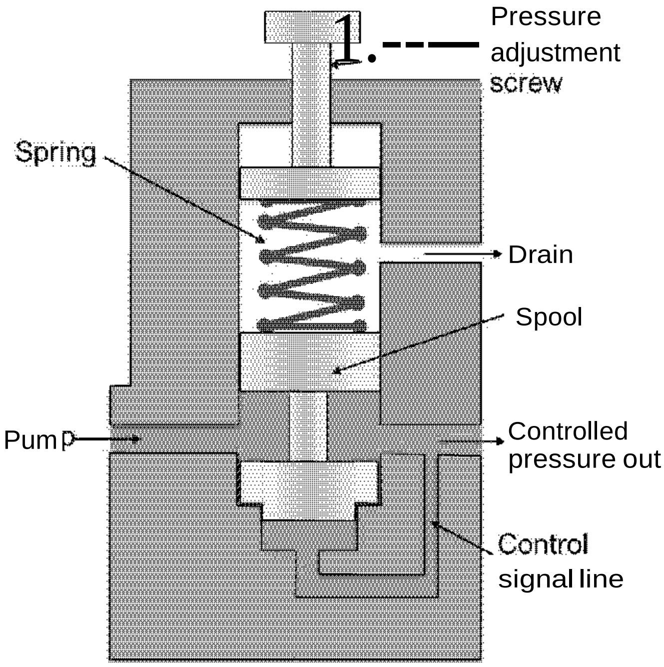
The schematic of counterbalance valve is shown in Figure . It is used to maintain the back pressure and to prevent a load from failing. The counterbalance valves can be used as breaking valves for decelerating heavy loads. These valves are used in vertical presses, lift trucks, loaders and other machine tools where position or hold suspended loads are important. Counterbalance valves work on the principle that the fluid is trapped under pressure until pilot pressure overcomes the pre-set value of spring force.



Counter Balance Valve

Fluid is then allowed to escape, letting the load to descend under control. This valve is normally closed until it is acted upon by a remote pilot pressure source. Therefore, a lower spring force is sufficient. It leads to the valve operation at the lower pilot pressure and hence the power consumption reduces, pump life increases and the fluid temperature decreases.

5. *Pressure Reducing Valve*



Pressure Reducing Valve

Sometimes a part of the system may need a lower pressure. This can be made possible by using pressure reducing valve as shown in Figure 5.6.5. These valves are used to limit the outlet pressure. Generally, they are used for the operation of branch circuits where the pressure may vary from the main hydraulic pressure lines. These are open type valve and have a spring chamber with an adjustable spring, a movable spool as shown in figure. A drain is provided to return the leaked fluid in the spring (control) chamber. A free flow passage is provided from inlet port to the outlet port until a signal from the outlet port tends to throttle the passage through the valve. The pilot pressure opposes the spring force and when both are balanced, the downstream is controlled at the pressure setting. When the pressure in the reduced pressure line exceeds the valve setting, the spool moves to reduce the flow passage area by compressing the spring. It can be seen from the figure that if the spring force is more, the valve opens wider and if the controlled pressure has greater force, the valves moves towards the spring and throttles the flow.

2.4.7 ACCESSORIES OF HYDRAULIC SYSTEM:

A. HYDRAULIC RESERVOIRS:

The hydraulic reservoir is a container for holding the fluid required to supply the system, including a reserve to cover any losses from minor leakage and evaporation. The reservoir can be designed to provide space for fluid expansion, permit air entrained in the fluid to escape, and to help cool the fluid. Filling reservoirs to the top during servicing leaves no space for expansion. Most reservoirs are designed with the rim at the filler neck below the top of the reservoir to prevent overfilling. Some means of checking the fluid level is usually provided on a reservoir. This may be a glass or plastic sight gage, a tube, or a dipstick. Hydraulic reservoirs are either vented to the atmosphere or closed to the atmosphere and pressurized. A description of each type follows.

Vented Reservoir:

A vented reservoir is one that is open to atmospheric pressure through a vent line. Because atmospheric pressure and gravity are the forces which cause the fluid to flow to the pump, a vented reservoir is mounted at the highest point in the hydraulic system. Air is drawn into and exhausted from the reservoir through a vent line. A filter is usually installed in the vent line to prevent foreign material from being taken into the system.

Pressurized Reservoir:

A pressurized reservoir is sealed from the atmosphere. This reservoir is pressurized either by engine bleed air or by hydraulic pressure produced within the hydraulic system itself. Pressurized reservoirs are used on aircraft intended for high altitude flight, where atmospheric pressure is not enough to cause fluid flow to the pump.

Hydraulic reservoirs

A hydraulic system is closed, and the oil used is stored in a tank or reservoir to which it is returned after use. Although probably the most mundane part of the system, the design and maintenance of the reservoir is of paramount importance for reliable operation. Figure shows details of a typical reservoir.

The volume of fluid in a tank varies according to temperature and the state of the actuators in the system, being minimum at low

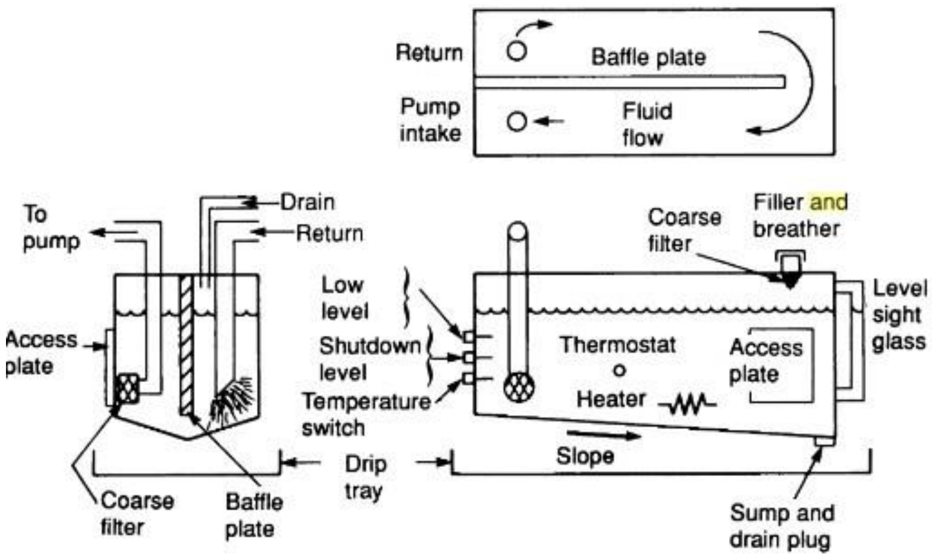


Figure Construction of a hydraulic reservoir

temperature with all cylinders extended, and maximum at high temperature with all cylinders retracted. Normally a reservoir is designed to hold about three to four times the volume of fluid taken by the pumps each minute. A substantial space above the fluid must be included to allow for volume change and to prevent any froth on the surface from spilling out.

The tank also serves as a heat exchanger, allowing fluid heat to be removed. To obtain maximum cooling, fluid is forced to follow the walls of the tank, from the return line to pump suction inlet, by a baffle plate down the tank centre line. This plate also encourages any contamination to fall to the tank bottom before reaching the pump inlet, and allows any entrapped air to escape to the surface. The main return line is below the oil surface (to reduce splashing and froth) and is directed at a wall to enhance cooling. Low pressure returns (such as drains from motors or valves) must be returned above fluid level to prevent back pressure and formation of hydraulic locks.

Fluid level is critical. If it is too low, a whirlpool forms above the pump inlet, resulting in air being drawn into the pump. This air results in maloperation, and will probably result in pump damage.

A level sight glass is essential to allow maintenance checks to be carried out. The only route for oil to leave a hydraulic system is, of course, by leaks so the cause of any gross loss of fluid needs investigation. In all bar the smallest and simplest systems, two electrical float switches are generally included giving a remote (low level) warning indication and a last ditch (very low level) signal which leads to automatic shutdown of the pump before damage can occur.

The temperature of fluid in the tank also needs monitoring and as an absolute minimum a simple visual thermometer should be included. The ideal temperature range is around 45 to 50°C and, usually, the problem is keeping the temperature down to this level. Ideally an electrical over-temperature switch is used to warn the user when oil temperature is too high.

When the system is used intermittently, or started up from cold, oil temperature can be too low, leading to sluggish operation and premature wear. A low temperature thermostat and electrical heater may be included to keep the oil at an optimum temperature when the system is not in use.

Reservoirs are designed to act as collecting points for all the dirt particles and contamination in the system and are generally constructed with a V-shaped cross section forming a sump. A slight slope ensures contamination collects at the lower end where a drain plug is situated. Often magnetic drain plugs are used to trap metallic particles.

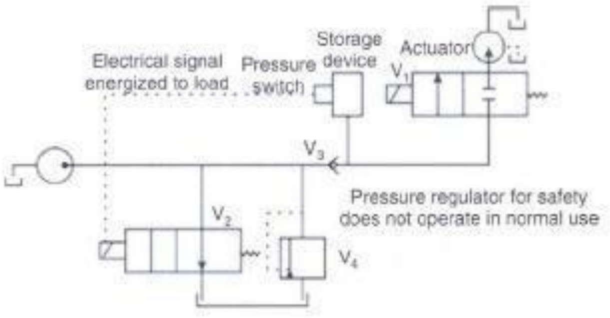
Reservoirs should be drained periodically for cleaning, and a removable man access plate is included for this purpose. This is *not* the most attractive of jobs!

Oil is added through a filler cap in the tank top. This doubles as a breather allowing air into and out of the tank as the volume of fluid changes. A coarse filter below the breather prevents contamination entering the tank as fluid is added.

Reservoirs are generally constructed from welded steel plate with thin side walls to encourage heat loss. The inside of the tank is shot blasted then treated with protective paint to prevent formation of rust particles.

At some time in the life of a hydraulic system there will eventually be oil spillage around the tank, whether from leakage, over-enthusiastic filling or careless maintenance. It is therefore good practice to put substantial drip trays under reservoir pumps and associated valves to limit oil spread when the inevitable mishaps occur.

B. HYDRAULIC ACCUMULATOR:



A hydraulic accumulator is a device that stores the potential energy of an incompressible fluid held under pressure by an external source against some dynamic force. This dynamic force can come from different sources. The stored potential energy in the accumulator is a quick secondary source of fluid power capable of doing useful work.

It is a simple hydraulic device which stores energy in the form of fluid pressure. This stored pressure may be suddenly or intermittently released as per the requirement. In the case of a hydraulic lift or hydraulic crane, a large amount of energy is required when the lift or crane is moving upward. This energy is supplied from the hydraulic accumulator. But when the lift is moving in the downward direction, it does not require a huge amount of energy. During this particular time, the oil or hydraulic fluid pumped from the pump is stored in the accumulator for future use.

A system operates intermittently at a pressure ranging between 150 bar (2175 psi) and 200 bar (2900 psi), and needing a flow rate of 100 1pm for 10 s at a frequency of one every minute. With a simple system consisting of a pump, pressure regulator and loading valves, this requires a 200 bar (2900 psi), 100-lpm pump driven by a 50 hp (37 kW) motor, which spends around 85% of its time, unloading to the tank. When an accumulator is installed in the system as shown in Figure, it can store and release a quantity of fluid at the required system pressure.

Accumulators are used mainly on the lift equipment to provide positive clamping action on the heavy loads when a pump's flow is diverted to lifting or other operations. An accumulator acts as a safety device to prevent a load from being dropped in case of an engine or pump failure or fluid leak. On lifts and other equipment, accumulators absorb shock, which results from a load starting, stopping, or reversal.

There are three basic types of accumulator used in hydraulic system. They are:

1. Weight – Loaded, or gravity, type

2. Spring -Loaded type
3. Gas – Loaded type

1. **Weight – Loaded Accumulator:** This type consists of a vertical, heavy- wall steel cylinder, which incorporates a piston with packing to pressure leakage. A dead weight is attached to the top of the piston. The force of gravity of the deadweight provides the potential energy in the accumulator. This type of accumulator creates a constant fluid pressure throughout the full volume output of the unit regardless of the rate and quantity of output. The main disadvantage of this type of accumulator is extremely large size and heavy weight which makes it unsuitable for mobile equipment.

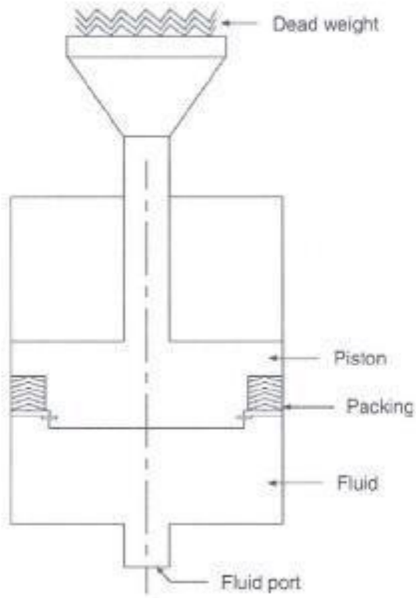


Figure 7.14
Weight-loaded accumulator

2. **Spring – Loaded Accumulator :** A spring loaded accumulator is similar to the weight – loaded type except that the piston is preloaded with a spring. The spring is the source of energy that acts against the piston, forcing the fluid into the hydraulic system. The pressure generated by this type of accumulator depends on the size and pre-loading of the spring. In addition, the pressure exerted on the fluid is not a constant. The spring- loaded accumulator typically delivers a relatively small volume of oil at low pressures. Thus, they tend to be heavy and large for high- pressure, large – volume systems. This type of accumulator should not be used for applications requiring high cycle rates because the spring will fatigue and lose its elasticity. The result is an inoperative accumulator.

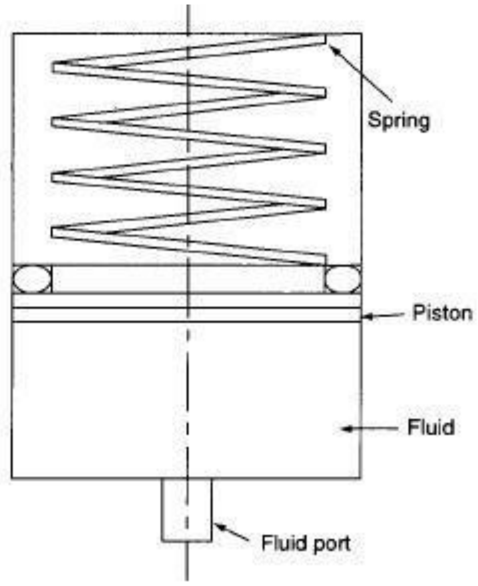


Figure 7.15
Spring-loaded accumulator

3. Gas loaded Accumulator:

These types of accumulators (frequently referred to as hydro-pneumatic accumulators) have been found to be more practically viable as compared with the weight and spring- loaded types. The gas loaded type operates in accordance with Boyle's law of gases, according to which the pressure of a gas is found to vary inversely with its volume for a constant temperature process.

The compressibility of the gas accounts for the storage of potential energy in these accumulators. This energy forces the oil out of the accumulator when the gas expands, due to a reduction in system pressure.

Gas-loaded accumulators fall under two main categories:
1. Non-separator type
2. Separator type.

Non-Separator Type Hydraulic Accumulator

The non-separator type consists of a fully enclosed shell containing an oil port at the bottom and the gas-charging valve at the top. The valve is confined to the top and the oil to the bottom of the shell. There is no physical separator between the gas and oil, and thus the gas pushes directly on the oil.

The main advantage of this type of accumulator is its ability to handle a large volume of oil. However, its disadvantage lies in the fact that the oil tends to absorb gas due to the lack of a separator.

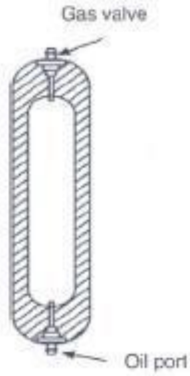


Figure 7.16
Non-separator-type gas loaded accumulator

Separator Type Hydraulic Accumulator

- Diaphragm Type Separator Gas Loaded Hydraulic Accumulator

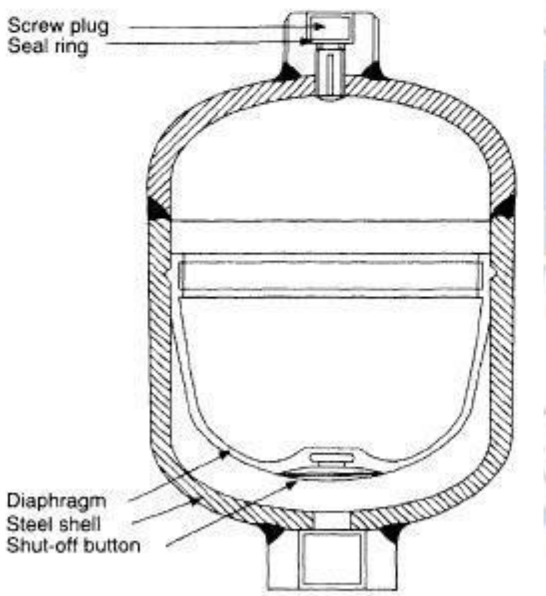


Figure 7.18
Diaphragm-type accumulator

The diaphragm-type accumulator consists of a diaphragm secured in a shell and serving as an elastic barrier between the oil and the gas. The cross-sectional view of a diaphragm type accumulator is shown in Figure .

A shut off button which is secured at the base of the diaphragm, covers the inlet of the Hne connection when the diaphragm is fully stretched. This prevents the diaphragm from being pressed into the opening during the precharge period. On the gas side, the screw plug allows control of the charge pressure and the charging of the accumulator by means of a charging and testing device.

- Piston Type Separator Gas Loaded Hydraulic Accumulator

This accumulator consists of a cylinder containing a freely floating piston with proper seals, as illustrated in Figure. The piston serves as a barrier between the gas and oil. A threaded lock ring provides a safety feature that prevents the operator from disassembling the unit while it is precharged. The main disadvantage of piston-type accumulators is that they are very expensive and have size limitations. In low-pressure systems, the piston and seal friction also poses problems. Piston accumulators should not be used as pressure pulsation dampeners or shock absorbers because of the inertia of the piston and the friction in the seals. The principle advantage of the piston-type accumulator lies in its ability to handle very high- or low-temperature system fluids, through the utilization of compatible O-ring seals.

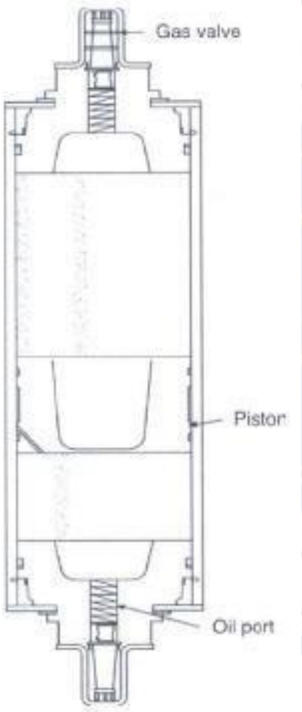


Figure 7.17
Piston-type accumulator

- BLADDER TYPE SEPARATOR GAS LOADED HYDRAULIC ACCUMULATOR

The bladder is fitted to the accumulator by means of a vulcanized gas-valve element that can be installed or removed through the shell opening at the poppet valve. The poppet valve closes the inlet when the bladder is fully expanded. This prevents the bladder from being pressed into the opening. A shock-absorbing device, protects the valve against accidental shocks, during a quick opening.

The greatest advantage with these accumulators is the positive sealing between the gas and oil chambers. The Weight bladder provides a quick pressure response for pressure regulation as well as applications involving pump pulsations and shock dampening.

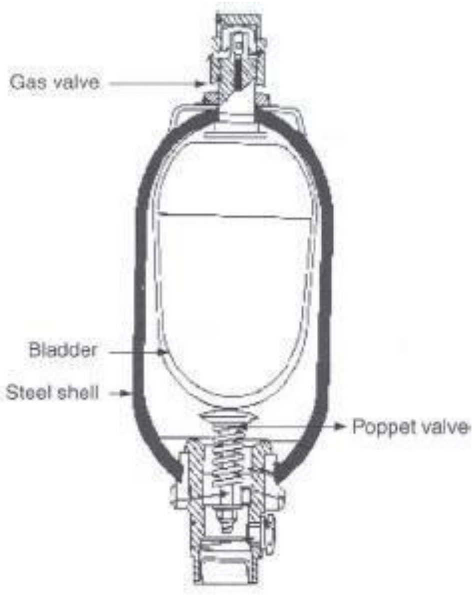
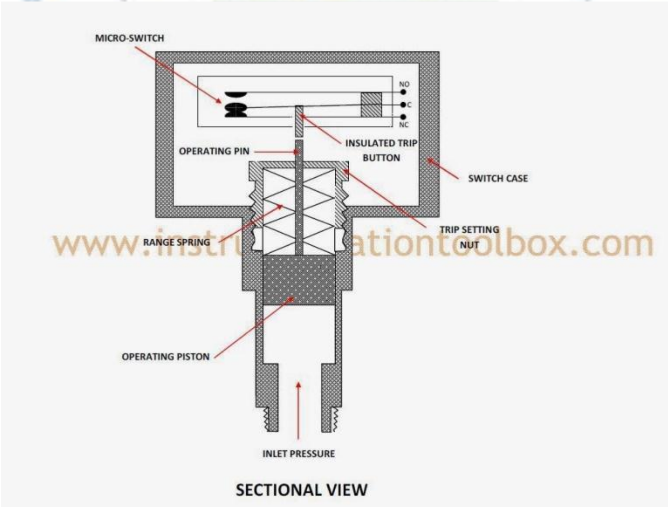


Figure 7.20
Bladder-type accumulator (Courtesy of Robert Bosch Corp.)

C. PRESSURE SWITCH



Pressure switches are actuated by a change in the pressure of a liquid or gas. They activate electromechanical or solid-state switches upon reaching a specific pressure level. The pressure at which an electric circuit turns ON or OFF is called Set point of switch. The most important parameter to consider is the pressure range that is needed to be switched at, or the range over which linear output is needed. A Bourdon tube or bellows can be used to actuate the switch. The pressure is fed inside the bellows which causes the contact of the plate with the circuit and current flows which either on the alarm or send signals to control center.

Pressure switch can be modified so as to make a low pressure contact, In addition to a high pressure contact. It is adjustable. The contacts in a pressure switch may be normally closed when the pressure is below the set point for example; the contact in a normally open switch remains opened until the pressure rises above the set point. Then the sensing element makes the contacts snap to close position. The contacts open again when the pressure falls below the set point. The contacts in a normally closed switch remain closed until the pressure rises above the set point. Then the contacts snap open and remain open until a pressure drops below the set point again. Most switches contain the two sets of contacts, one normally open and other normally closed.

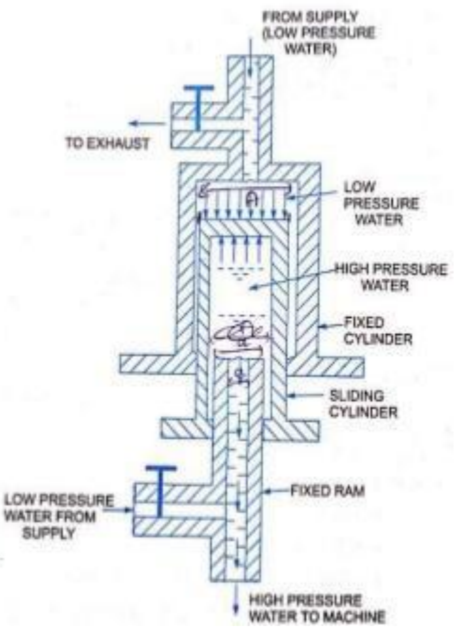
Choices for **pressure switches** measurement ranges include absolute, gauge, vacuum, differential, and sealed. Absolute switches are used where pressures are to be measured independently of the natural fluctuations in atmospheric pressure. The pressure of the media to be measured is compared against a reference pressure of absolute zero (absolute vacuum) in a sealed reference chamber. Vacuum measurement switches measure vacuum pressure (negative pressure).

Differential **pressure switches** give the relative pressure between two points. If both operating pressures are the same, the measuring element cannot move and no pressure will be indicated. A differential pressure is indicated when one pressure is higher or lower. Low differential pressures can be measured directly in cases of high static pressures. Sealed gauge pressure measurement is similar in concept to an Absolute Pressure switch, except that the pressure of the media to be measured is compared to standard atmospheric pressure (at sea-level).

HYDRAULIC INTENSIFIER

- The device, which is used to increase the intensity of pressure of water by means of hydraulic energy available from a large amount of water at a low pressure, is called the hydraulic intensifier. Such a device is needed when the hydraulic machines such as hydraulic press as hydraulic press requires water at very high pressure which cannot be obtained from the main supply directly.
- A hydraulic intensifier consist of fixed ram through which the water, under a high pressure, flows to the machine. A hollow inverted sliding cylinder, containing water under high pressure, is mounted over the fixed ram. The inverted sliding cylinder is surrounded by another fixed inverted cylinder which contains water from the main supply at a low pressure as shown in fig
- There are three main parts in the hydraulic intensifiers to be noted. They are

1. Fixed ram,
2. Hollow inverted sliding cylinder,
3. Fixed inverted cylinder.



FLUID POWER ANSI SYMBOL

- r-o1t

HYDRAULIC SYMBOLS

•Lines

___________	Li1.,Working (1Aai1)
------------	li1e. Pibtor Drain
... ----i>----	Flow Directio1 Hydra1li: **Pneumatic**
---f'-- _ I	li1es Ctossi1g
-L	Lioes Joiniog
,..........	li1es Wit• Fixed Restri:tiru
	Li1e. Flexl>le
A	Stiltioa li!sling **Meas ureme1tor Power** 1112-0ff
O	Varioble Cornpo1e11(ru arrow 1'ro1gh symbol at 41"}
/	Pressure Cornpensall!d Uoits (Anowpara llel., short side ofsyrrl>oO
	li!ft1lera11..caoseor Effect
Reservoir	
I_	VenllOd **PR!.ssurized**
Lino., 10 llt!Servoir	
JJ	Above Fluid Level Below Floid Lewi
----±	VenllOd IAanilokl

•Hydraulic Pumps

0	Fixed Displaceme1t
O	Variobie Displacemeat

•Motors and Cylinders

Hydraulic	
0	Fixed Displaceme1t
O	Variobie Oisplacemeat
L1 1	Cy1ild<1 Siogle·Acti1g
Cylindet Oo1ble-AC1ing	
I_II___:	Silgle Eld Rod
fiꞨ	Doublo Eid Rod
I_W@5=	Ad joslab le Cushio1 Adva1<e01Iy Electric Motor
I,11 8	Ace111ula.,t Spring loaded Difreotial Pi<IDn
8	Acca11ula.,t Gas Cllal!Jed
	HNll!r

•Miscellaneous Units

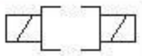
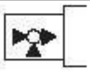
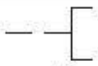
	Coolor
	I!rnpei:ollre Contmller
-₵-	Fillet Strai1er
--{ZJw	"""u"'Switc•
O	Pressu"' hldi:ator
CD	I!rnpelillllt! lodic.JIDr
L__ _J	Compo oeat EKlosore
Of-	Di""tio1 of Suh Rotatio1 (assu 11e anow 01 nearside ots•ah)

•Methods of Operation

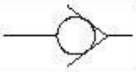
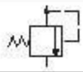
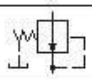
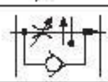
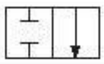
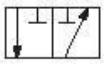
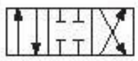
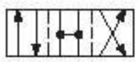
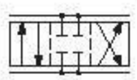
W\	Sprilg
	Manal
CJ=[	Pas• htto1
k	rasi..r.u Lever
)=[	Pedal or Treadle
o=[	Mec•aai:al
!'''	Oell!n t
cu	Plt!ssu"' Cornpe nsated

HYDRAULIC SYMBOLS

Methods of Operation

	Solenoid, Single Winding
	Servo Control
Pilot Pressure	
	Remote Supply
	Internal Supply

Valves

	Check
	On-Off (manual shut-off)
	Pressure Relief
	Pressure Reducing
	Flow Control, Adjustable - Non-Compensated
	Flow Control, Adjustable (Temperature and pressure compensated)
	Two-Position Two Connection
	Two-Position Three Connection
	Two-Position Four Connection
	Three-Position Four Connection
	Two-Position In Transition
	Valves Capable of Infinite Positioning (Horizontal bars indicate infinite positioning ability)

Color Code for Fluid Power Schematic Drawings

Black	Intensified Pressure
Red	Supply
Intermittent Red	Charging Pressure
Intermittent Red	Reduced Pressure
Intermittent Red	Pilot Pressure
Yellow	Metered Flow
Blue	Exhaust
Green	Intake
Green	Drain
Blank	Inactive

UNIT III
HYDRAULIC CIRCUITS AND SYSTEMS

Industrial hydraulic circuits- Regenerative, Pump Unloading, Double-pump, Pressure Intensifier, Air over oil, Sequence, Reciprocation, Synchronization, Fail-safe, Speed control, Hydrostatic transmission, Accumulators, Electro hydraulic circuits, Mechanical Hydraulic servo systems.

A basic hydraulic circuit consists of a power supply, pump, reservoir, relief valve and a control valve.

Basic hydraulic power units can have specific control valves and activators to properly control hydraulic devices. Examples: Single or Double Acting Hydraulic Cylinders, Hydraulic Motors or to send fluid and pressure to a remote location.

Custom designing a hydraulic circuit is to specifically build the complete circuit to satisfy all the requirements of the power unit.

Design Considerations :

• Safety of Operation:

1. Pressure and Temperature ratings.
2. Interlocks for sequential operations
3. Emergency shutdown features.
4. Power failure locks.
5. Operation speed.
6. Environment conditions.

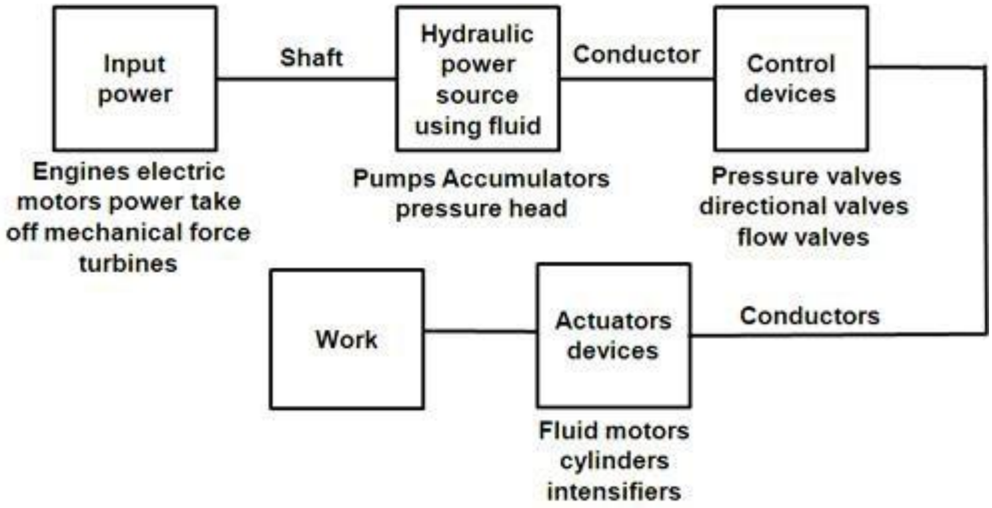
• Meet functional requirements :

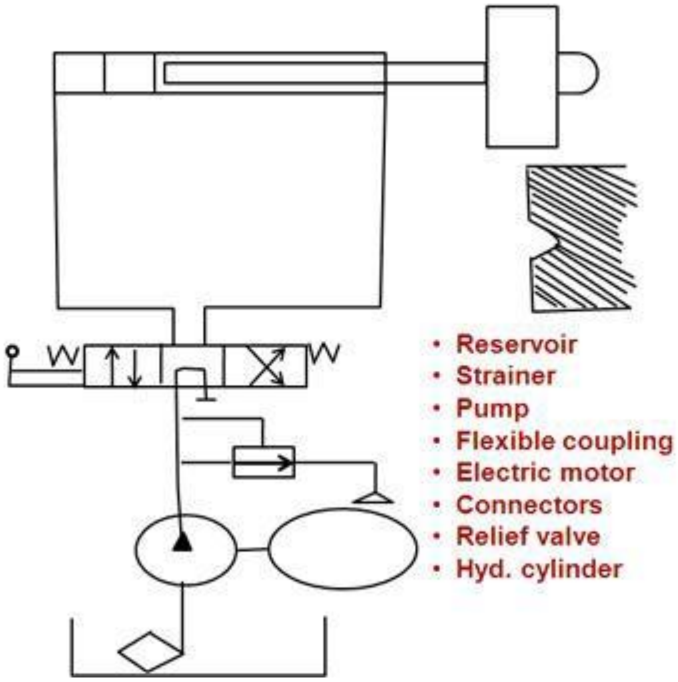
1. Meet required performance specification.
2. Life expectancy same as machine.
3. Facilitate good maintenance practice.
4. Compatibility with electrical and mechanical components.
5. Withstand operational hazards.

• Efficiency of Operation :

1. Keep system Simple, Safe and Functional.
2. Access to parts need repair or adjustment.
3. Design to keep min operational cost.
4. Design to prevent and remove contamination.

Linear Circuits :





Some of the hydraulic circuit includes:

Regenerative circuit

Pump Unloading circuit

Double-pump circuit

Pressure Intensifier circuit

Air over oil circuit

Sequence circuit - Reciprocation circuit

Synchronization circuit

Fail-safe circuit

Speed control circuit

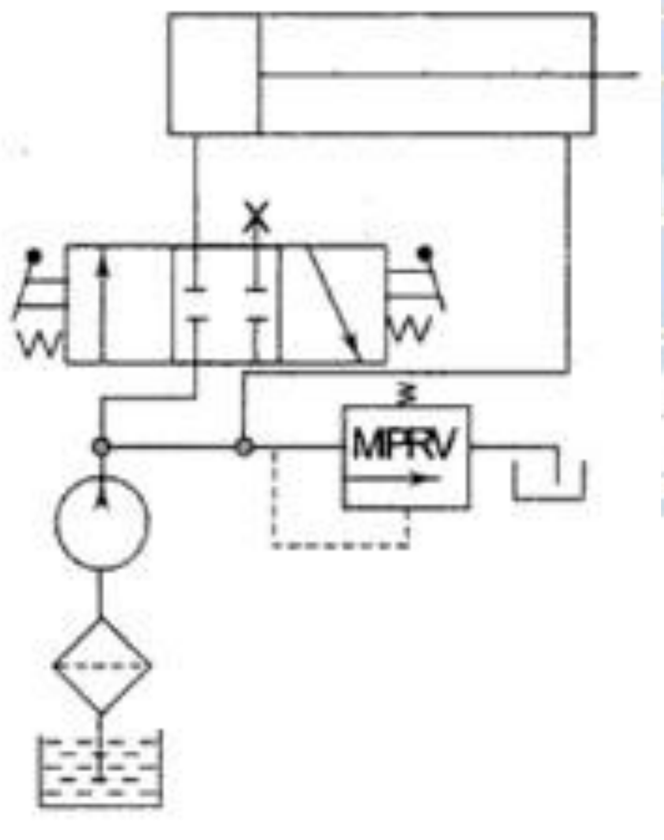
Hydrostatic transmission

Accumulators

Electro hydraulic circuits Mechanical

Hydraulic servo systems.

REGENERATION CIRCUITS

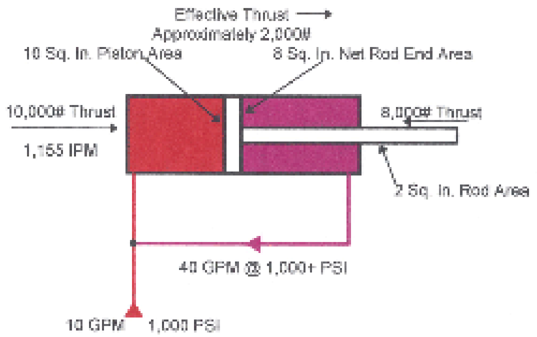


Regeneration circuits can double the extension speed of a single-rod cylinder without using a larger pump. This means that regeneration circuits save money because a smaller pump, motor, and tank can produce the desired cycle time. It also means that the circuit costs less to operate over the life of the machine.

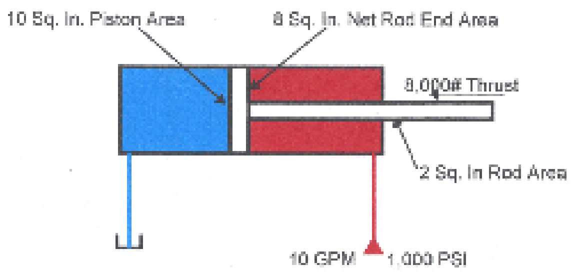
A regeneration circuit can also replace a double rod-end cylinder in some circuits. With equal rod diameters, a double-rod cylinder's area is the same on both ends. Equal areas mean identical force and speed both ways at a given pressure and flow. Reciprocating tables often use double rod-end cylinders for this reason. When the main function of a double rod-end cylinder is equal speed and power in both directions of travel, replace it with a regeneration circuit.

A double rod-end cylinder costs more than a cylinder with a single oversize rod; the extra rod needs space in which to move; and the second rod seal is another potential leakage source. To eliminate these objections, use the full-time regeneration circuit shown in Figures 17-6 and 17-8. Extension and retraction speed (as well as thrust) is the same, without the extra rod and its problems.

One disadvantage to using cylinders with a single oversize rod is that speed and thrust are not identical if the rod diameter ratio is not exactly 2:1. Most cataloged 2:1 rod diameters are only close to that ratio. A standard NFPA 3.25-in. bore cylinder comes with a 2.00-in. diameter rod as a 2:1 differential. If using this cylinder in a full-time regeneration circuit, speed is about 21% faster on the extension stroke, with about 21% less force than the retraction stroke.



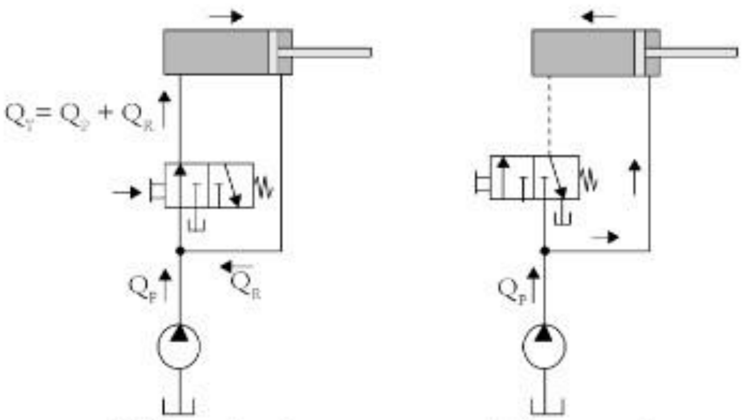
Forward stroke



Return stroke

Regenerative Circuit

In an earlier chapter, we have learned that a typical conventional double-acting hydraulic cylinder with piston area 'A_p' and piston-rod area 'A_r' produces somewhat greater speed when retracting than when extending provided that the pump flow is constant. However, many hydraulic circuits require faster extension stroke to reduce their overall cycle times. A regenerative circuit can be employed to increase the speed of the cylinder during its extension stroke. The idea of the regenerative circuit is explained with the help of Figure 11.13. The circuit consists of a hydraulic cylinder powered by a fixed-displacement pump with a flow rate 'Q_P' and controlled by a 3/2-DC valve. The lines to the ports of the cylinder are connected in parallel.



(a) Forward stroke (b) Return stroke

During the forward stroke of the cylinder, fluid from the pump (Q_P) flows to the cap end of the cylinder through the DC valve and flow from the piston-rod end (Q_R) regenerates with the pump flow. During its forward stroke, the total flow (Q_T) to the cap end of the cylinder is the sum of Q_P and Q_R.

That is, $$Q_T = Q_P + Q_R$$

Therefore, the pump flow rate Q_P is given by:

$$Q_P = Q_T - Q_R$$

As we are aware, the total flow rate is the product of the piston area (A_P) and the extension speed (v_{ext}) and the regenerative flow rate is the product of the active area on the piston-rod side (that is, $A_P - A_r$) we have,

$$Q_P = A_P \times v_{ext} - (A_P - A_r) \times v_{ext}$$

$$Q_P = A_r \times v_{ext}$$

Therefore, $$v_{ext} = Q_P / A_r$$

The equation mentioned above suggests that the speed of extension stroke equals the pump flow rate divided by the piston-rod area. Thus, a small rod area provides a significant extension speed.

Ratio of Extension and Retraction Speeds: The ratio of the extension speed (v_{ext}) and the retraction speed (V_{ret}) of a hydraulic cylinder can be related to the area ratio (A_p/A_r) of the cylinder. The area ratio can be calculated in the following manner:

Retraction speed, $v_{ret} = Q_P / (A_p - A_r)$

Therefore, $v_{ext} / V_{ret} = (A_p - A_r) / A_r$

$v_{ext} / V_{ret} = (A_p/A_r) - 1$

The equation mentioned above suggests that higher the ratio of the piston area to the piston-rod area of the cylinder, the greater would be the ratio of its extending speed to its retraction speed. For the particular case, when the piston area is equal to two times the piston-rod area, the extension and retraction speeds would be equal.

Load-carrying Capacity: The load-carrying capacity of the regenerative hydraulic cylinder during its extension stroke is less than that would have obtained from a regular double-acting hydraulic cylinder. The load-carrying capacity of the cylinder during its extension stroke equals the system pressure times the piston-rod area rather than the piston area. This fact is because the pressure acts on both sides of the piston during the extension stroke of the cylinder.

PUMP UNLOADING CIRCUIT:

In this circuit, the unloading valve opens as the cylinder reaches the end of its extension stroke. This is because the check valve keeps the high-pressure oil in the pilot line of the unloading valve. When the DCV is shifted to retract the cylinder, the motion of the cylinder reduces the pressure in the pilot line of the unloading valve. This resets the unloading valve until the cylinder is fully retracted at the point where the unloading valve unloads the pump. It is thus seen that the unloading valve unloads the pump at the end of the extending and retracting strokes as well as in the spring-centred position of the DCV.

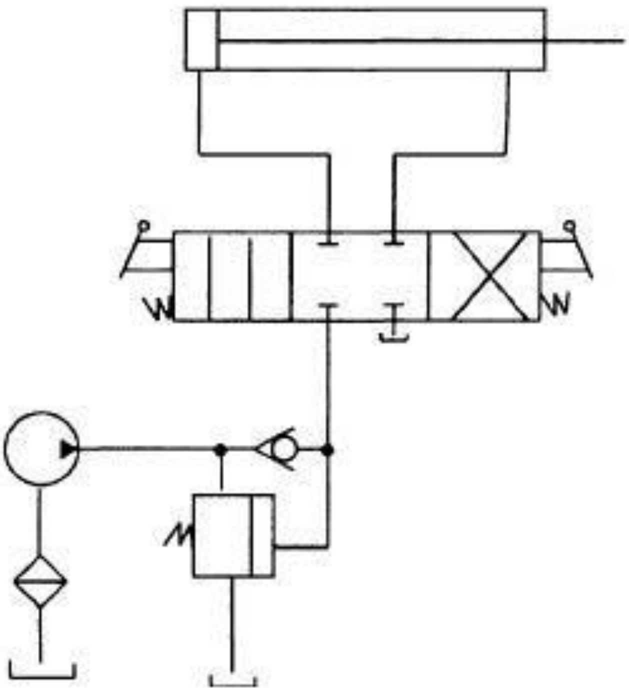


Figure 10.4
Pump unloading circuit

DOUBLE-PUMP CIRCUIT

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

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

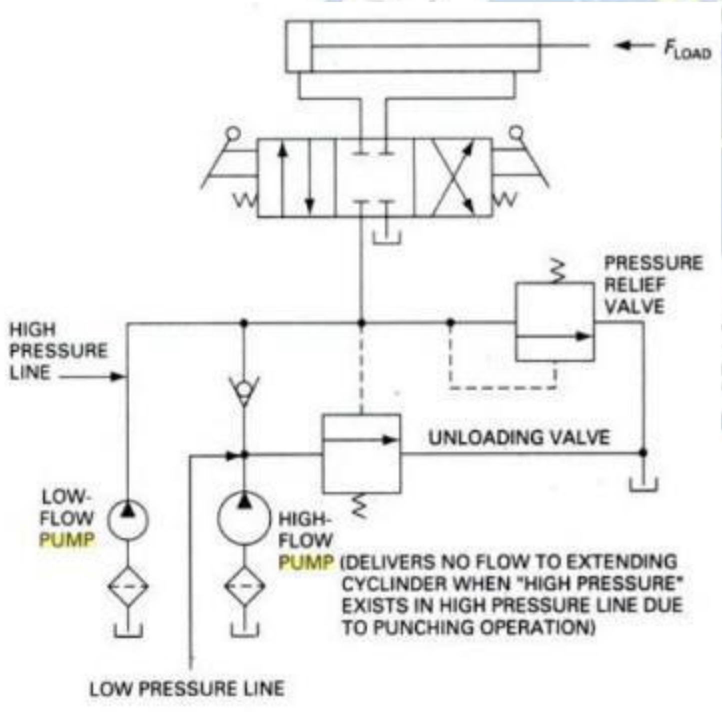


Figure 5-8 shows a circuit that uses two pumps, one high-pressure, low-flow pump and the other low-pressure, high-flow pump. One can find application in a punch press in which the hydraulic ram must extend rapidly over a large distance with very low pressure but high flow requirements. However, during the short motion portion when the punching operation occurs, the pressure requirements are high due to the punching load. Since the cylinder travel is small during the punching operation, the flow-rate requirements are also low.

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

PRESSURE INTENSIFIER CIRCUIT

What are Pressure Intensifiers ?

- ✓ Pressure intensifiers, also known as ***pressure boosters***, are used to compress the liquid in a hydraulic system to a value above the pump discharge pressure.
- ✓ In other words, *a hydraulic intensifier is a device which converts a large-volume, low-pressure fluid supply into a proportionately small-volume, high-pressure fluid outlet.*
- ✓ The intensifier is usually located in between the pump and the machine (*e.g.*, press, crane, lift) that needs high pressure liquid for its operation.
- ✓ The action of the intensifier is similar to that of a ***step-up electrical transformer.***
- ✓ It finds its application at places where a liquid of very high pressure is to be developed from available low pressure. Typical applications include hydraulic presses, riveting machines, and spot-welders.

Construction and Working

The construction and operation of a typical pressure intensifier is illustrated in Fig.8.16.

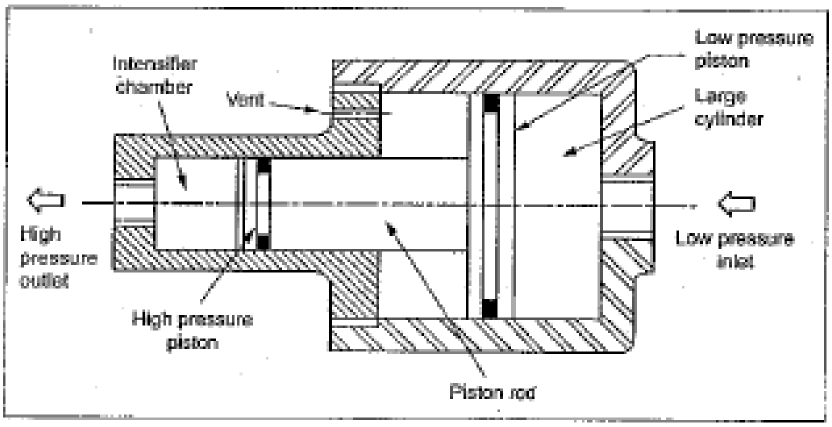


Fig. 8.16. Operation of a pressure intensifier

the force on the fluid in the intensifier chamber of smaller cylinder.

13.3. Intensifier Ratio

It may be noted that the increase in pressure is directly proportional to the difference in eas of the two sizes of pistons.

Let P_o = Pressure exerted on larger or 'operating' end of the piston,

P_i = Pressure exerted by smaller or 'intensifying' end of the piston,

A_o = Area of the larger or 'operating' end of the piston, and

A_i = Area of the smaller or 'intensifying' end of the piston.

Since force load acting on the two pistons is same, we get

$$P_o \times A_o = P_i \times A_i$$

or

$$\text{Intensifier ratio, } \frac{P_i}{P_o} = \frac{A_o}{A_i} \quad \ldots (8.3)$$

The volume output is inversely proportional to the above ratio. Therefore we can write,

$$\frac{\text{High outlet pressure } (P_i)}{\text{Low inlet pressure } (P_o)} = \frac{\text{Area of large piston } (A_o)}{\text{Area of small piston (or piston rod) } (A_i)}$$

$$= \frac{\text{High inlet flow rate } (Q_{in})}{\text{Low outlet flow rate } (Q_{out})} \quad \ldots (8.4)$$

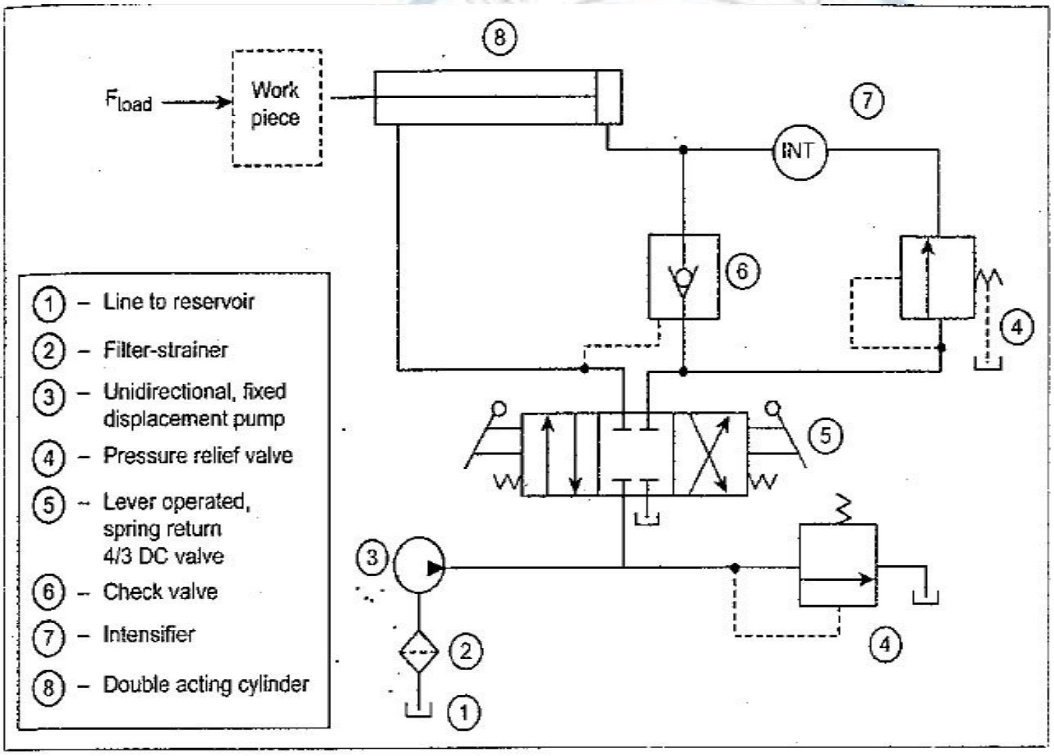


Fig. 8.17. Pressure intensifier circuit

8.14. PRESSURE INTENSIFIER CIRCUITS

8.14.1. Intensifier Circuit in Punching Press Application

As we know, usually a heavy punching press requires two pumps (a low-pressure pump and a high-pressure pump) to obtain the high-pressure outlet flow required for the operation. But with the use of a pressure intensifier, one can eliminate the expensive high-pressure pump in the punching press application.

8.14.1.1. Circuit

Fig.8.17 shows a basic hydraulic circuit employing an intensifier for use in a punching operation. This circuit consists of a low-pressure pump, 4/3 DC valve, pilot check valve, sequence valve, pressure intensifier, and cylinder. As shown in Fig.8.17, the intensifier should be installed closer to the cylinder to shorten the high-pressure lines.

8.14.1.2. Operation

First operator places workpiece in fixture and shifts handle of 4/2 DC valve. When the 4/2 DC valve is shifted to the right side position, the oil flows to the blind end of the cylinder through the check valve. When the pressure in the cylinder reaches the sequence valve pressure setting, the sequence valve opens and supplies the flow to the intensifier. Now the intensifier starts to operate and gives high-pressure output. This high-pressure output of the intensifier closes the pilot check valve and pressurizes the blind end of the cylinder to perform the punching operation.

When the 4/2 DC valve is shifted to the left side position, the oil flows to the rod end of the cylinder. When it builds-up the pressure, the pilot signal opens the check valve. Thus the cylinder is retracted to the starting position.

Air-Over-Oil Intensifier Circuit

- ✓ In some applications, the hydraulic and pneumatic circuits are coupled to best use of the advantages of both oil and air mediums.
- ✓ This combination circuit is also known as ***hydro-pneumatic*** or ***pneumo-hydraulic circuits*** or ***dual pressure systems.***

Circuit

Fig.8.18 shows a typical air-over-oil intensifier. This circuit can be used for drawing a cylinder over a large distance at a low pressure and then over a small distance at high pressure (such as in punch press applications). This circuit consists two lines—air lines and oil lines. In the circuit, the air lines are shown by single lines and oil lines by double lines.

Operation

Extension : When the first 4/2 DC valve (valve 1) is shifted to left mode, the air from the reservoir flows to the approach tank. In the approach tank, the air forces the oil to the blind end of the cylinder through the bottom of the intensifier, as shown by double lines in Fig.8.18. Now the cylinder extends.

Useful Work : When the cylinder experiences its load, the second 4/2 DC valve (valve 2) is actuated to the left mode. This valve position sends air to the top end of the intensifier.

Now the intensifier moves down, and the piston of the intensifier blocks the path of oil from the approach tank. Now the cylinder receives high pressure oil at the blind end to perform the useful work such as punching operation.

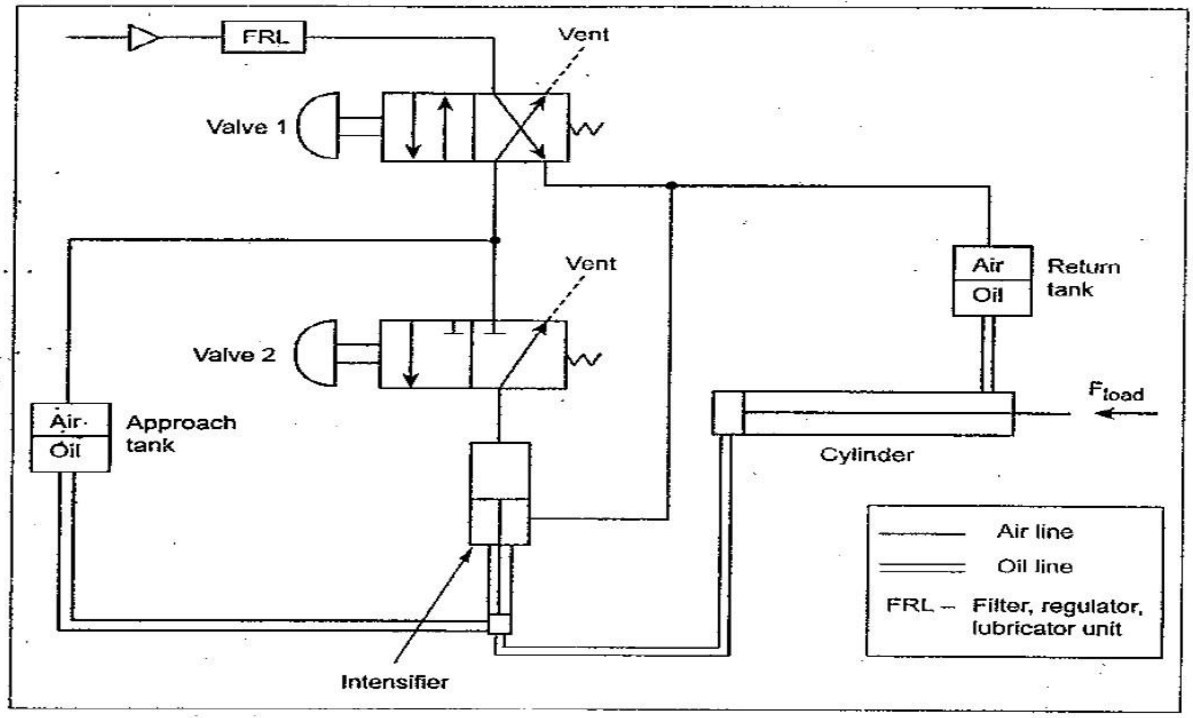
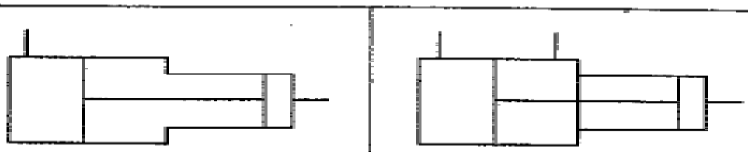


Fig. 8.18. Air-over-oil intensifier circuit

Retraction : When the valve 2 is released (shifted to right mode), the air flow from the reservoir is blocked. The air from the top end of the intensifier is vented to the atmosphere. This completes the high pressure portion of the cycle.

When valve 1 is released (*i.e.*, shifted to right mode), the air flow is diverted to return tank and also the air in the approach tank is vented. The diverted air flow pushes the oil to the rod end of the cylinder. This causes the cylinder to retract. The oil from the piston end of the cylinder is diverted back to the approach tank through the bottom end of the intensifier. This completes the entire cycle of operation.



(a) Pressure intensifier, single acting piston

(b) Pressure intensifier, double acting piston

Fig. 8.19. Graphic symbol for a pressure intensifier

SEQUENCE CIRCUIT

The circuit depicted in Figure contains a hydraulic system in which two sequence valves are used to control the sequence of operation of two double-acting cylinders.

When the DCV is shifted into its left envelope mode, the left cylinder extends completely and then the right cylinder extends. If the DCV is shifted into its right envelope mode, the right cylinder retracts fully followed by the left cylinder. This sequence of the cylinder operation is controlled by the sequence valves. The spring centered position of the DCV locks both the cylinders in place.

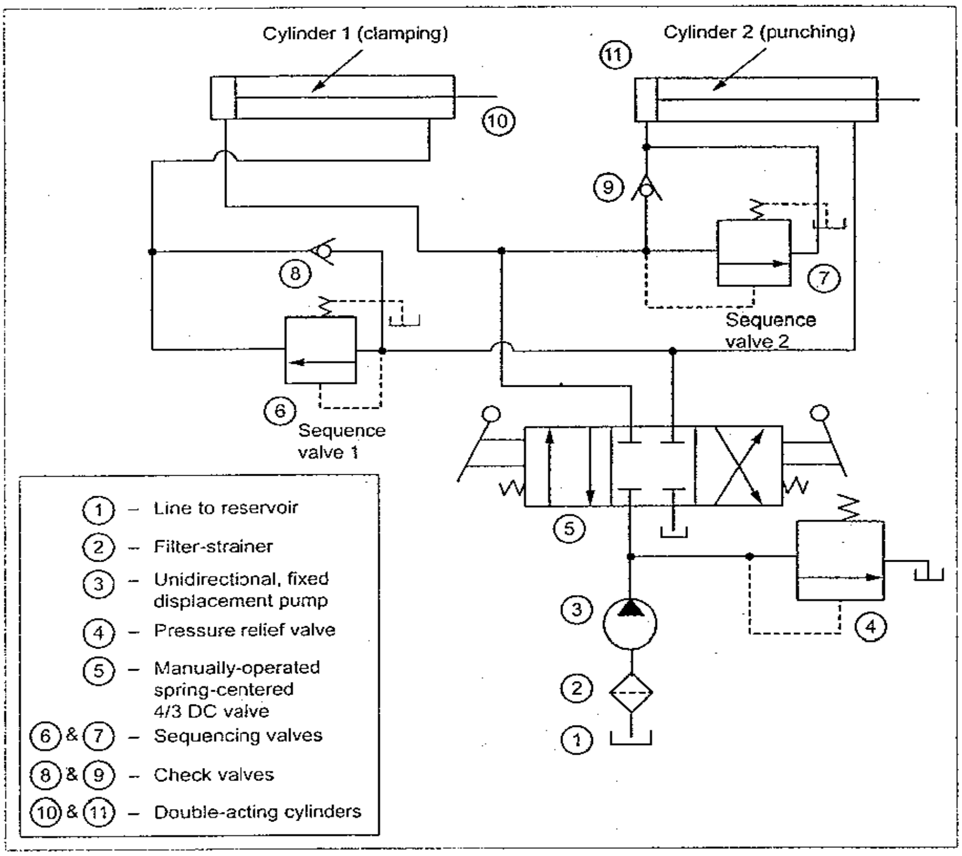


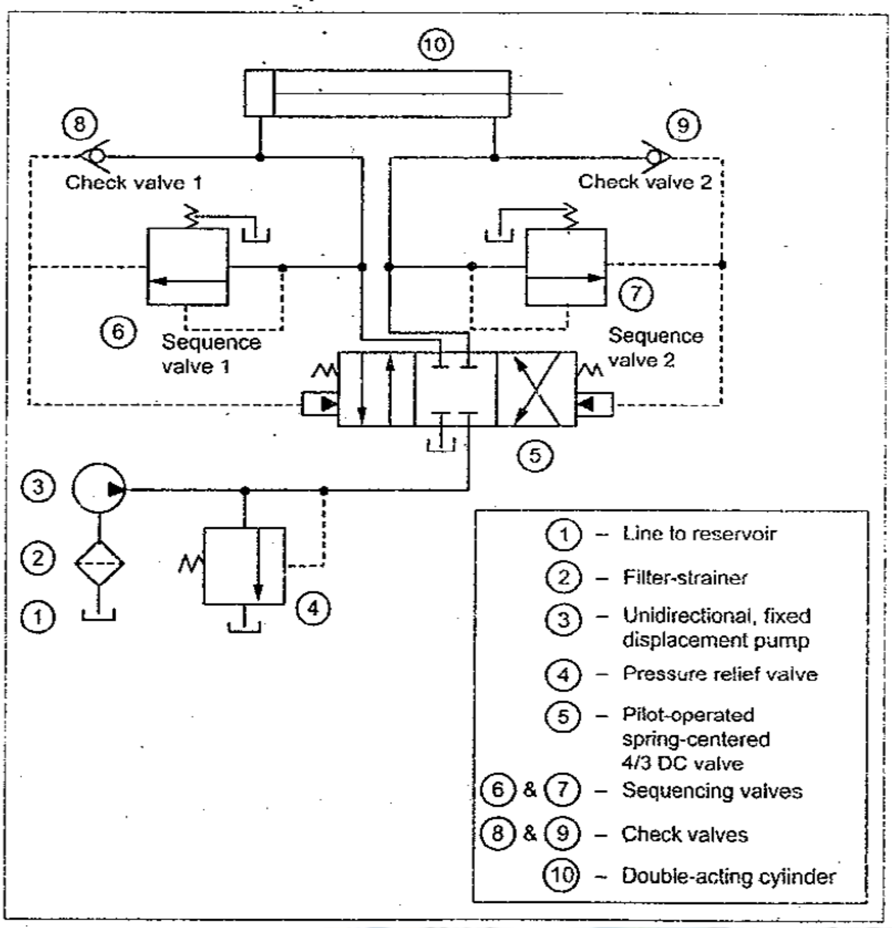
Fig. 13.5. Hydraulic cylinder sequence circuit (for clamping and punching operations)

13.8.2. Operation

Left mode position : When the 4/3 DC valve is shifted manually to the left envelope flow path configuration, the cylinder-1 extends completely and the workpiece is clamped. Once the cylinder-1 reaches its end of the stroke, pressure is increased and sequence valve 1 opens and the oil starts to flow into the cylinder-2. Now the cylinder-2 extends to drive a spindle to do punching operation in the workpiece.

Right mode position : When the 4/3 DC valve is shifted to the right mode, the cylinder-2 retracts. Once the cylinder-2 retracts completely, the sequence valve 2 opens and the oil starts to flow into the cylinder-1. It causes the cylinder-1 to retract and hence the unclamping of workpiece is achieved.

AUTOMATIC RECIPROCATION CIRCUIT:



13.9.2. Operation

Retraction : When the 4/3 DC valve is shifted to the left envelope flow path configuration, oil flows from the pump to the rod end of the cylinder. This pump flow retracts the cylinder. The check valve 1 prevents shifting of the 4/3 DC valve until the full retraction stroke completes. As the piston reaches its end of stroke, the pressure builds up in the sequence valve 1 and it opens. This allows the pilot pressure signal to shift the DC valve to the right mode.

Extension : When the pilot signal shifts the 4/3 DC valve to the right mode, the oil flows to the blind end of the cylinder. This pump flow extends the cylinder. The check valve 2 prevents shifting of the DC valve until the full extension stroke completes. As the piston reaches its end of stroke, the pressure builds-up in the sequence valve 2 and it opens. This allows the pilot pressure signal to shift the DC valve to the left mode again.

Thus the sequence repeats and the cylinder reciprocates continuously.

SYNCHRONIZATION CIRCUIT

HYDRAULIC CYLINDER SYNCHRONIZING CIRCUITS

There are many industrial applications require nearly perfect synchronization of movement of two or more cylinders in order to complete some phase of operation. To accomplish the identical task from the cylinders at the same rate, synchronizing circuits are employed. This synchronization can be achieved in many ways such as (*i*) By using double-end cylinders in series, (*ii*) By using mechanically linked pistons, (*iii*) By using hydraulic motors as metering devices, (*iv*) By using flow control valves, (*v*) By using air-hydraulic cylinders in series, *etc.*

Now we shall discuss how synchronization is achieved using the double-end cylinders in series.

Synchronizing Hydraulic Cylinders Connected in Series

Circuit

Fig.13.7 illustrates a circuit to synchronize two cylinders by connecting them in series. This circuit uses a solenoid-operated, spring-offset 4/3 DC valve and two double-acting hydraulic cylinders.

Operation

Extension of cylinders 1 and 2 : When the 4/3 DC valve is shifted to the left envelope flow path configuration, oil flows from the pump to the blind end of cylinder 1 and thus the cylinder 1 extends. At the same time, oil from the rod end of cylinder 1 is forced to the blind end of cylinder 2 and thus the cylinder 2 also extends. Now the oil returns to the tank from the rod end of cylinder 2 via the DC valve. Once full extension of cylinders 1 and 2 are over, the DC valve is shifted to the right mode.

Retraction of cylinders 1 and 2 : When the 4/3 DC valve is shifted to the right mode, oil flows from the pump to the rod end of cylinder 2 and thus the cylinder 2 retracts. At the same time, oil from the blind end of cylinder 2 is forced to the rod end of cylinder 1 and thus the cylinder 1 also retracts. Now the oil returns to the tank from the blind end of cylinder 1 via the DC valve.

Thus both extension and retraction operations of both cylinders are synchronized by connecting them in series. But for the two cylinders to be synchronized, the piston area of cylinder 2 should be equal to the difference between the areas of the piston and rod for cylinder 1.

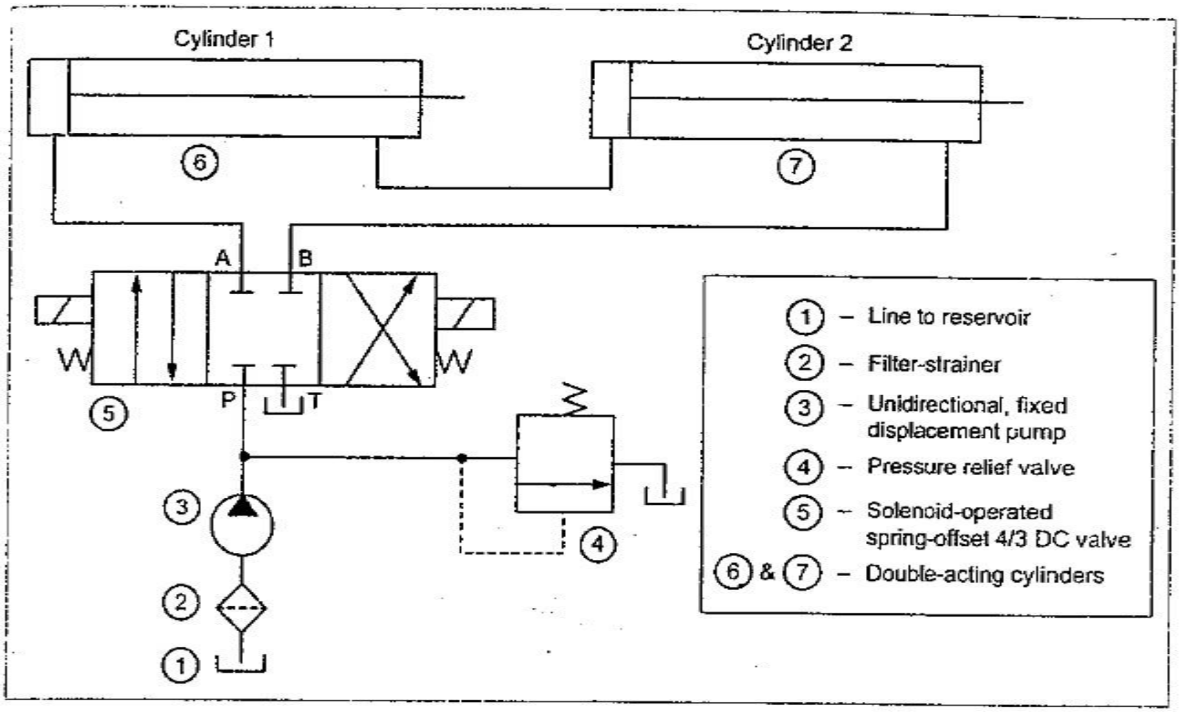


Fig. 13.7. Synchronizing hydraulic cylinders by connecting them in series

FAIL-SAFE CIRCUIT

Fail-safe circuits are designed to safeguard the operator, the machine, and the workpiece. These circuits prevent any possible injury to the operator or damage to the machine and the workpiece. One such fail-safe circuit is explained below.

13.13.1. Two Handed Safety Circuit

The two handed safety circuit is designed to protect an operator from accident.

13.13.2. Circuit

Fig.13.11 illustrates a typical two handed safety control circuit for safeguarding the operator from injury. This circuit uses a pilot-operated spring-offset 4/3 DC valve and two push buttons.

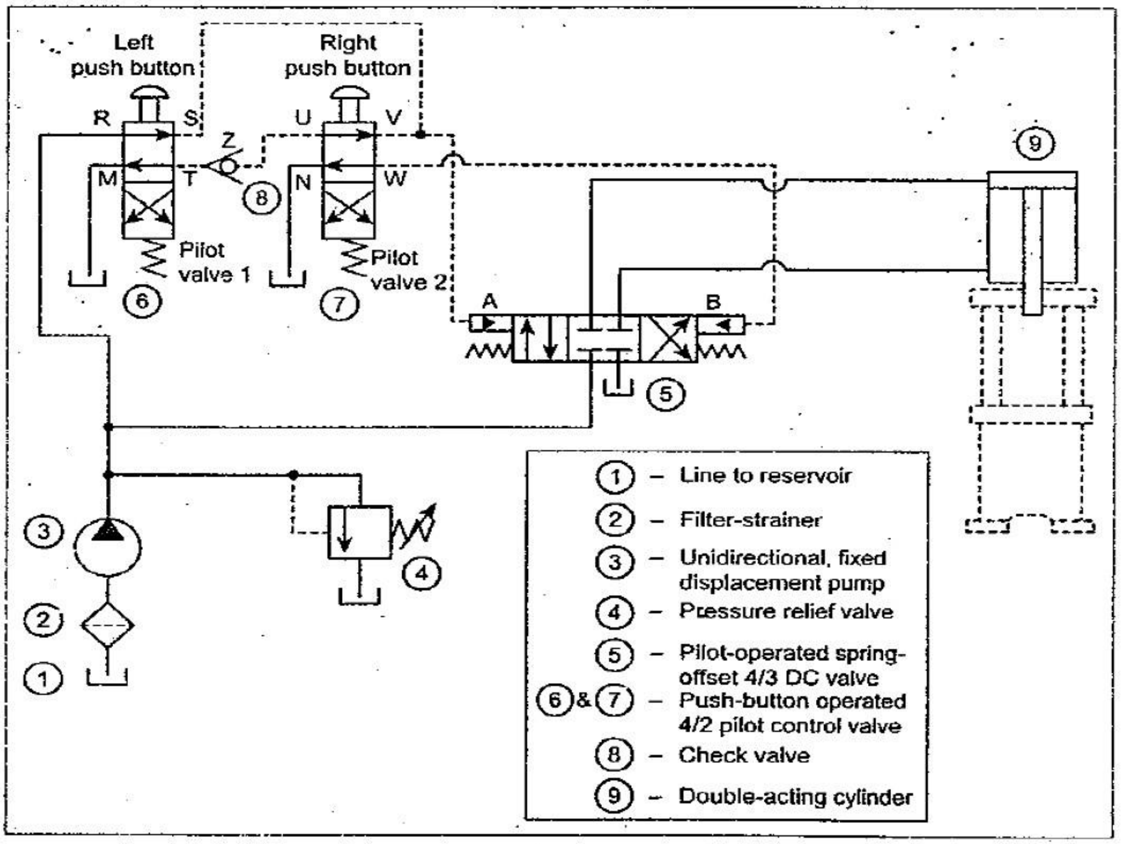


Fig. 13.11. Two handed safety control circuit

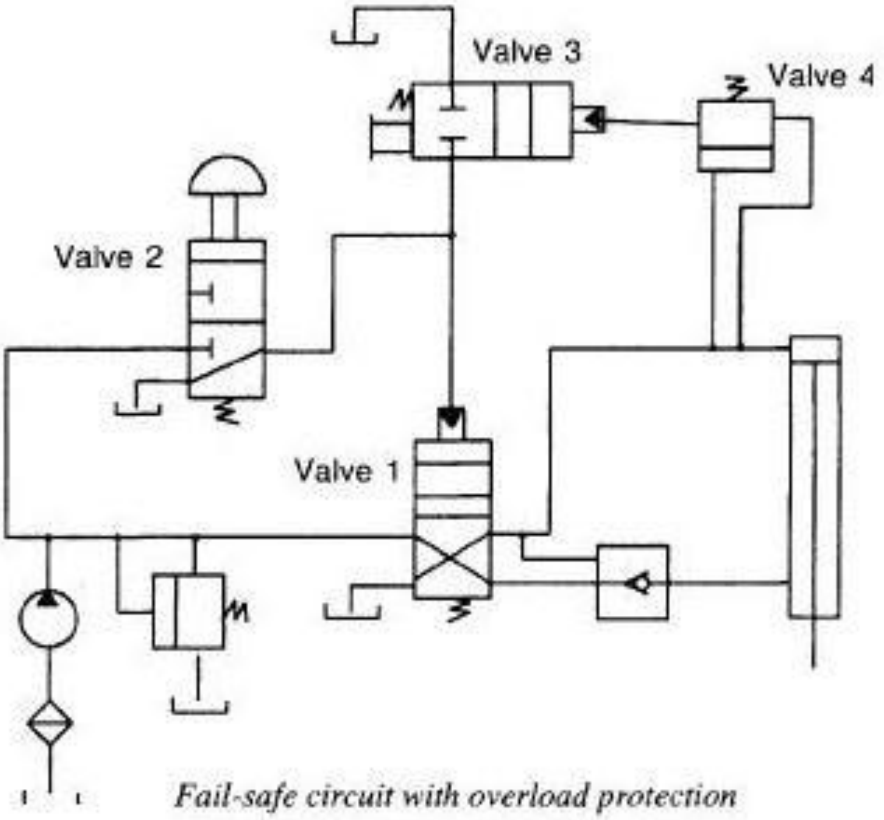
Operation:

The operation are as follows:

1. When the 4/3 DC valve is in its centre position, the oil flow is diverted back to tank through the pressure relief valve. Therefore the cylinder is hydraulically locked.
2. When operator pushes down both left and right push buttons, the oil flows in through port R of pilot valve 1 and out through port S, then through port V of pilot valve 2 and out port U. But check valve Z stops flow. At the same time, the oil also flows to pilot connection A of 4/3 DC valve causing the DC valve to shift to its left mode. When the DC valve is shifted to its left mode, the oil from the pump flows into the blank end of the cylinder and thus the cylinder extends. ***Thus the extension of cylinder takes place only when the operator depresses both the push buttons.***
3. When the operator pushes the right push button only, oil flows in through port R to port S of pilot valve 1, then through port V to port N of pilot valve 2. Thus the oil is drained to the tank through the pilot valve 2. This allows the 4/3 DC valve to return to neutral position; thus the cylinder is hydraulically locked.
4. When the operator pushes the left push button only, oil flows in port R of pilot valve 1 and out port T, then unseats ball in check valve Z, then on to port U of pilot valve 2, and out port V. Oil follows the path of least resistance so it passes in port S of pilot valve 1, out port M and into sump. It does not build up enough pressure to keep pilot pressure on pilot connection A so 4/3 DC valve shifts back to neutral position; thus the cylinder is hydraulically locked.
5. When the operator releases both left and right push buttons, oil flows in port R of pilot valve 1 and out port T, then through check valve Z and into port U of pilot valve 2. Now the oil flows out port W into pilot connection B of 4/3 DC valve shifting its position to right mode. When the 4/3 DC valve is shifted to its right mode, the oil from the pump flows into the rod end of the cylinder and hence the cylinder retracts. ***Thus the retraction of cylinder takes place only when the operator releases both the push buttons.***

FAIL SAFE CIRCUIT FOR OVERLOAD PROTECTION:

Figure 9-17 shows a fail-safe circuit that provides overload protection for system components. Directional control valve 1 is controlled by push-button three-way valve 2. When overload valve 3 is in its spring offset mode, it drains the pilot line of valve 1. If the cylinder experiences excessive resistance during the extension stroke, sequence valve 4 pilot-actuates overload valve 3. This drains the pilot line of valve 1, causing it to return to its spring offset mode. If a person then operates push-button valve 2, nothing will happen unless overload valve 3 is manually shifted into its blocked port configuration. Thus, the system components are protected against excessive pressure due to an excessive cylinder load during its extension stroke.



Fail-safe circuit with overload protection

SPEED CONTROL CIRCUIT

Speed control of a hydraulic cylinder is accomplished using a flow control valve. A flow control valve regulates the speed of the cylinder by controlling the flow rate to and of the actuator.

There are 3 types of speed control:
- Meter- in circuit (Primary control)
- Meter-out circuit (Secondary control)
- Bleed - off circuit (By pass control)

1. Meter – in Circuit : In this type of speed control, the flow control valve is placed between the pump and the actuator. Thereby, it controls the amount of fluid going into the actuator. Fig. shows meter-in circuit.

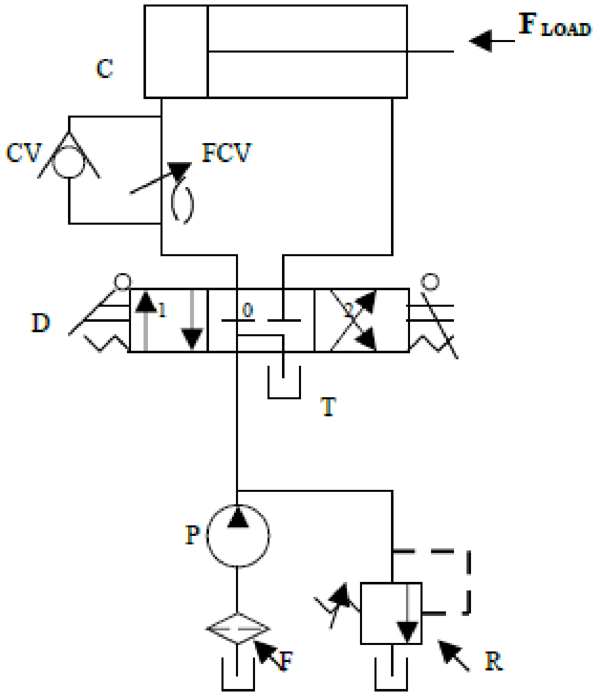


Fig 5.16. **Meter – in circuit.**

C = Double acting cylinder ; P = Pump ; T = Tank ; F = Filter

R = Relief Valve; CV = Check Valve ; FCV = Flow control Valve

D =3-position, 4 way ,Tandem center, Manually operated ,Spring Centered DCV

When the directional control valve is actuated to the 1st position, oil flows through the flow control valve to extend the cylinder. The extending speed of the cylinder depends on the setting (percent of full opening position) of the flow control valve. When the directional control valve is actuated to the 2nd position, the cylinder retracts as oil flows from the cylinder to the oil tank through the check valve as well as the flow control valve.

Meter – out Circuit: In this type of speed control, the flow control valve is placed between the actuator and the tank. Thereby, it controls the amount of fluid going out of the actuator. Fig. shows a meter-out circuit.

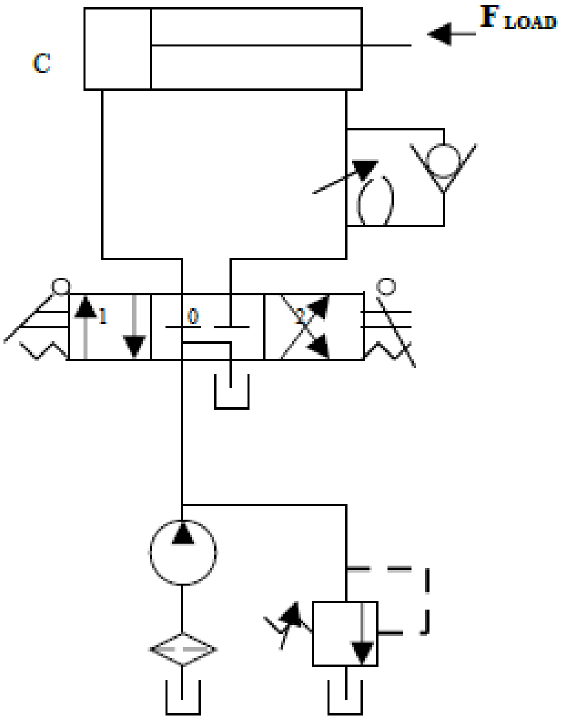


Fig 5.17. **Meter – out Circuit.**

C = Double acting cylinder; P = Pump ; T = Tank; F = Filter
R = Relief Valve; CV = Check Valve ; FCV = Flow control Valve
D =3-position, 4 way ,Tandem center, Manually operated and
Spring Centered DCV

Meter-in systems are used primarily when the external load opposes the direction of motion of the hydraulic cylinder. An example of the opposite situation is the case of a weight pulling downward on the piston rod of a vertical cylinder. In this case the weight would suddenly drop by pulling the piston rod down if a meter-in system is used even if the flow control valve is completely closed. Thus, the meter-out system is generally preferred over the meter-in type. One drawback of a meter-out system is the possibility of excessive pressure buildup in the rod end of the cylinder while it is extending. This is due to the magnitude of back pressure that the flow control valve can create depending on its nearness to being fully closed as well as the size of the external load and the piston-to-rod area ratio of the cylinder. In addition an excessive pressure buildup in the rod end of the cylinder results in a large pressure drop across the flow control valve. This produce the undesirable effect of a high heat generation rate with a resulting increase in oil temperature.

SPEED CONTROL OF MOTOR

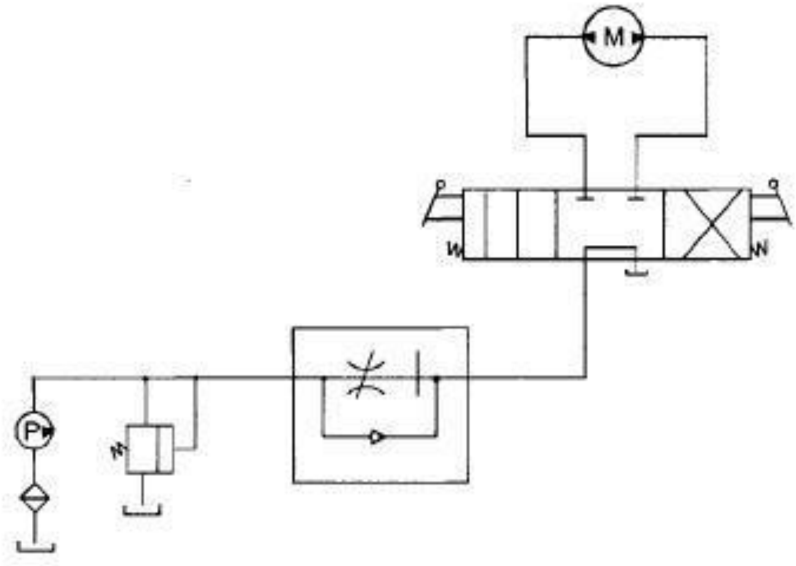


Figure 10.9
Speed control of a hydraulic motor

Figure shows a circuit in which speed control in a hydraulic circuit is accomplished using a pressure compensated flow control valve.

The operation of the circuit is as follows:

• In the spring-centered position of the tandem four-way valve, the motor is hydraulically locked.

• When the four-way valve is actuated into the left envelope, the motor rotates in one direction. Its speed can be varied by adjusting the setting of the throttle of the flow control valve. The speed can be infinitely varied as the excess oil goes through the pressure relief valve.

• When the four-way valve is de-activated, the motor stops suddenly and gets locked.

• When the right envelope of the four-way valve is in operation, the motor rotates in the opposite direction. The pressure relief valve provides overload protection when the motor experiences an excessive torque load.

ACCUMULATORS CIRCUIT:

1. Accumulator as an auxiliary power source:

The purpose of accumulator in this application is to store the oil delivered by the pump during a portion of the work cycle. The accumulator then releases the stored oil on demand to complete the cycle, thereby serving as a secondary power source.

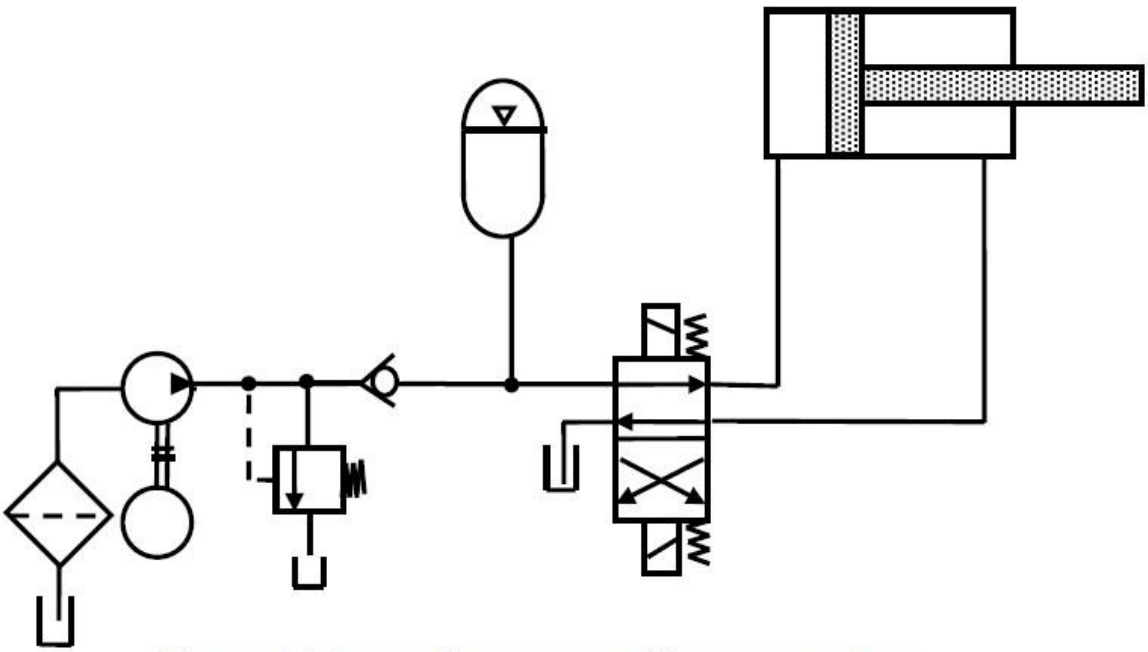


Figure 1.8 Accumulator as an auxiliary power source.

The schematic diagram is shown in Fig. 1.8. When the four-way valve is manually activated, oil flows from the accumulator to the blank end of the cylinder. This extends the piston until it reaches the end of the stroke. When the cylinder is in its fully extended position, the accumulator is being charged. The four-way valve is then deactivated for retraction of the cylinder oil flows from both the pump and accumulator to retract the cylinder rapidly.

2. Accumulator as a leakage compensator:

An accumulator can be used as a compensator for internal and external leakage during an extended period in which the system is pressurized but not in operation. The pump charges the accumulator and the system until the maximum pressure sets the pressure switch ON. The schematic diagram is shown in Fig. 1.9. The contacts on the pressure switch then open to automatically stop the electric motor that drives the pump. The accumulator then supplies leakage oil to the system during a long period. Finally, when the system pressure drops to the minimum pressure setting of the pressure switch, it closes the electrical circuit of the motor until the system gets recharged. The check valve is placed between the pump and accumulator so that the pump does not reverse when the motor is stopped and does not permit all the accumulator charge to drain back into the power unit. With this circuit, the only time the power unit operates is when the pressure drops to an unsafe operating level. This saves electric power and reduces the heat in the system

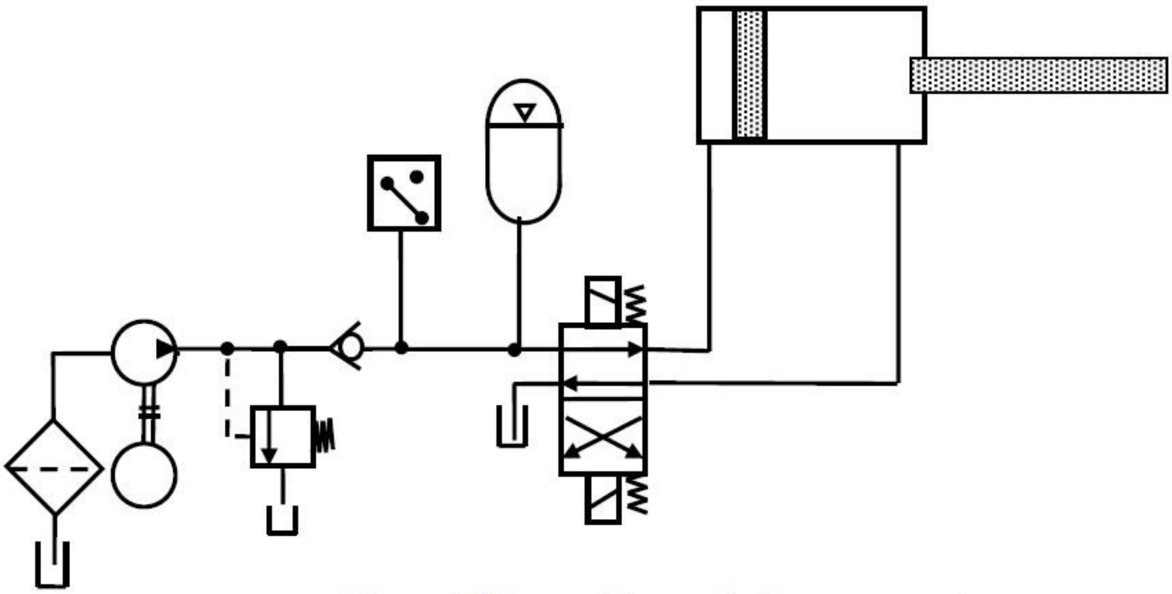
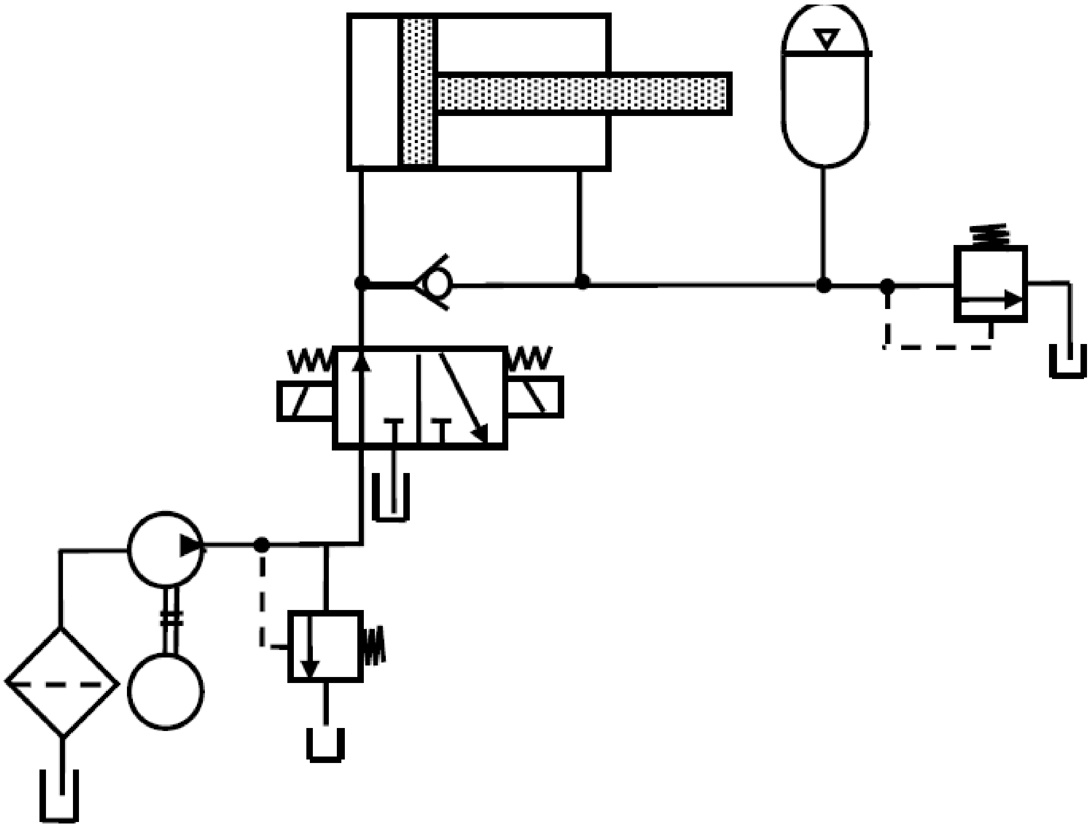


Figure 1.9 Accumulator as a leakage compensator.

3. Accumulator as an emergency power source:

In some hydraulic systems, safety dictates that a cylinder be retracted even though the normal supply of oil pressure is lost due to a pump or electrical power failures. The schematic diagram is shown in Fig. 1.10. In it, a solenoid activated three-way valve is used along with the accumulator. When the three-way valve is energized, oil flows to the blank end of the cylinder and also through the check valve into the accumulator and the rod end of the cylinder. The accumulator charges as the cylinder extends.

If the pump fails due to an electric failure, the solenoid de-energizes, shifting the valve to its spring offset mode. Then the oil stored under pressure is forced from the accumulator to the end of the cylinder. This retracts the cylinder to its starting position.



4. Accumulator as a hydraulic shock absorber:

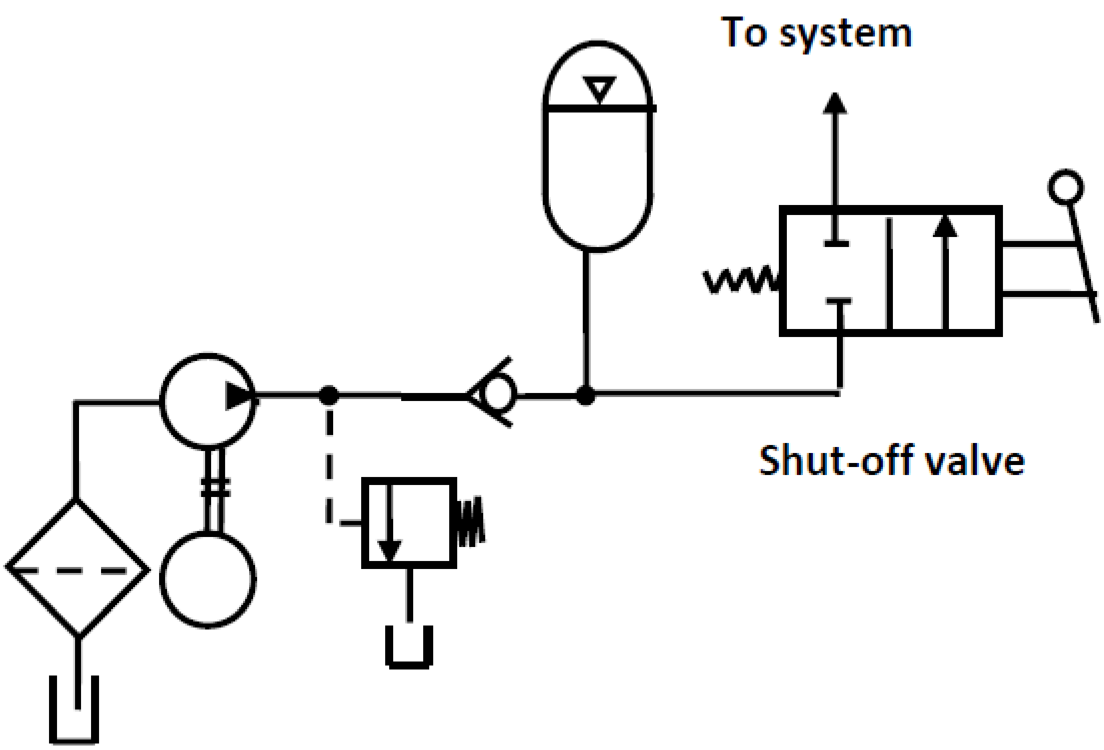


Figure 1.11 Accumulator as a hydraulic shock absorber.

One of the important applications of accumulators is the elimination of hydraulic shock.The schematic diagram is shown in Fig. 1.11. Hydraulic shock is caused by the sudden stoppage or declaration of a hydraulic fluid flowing at relatively high velocity in a pipe line. Rapidly closing a valve creates a compression wave. This compression wave travels at the speed of sound upstream to the end of the pipe and back again to the closed valve, which causes an increase in pressure.

The resulting rapid pressure pulsations or high-pressure surges may cause damage to the hydraulic system components. If an accumulation is installed near the rapidly closing valve, the pressure pulsations or high-pressure surges are suppressed.

5. Accumulator as a thermal expansion compensator:

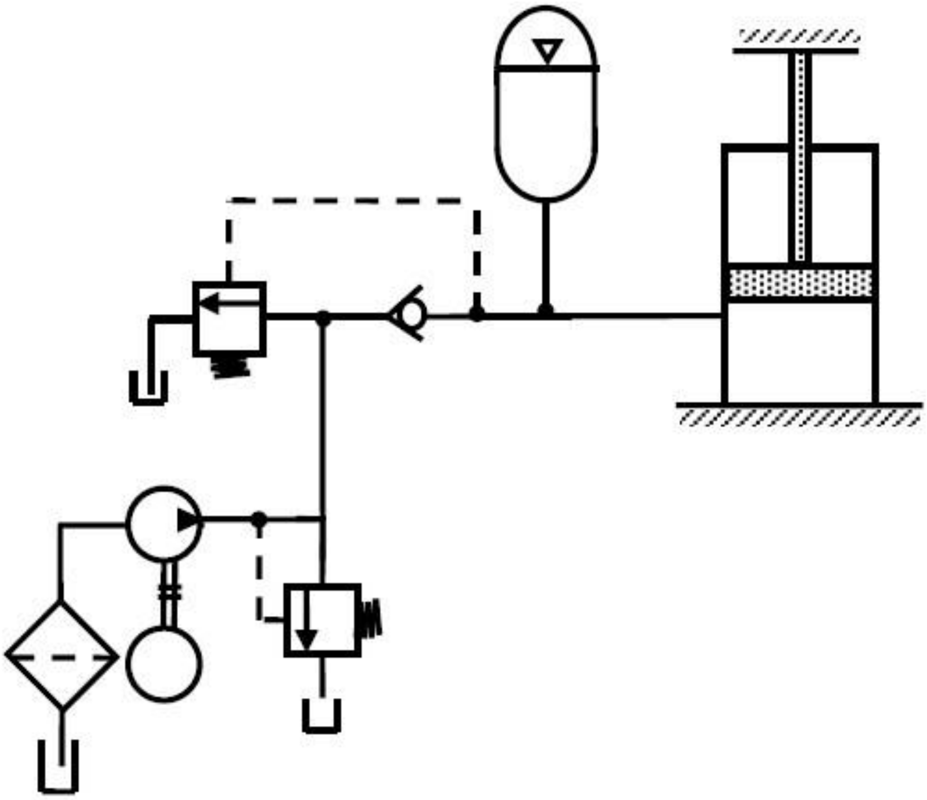


Figure 1.12 Accumulator as a thermal expansion compensator.

When closed-loop hydraulic systems are subjected to heat conditions, both the pipe lines and the hydraulic fluid expand volumetrically. Because the coefficient of cubical expansion of most fluids is higher than that for pipe material, this expanded liquid volume increases the entire system pressure. This condition may cause pressures to exceed the limits of safety and may damage the system components. Under these conditions, an accumulator of proper capacity pre-charged to the normal system working pressure is installed. It takes up any increase in the system fluid volume, thus reducing the system pressure to its safe limits. The accumulator also feeds the required volume into the system as thermal contraction takes place.The schematic diagram of such an arrangement is shown in Fig. 1.12.

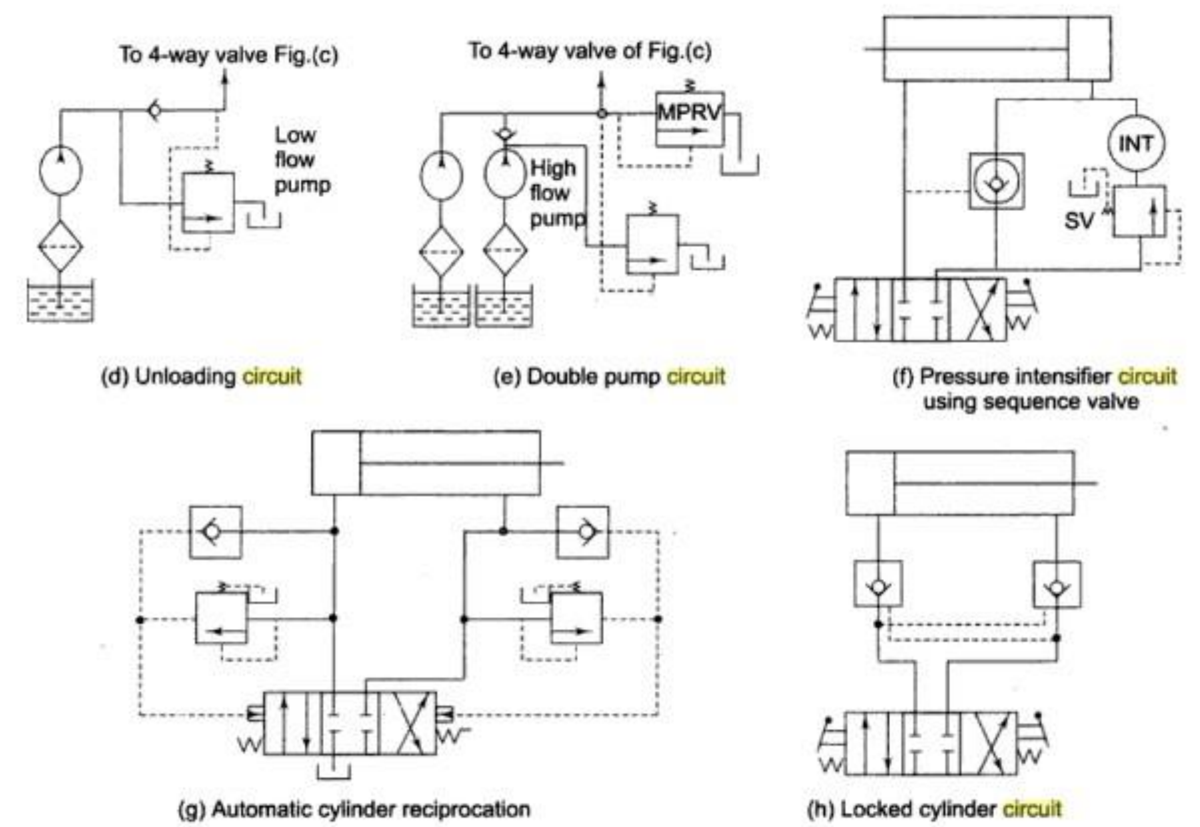


Fig. 10.10.18 Different hydraulic circuits

OSTATIC TRANSMISSION :

Figure are actually hydrostatic transmissions. They are called open-circuit drives because the pump draws its fluid from a reservoir. Its output is then directed to a hydraulic motor and discharged from the motor back into the reservoir.

Circuit Drives :

draws fluid from reservoir.
output directed to Hydraulic Motor.
arge from Motor into reservoir.

In a closed-circuit drive, exhaust oil from the motor is returned directly to the pump inlet. Figure 9-21 gives a circuit of a closed-circuit drive that allows for only one direction of motor rotation. The motor speed is varied by changing the pump displacement. The torque capacity of the motor can be adjusted by the pressure setting of the relief valve. Makeup oil to replenish leakage from the closed loop flows into the low-pressure side of the circuit through a line from the reservoir.

d Circuit Drive :

ust oil from the motor returned directly to pump inlet.

Circuit One-Direction Hydrostatic Transmission :

d Circuit that allows only one direction of motor rotation.

r speed varied by changing pump displacement.

e capacity of motor adjusted by pressure setting of the relief valve.

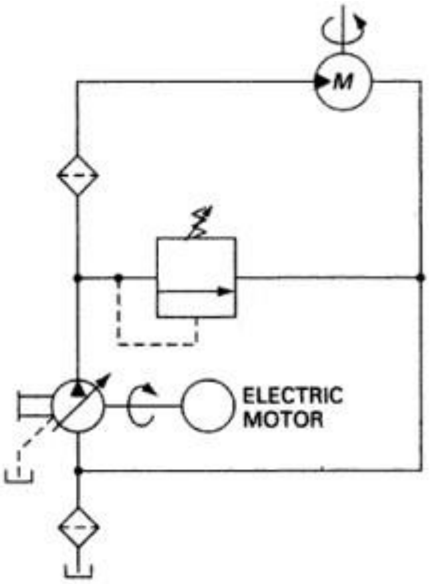


Figure 9-21. Closed-circuit one-direction hydrostatic transmission.

Circuit Reversible Direction Hydrostatic Transmission :

Many hydrostatic transmissions are reversible closed-circuit drives that use a variable displacement reversible pump. This allows the motor to be driven in either direction and at infinitely variable speeds depending on the position of the pump displacement control. Figure 9-22 shows a circuit of such a system using a fixed displacement hydraulic motor. Internal leakage losses are made up by a replenishing pump, which keeps a positive pressure on the low-pressure side of the system. There are two check and two relief valves to accommodate the two directions of flow and motor rotation.

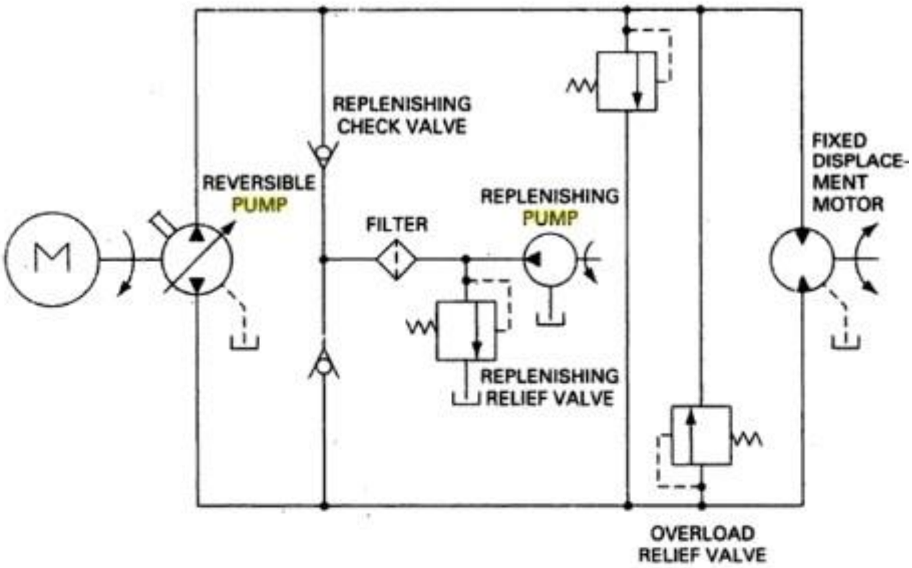


Figure 9-22. Closed-circuit reversible-direction hydrostatic transmission. *(Courtesy of Sperry Vickers, Sperry Rand Corp., Troy, Michigan.)*

UNIT IV PNEUMATIC AND ELECTRO PNEUMATIC SYSTEMS

Compressors- Filter, Regulator, Lubricator, *Muffler,* Air control Valves, Quick Exhaust valves, Pneumatic actuators, Servo systems. Introduction to Fluidics, Pneumatic logic circuits.

Pneumatic teclrnology 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:

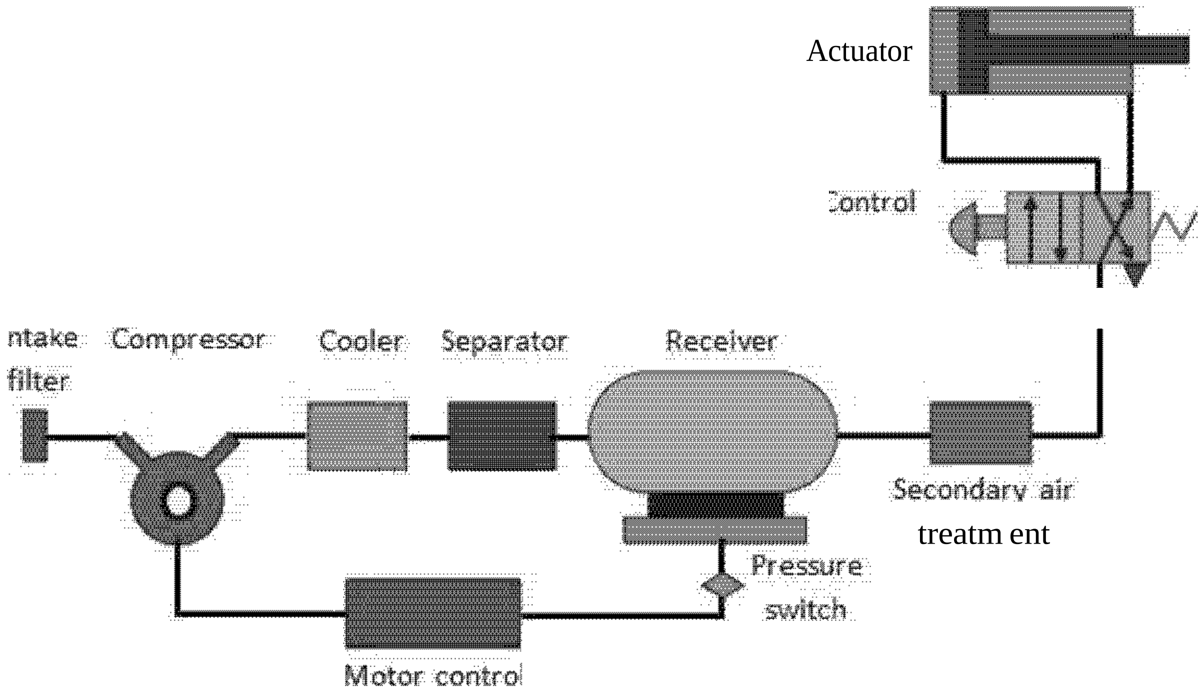


Fig. 6.1.1 Components of a pneumatic system

Important components of a pneumatic system are shown in fig.6.1.1.

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 corning 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 6.1.2. 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

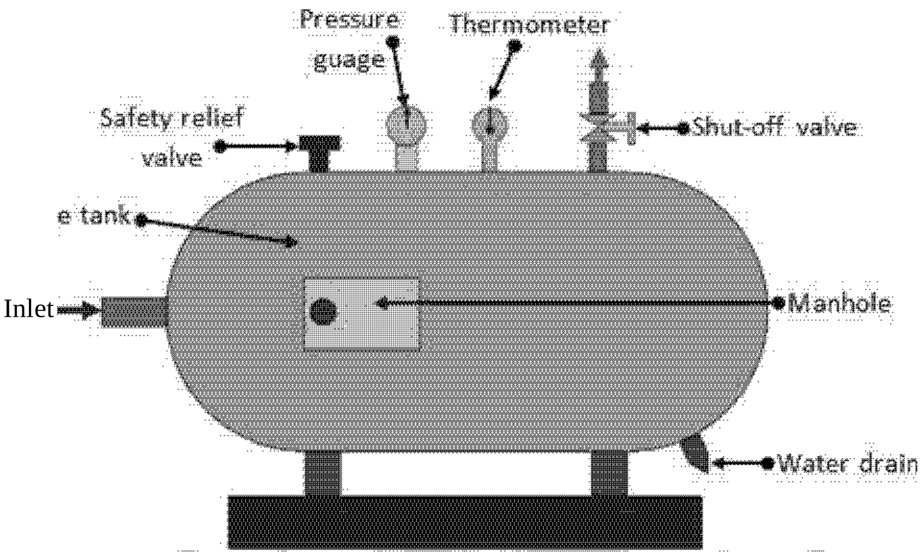


Fig.6. 1.2 Air receiver

COMPRESSORS:

It is a mechanical device which converts mechanical energy intD 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.

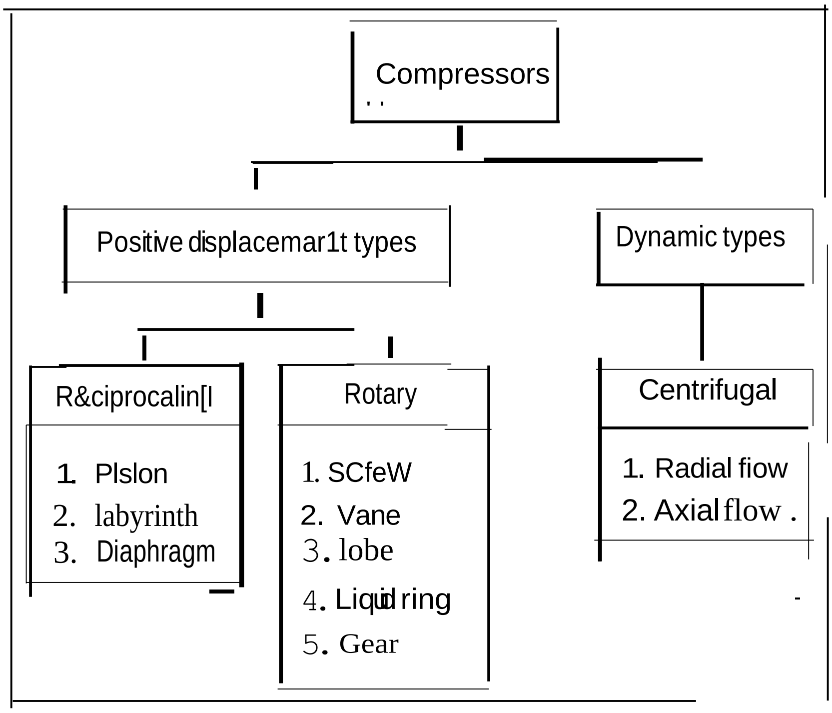
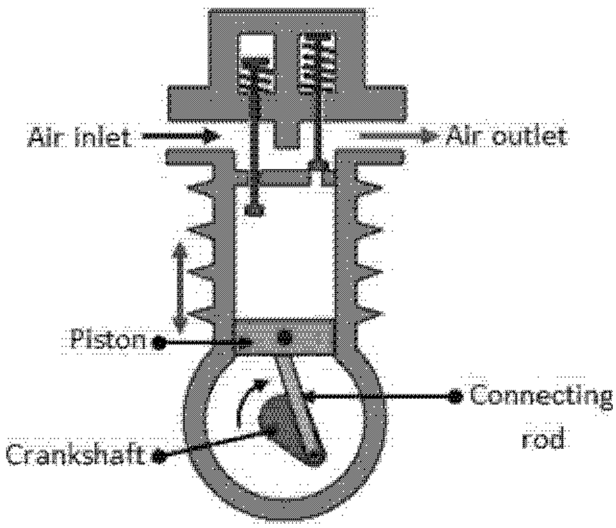


Fig. 11.J. Types (If air compressors

Piston compressors

Piston compressors are commonly used in pneumatic systems. The simplest form is single cylinder compressor (Fig. 6. L3). 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.



1. Diaphragm compressor

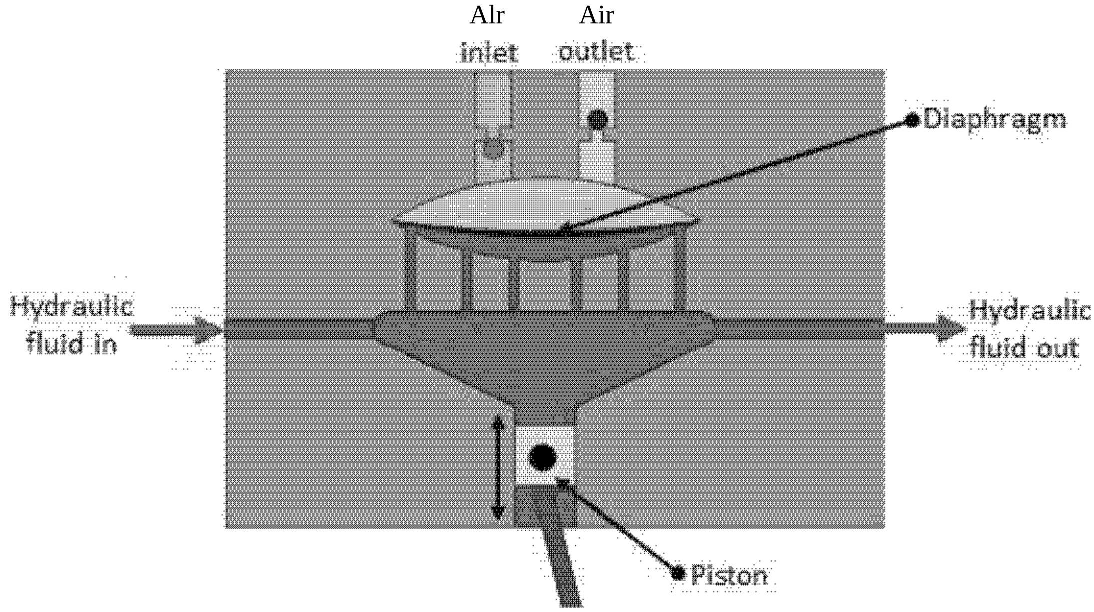


Fig. 6.2.1 Diaphragm compressor

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 6.2.1 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.

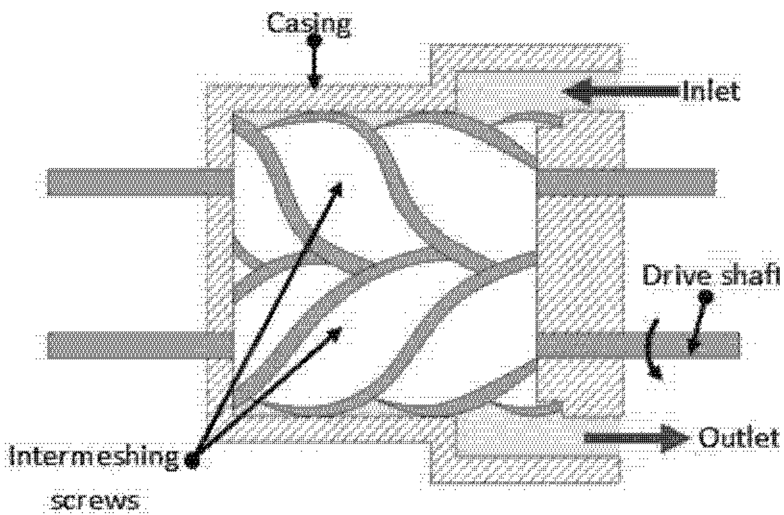


Fig. 6.2.2 Screw cmnrnre"<or

3. Rotary vane compressors

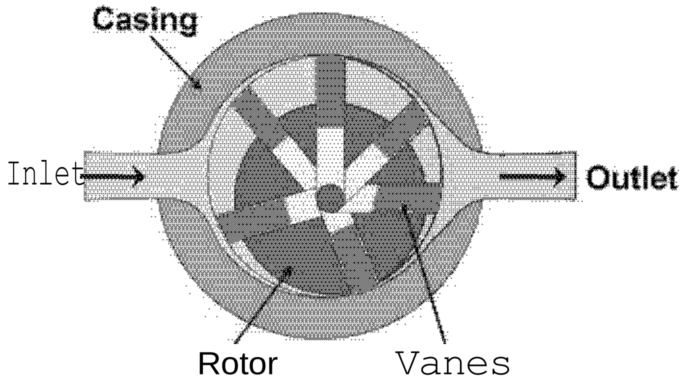


Fig. 6.2.3 Rotary vane compressor

The principle of operation of vane compressor is similar to the hydraulic vane pump. Figure 6.2.3 shows 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. Ifthe eccentricity is zero no flow takes place.

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 tluough 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.

Air filter and water trap is used to

- Prevent any solid contaminants from entering in the system.
- Condense and remove water vapour that is present in the compressed air.

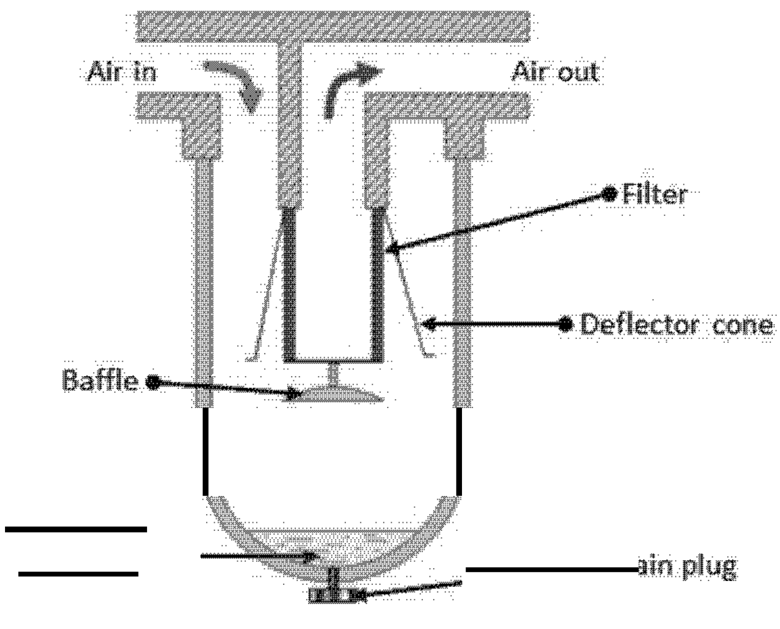


Fig. 6.3.2 Air filter and water trap

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.

Lubricators

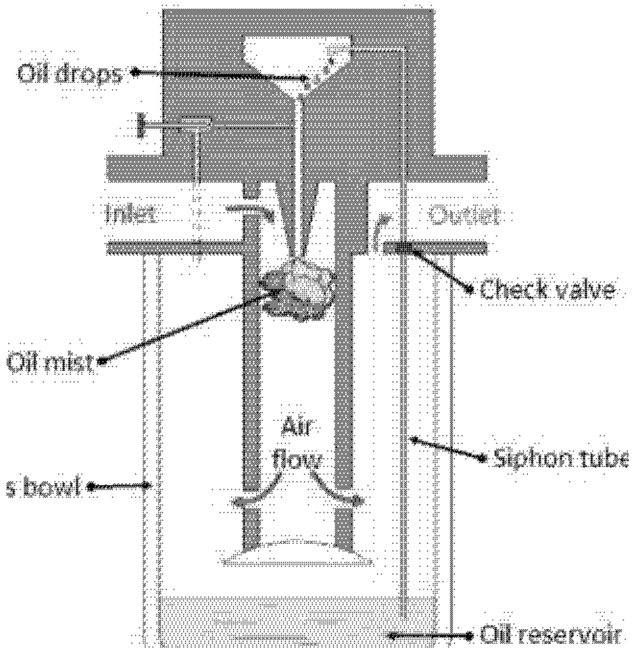


Fig. 6.3.6 Air lubricator

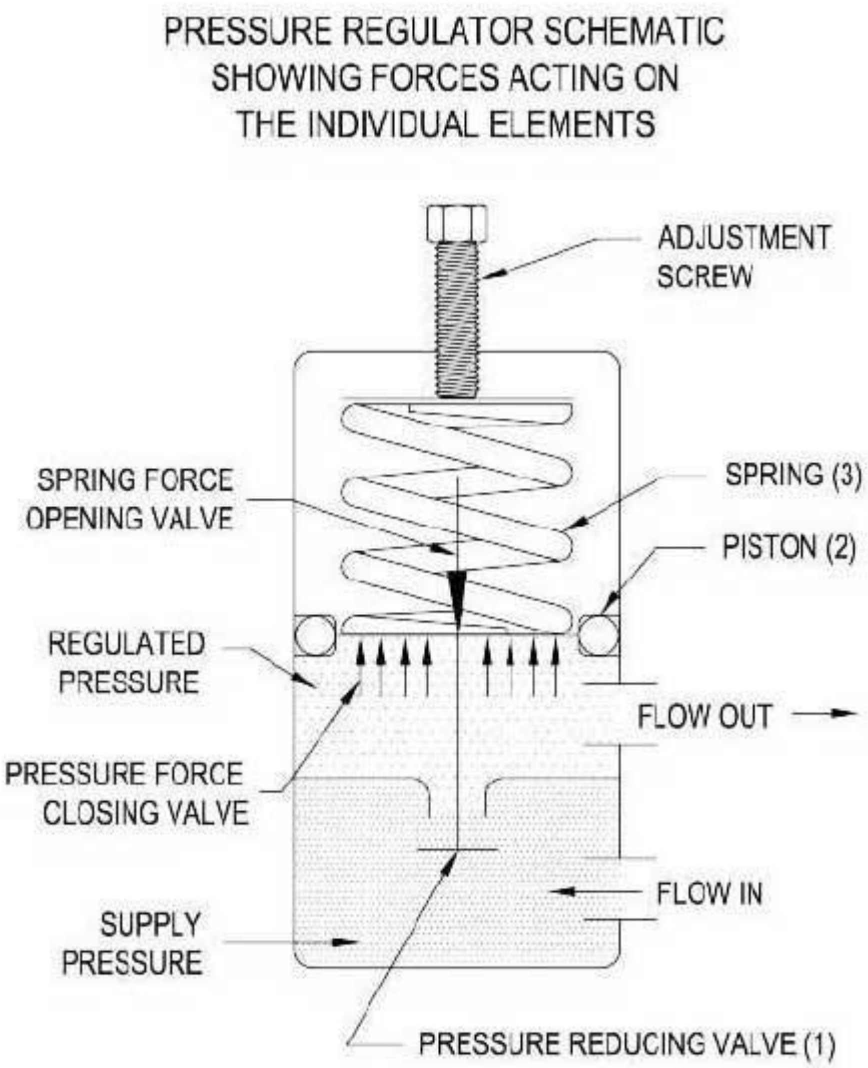
The compressed air is first filtered and then passed through a lubricator in order to form a mist of oil and air to provide lubrication to the mating components. Figure 6.3.6 shows the schematic of a typical lubricator. The principle of working of venturirneter is followed in the operation of lubricator. 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.

PRESSURE REGULATOR

A pressure regulator is comprised of three functional elements

1. A pressure reducing or restrictive element. Often this is a spring loaded poppet valve.
2. A sensing element. Typically a diaphragm or piston.
3. A reference force element. Most commonly a spring.

In operation, the reference force generated by the spring opens the valve. The opening of the valve applies pressure to the sensing element which in tum closes the valve until it is open just enough to maintain the set pressure. The simplified schematic "Pressure Regulator Schematic" illustrates this force balance arrangement. (see below)



(1) Pressure Reducing Element (poppet valve)
Most commonly, regulators employ a spring loaded "poppet" valve as a restrictive element. The poppet includes an elastomeric seal or, in some high pressure designs a thermoplastic seal, which is configured to make a seal on a valve seat. When the spring force moves the seal away from the valve seat, fluid is allowed to flow from the inlet of the regulator to the outlet. As the outlet pressure rises, the force generated by the sensing element resists the force of the spring and the valve is closed. These two forces reach a balance point at the set point of the pressure regulator. When the downstream pressure drops below the set-point, the spring pushes the poppet away from the valve seat and additional fluid is allowed to flow from the inlet to the outlet until the force balance is restored.

(2) Sensing Element (piston or diaphragm)
Piston style designs are often used when higher outlet pressures are required, when ruggedness is a concern or when the outlet pressure does not have to be held to a tight tolerance. Piston designs tend to be sluggish, as compared to diaphragm designs, because of the friction between the piston seal and the regulator body.

In low pressure applications, or when high accuracy is required, the diaphragm style is preferred. Diaphragm regulators employ a thin disc shaped element which is used to sense pressure changes. They are usually made of an elastomer, however, thin convoluted metal is used in special applications. Diaphragms essentially eliminate the friction inherent with piston style designs.

Additionally, for a particular regulator size, it is often possible to provide a greater sensing area with a diapluagrn design than would be feasible if a piston style design was employed.

(3) The Reference Force Element (spring)

The reference force element is usually a mechanical spring. This spring exerts a force on the sensing element and acts to open the valve. Most regulators are designed with an adjustment which allows the user to adjust the outlet pressure set-point by changing the force exerted by the reference spring.

Regulator Accuracy and Capacity

The accuracy of a pressure regulator is determined by charting outlet pressure versus flow rate. The resulting graph shows the drop in outlet pressure as the flow rate increases. This phenomenon is known as droop. Pressure regulator accuracy is defmed as how much droop the device exhibits over a range of flows; less droop equals greater accuracy. The pressure versus flow curves provided in the graph "Direct Acting Pressure Regulator Operating Map", indicates the useful regulating capacity of the regulator. When selecting a regulator, engineers should examine pressure versus flow curves to ensure the regulator can meet the performance requirements necessary for the proposed application.

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 tluee 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

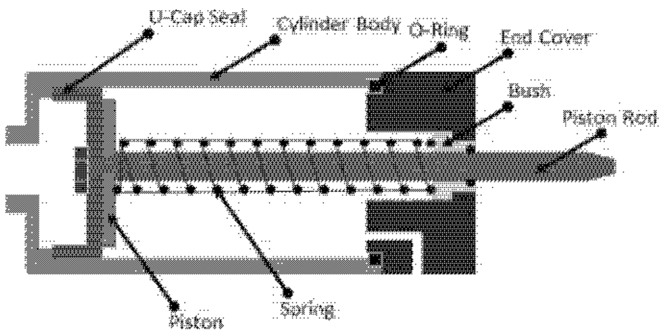


Fig. 6.4.1 Single acting cylinder

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

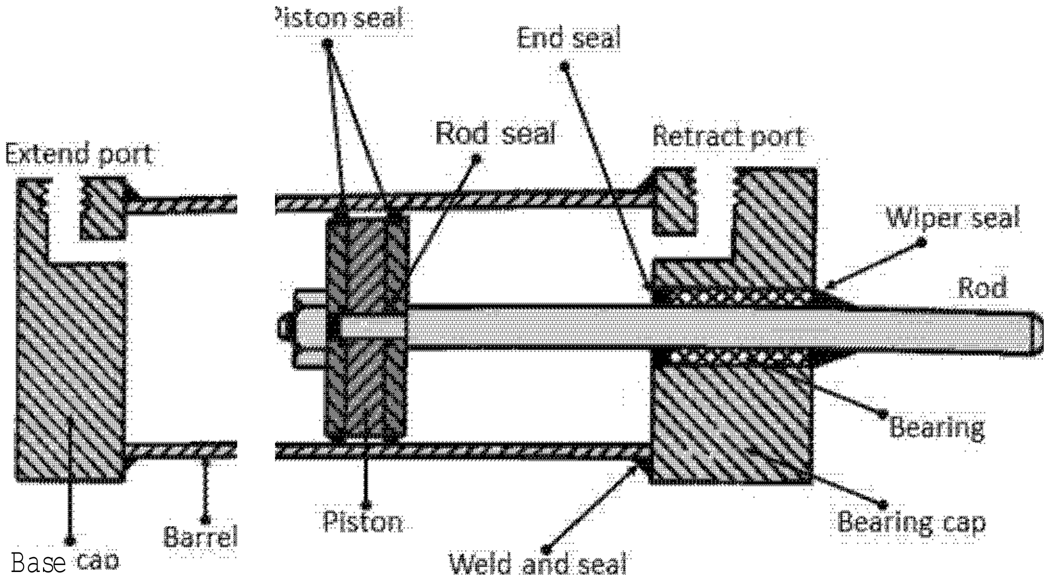


Fig. 6.4.2 Double acting cylinder

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

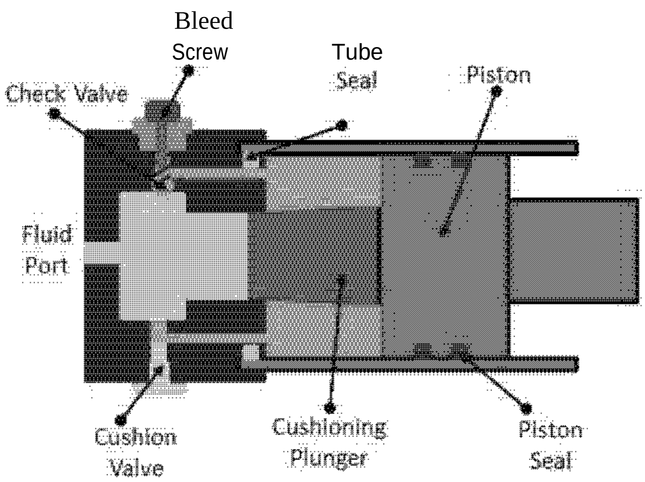


Fig. 6.4.3 Cylinder end cushioning

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.

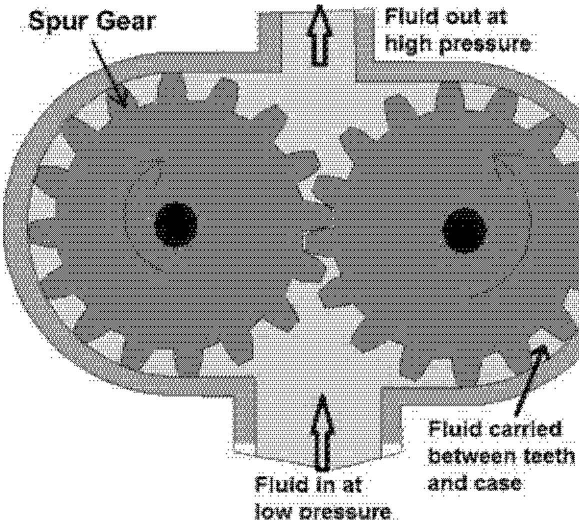


Fig. 6.4.4 Gear motor

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).

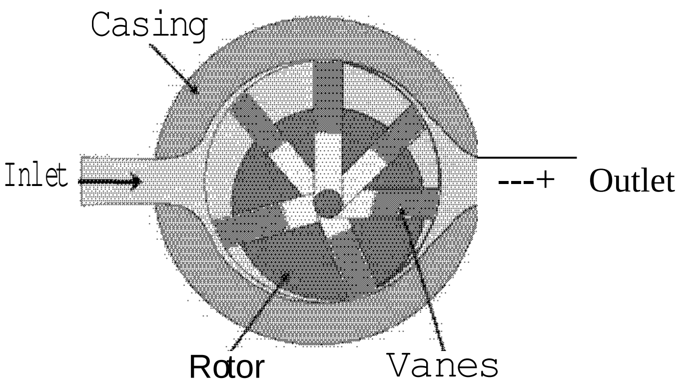
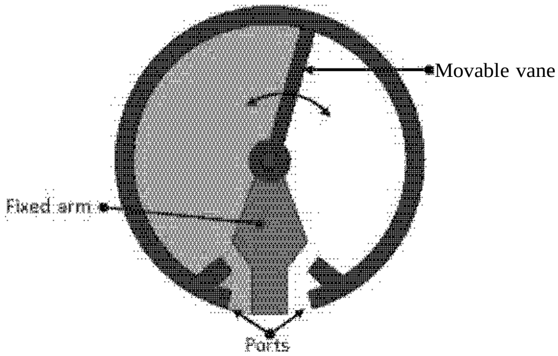


Fig. 6.4.5 Vane motor

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.



MUFFLER

11.10.1. What are Mufflers ?

- *Function :* The function of muffler (also known as pneumatic exhaust silencer) is to control the noise caused by a rapidly exhausting air-stream flowing into the atmosphere.
- Noise created by air exhausting from an air system not only cause nervous tension and dissatisfaction among the operators, but also results in mental fatigue, lack of concentration, and inefficiency. This exhaust noises can be greatly reduced by installing a muffler at each pneumatic exhaust port.

11.10.2. Construction and Operation

The construction and opention of a typical pneumatic silencer is illustrated in Fig. 11.13(a).

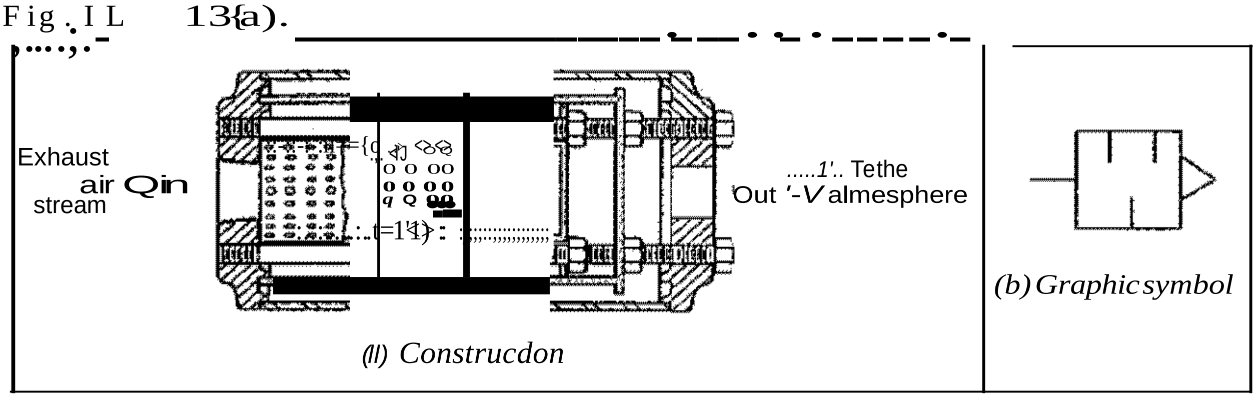


Fig. 11.13. Muffler

As shown in Fig. 11.13 *(a),* the exhaust air stream enters one end, and passes out the another end after passing through a series of baffles. The baffle tuhes are perforated with a large number of small holes. The outer shell acts as a barrier and helps guide the stream toward the exit to the atmosphere.

AIR CONTROL VALVES

Valve are defined as devices to control or regulate the commencement, termination and direction and also the pressure or rate of flow of a fluid under pressure which is delivered by a compressor or vacuum pump or is stored in a vessel.

Values of one sort or another, perform three main function in pneumatic installation

- They control the supply of air to power units, example cylinders
- They provide signal which govern the sequence of operation
- They act as interlock and safety devices

The type of valve used is of little importance in a pneumatic control for most part. What is important is the function that can be initiated with the valves, its mode of actuation and line connection size, the last named characteristics also determining the flow size of the valve. Valves used in pneumatics mainly have a control function that is when they act on some process, operation or quantity to be stopped. A control function requires control energy, it being desirable to achieve the greatest possible effect with the least effort. The form of control energy will be dictated by the valve's mode of actuation and may be manual, mechanical, electrical hydraulic or pneumatic.

Valve available for pneumatic control can be classified into four principal groups according to their function:

1. Direction control valve
2. Non return valves
3. Flow control valves
4. Pressure control valves

1.2 DIRECTION CONTROL VALVES

Pneumatic systems like hydraulic system also require control valves to direct and regulate the flow of fluid from the compressor to the various devices like air actuators and air motors. In order to control the movement of air actuators, compressed air has to be regulated, controlled and reversed with a predetermined sequence. Pressure and flow rates of the compressed air to be controlled to obtain the desired level of force and speed of air actuators.

The function of directional control valve is to control the direction of flow in the pneumatic circuit. DCVs are used to start, stop and regulate the direction of air flow and to help in the distribution of air in the required line.

6.2.1 TYPES OF DIRECTION CONTROL VALVES

Directional valves control the way the air passes and are used principally for controlling commencement, termination and direction of air flow. The different classification scheme of the pneumatic cylinders are given below

1. Based on construction

i) Poppet or seat valves
- Ball seat valve
- Disc seat valve
- Diaphragm Valves

ii) Sliding spool valves
- Longitudinal slide valve
- Suspended spool valves

- Rotary spool valves

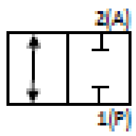
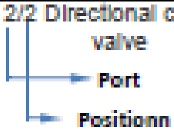
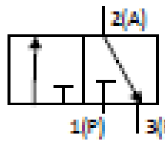
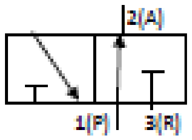
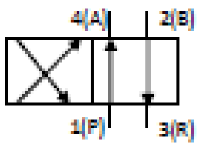
Based on the Number of ports :
i) Two way valves
ii) Three way valves
iii) Four way valves

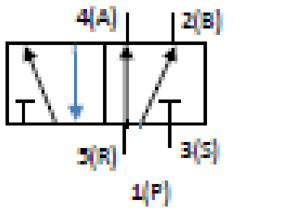
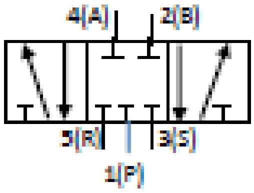
ISO DESIGNATION OF DIRECTION CONTROL VALVES

Valves are represented by symbols because actual construction is quite complex. A symbol specifies function of the valve, method of actuation, no of ports and ways. Pneumatic symbols have been standardised in ISO 1219-1:2006. (Fluid power systems and components – Graphic symbols and circuit diagram).

Port	Old (Letter) system	ISO (Number) System	Remarks
Pressure port	P	1	Supply port
Working port	A	2	3/2 DCV
Working ports	A, B	4, 2	4/2 or 5/2 DCV
Exhaust port	R	3	3/2 DCV
Exhaust ports	R, S	5,3	%/2 DCV
Pilot ports	Z or Y	12	Pilot line (flow 1-2)
Pilot ports	Z	14	Pilot line (flow 1-4)
Pilot ports	Z or Y	10	Pilot line (no flow)
Internal pilot ports	Pz, Py	81, 91	Auxiliary pilot line

Ports and position: DCVs are described by the number of port connections or ways they control. For example: Two way, three – way, four way valves. Table shows the Port markings of DCVs and Table shows commonly used DCVs with old and new designations.

Port and position	
	2/2 Directional control valve 
	3/2 Directional control valve (normally closed)
	3/2 Directional control valve (normally open)
	4/2 Directional control valve

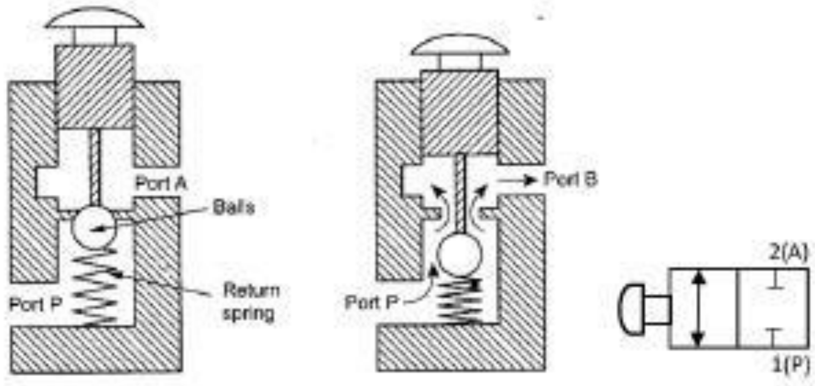
	5/2 Directional control valve
	5/3 Directional control valve

POPPET DIRECTION CONTROL VALVES

There are two different types of poppet valves, namely ball seat valve and disc seat valve.

A.Ball seat valve.

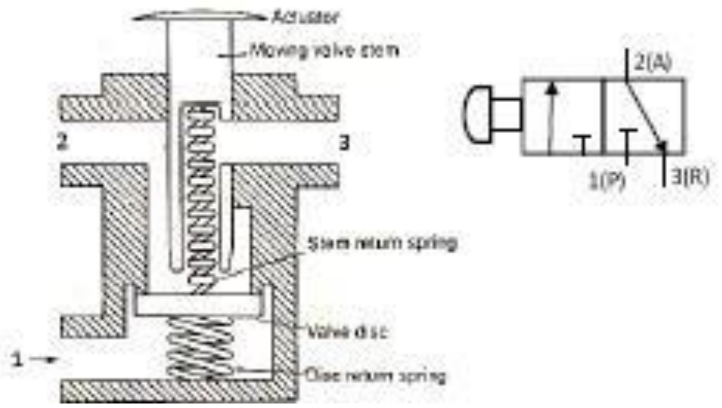
In a poppet valve, discs, cones or balls are used to control flow. Figure 1.1 shows the construction of a simple 2/2 normally closed valve. If the push button is pressed, ball will lift off from its seat and allows the air to flow from port P to port B. When the push button is released, spring force and air pressure keeps the ball back and closes air flow from port P to port B. Valve position are shown in Figure 1.1(a) 1.1 (b) 1.1(C)



(a) Poppet position 1 *(b) Poppet position 2* (c) Symbol

B. Disc seat poppet valve

Figure 1.2 shows the construction of a disc type 3/2 way DCV. When push button is released, ports 1 and 3 are connected via hollow pushbutton stem. If the push button is pressed, port 3 is first blocked by the moving valve stem and then valve disc is pushed down so as to open the valve thus connecting port 1 and 3. When the push button is released, spring and air pressure from port 1 closes the valve.



Advantages of poppet valves are as follows
i) Response of poppet valve is very fast- short stroke to provide maximum flow opening

ii) They give larger opening (larger flow) of valves for a small stroke

iii) The valve seats are usually simple elastic seals so wear is minimum

iv)) They are insensitive to dust and dirt and they are robust, seats are self cleaning

v) Maintenance is easy and economical.

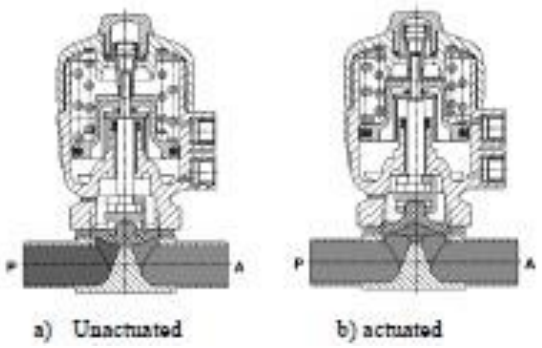
vi) They are inexpensive

vii) They give longer service life: short stroke and few wearing parts give minimum wear and maximum life capabilities

Disadvantages of poppet valves are as follows
i) The actuating force is relatively high, as it is necessary to overcome the force of the built in reset spring and the air pressure.

ii) They are noisy if flow fluctuation is large.

C.Diaphragm valves
The diaphragm between the actuator and valve body hermetically isolates the fluid from the actuator.
The valves are maintenance-free and extremely robust and can be retrofitted with a comprehensive range of accessories, e.g. electrical position feedback, stroke limitation or manual override.



Closed position: When de-energized, the valve is closed by spring action
Open position: If the actuator is pressurized by the control pressure, it simultaneously lifts the control piston and the valve spindle to open the valve.

112.4.2. _Two-Way Valves

12.4.2..1.Consbruction and Operatio:n

_ The construe and operation of an .aiir-piloted *(i.e.,* air-operated),. n.Vo-;"ray pneumatic "\1'JE"eis: ilhlstr.ated m F'ing..12..2.

Bag,]caJlly two-way valve is an 01-0ff type 'i'alve. This *212* 'Way has two ports "(a smppty port and an exhaust port) Bil'ild tvli'O positions (open and closed).As shown m Fiig.]2.2, 212 way alve iis a\rail bfe to operare eilher normatlly open or normally closed comfitions..

:--_A mmnally open two-way valve {fig_-12.2(a)) perrnifs How iim. its: no:nM!al or in its rest positco111 and bfocks fiow when actuated. The twnnaTmy closed valve (fig.12.2(li)) bkd:: fki.w _jP,jts nomta] position and permits How v.i-hen actuared.

;J, .Tnese valves have lone: l:iifeamd can be used li:o haml'.le df'lii' and Inhnted .:a:iir

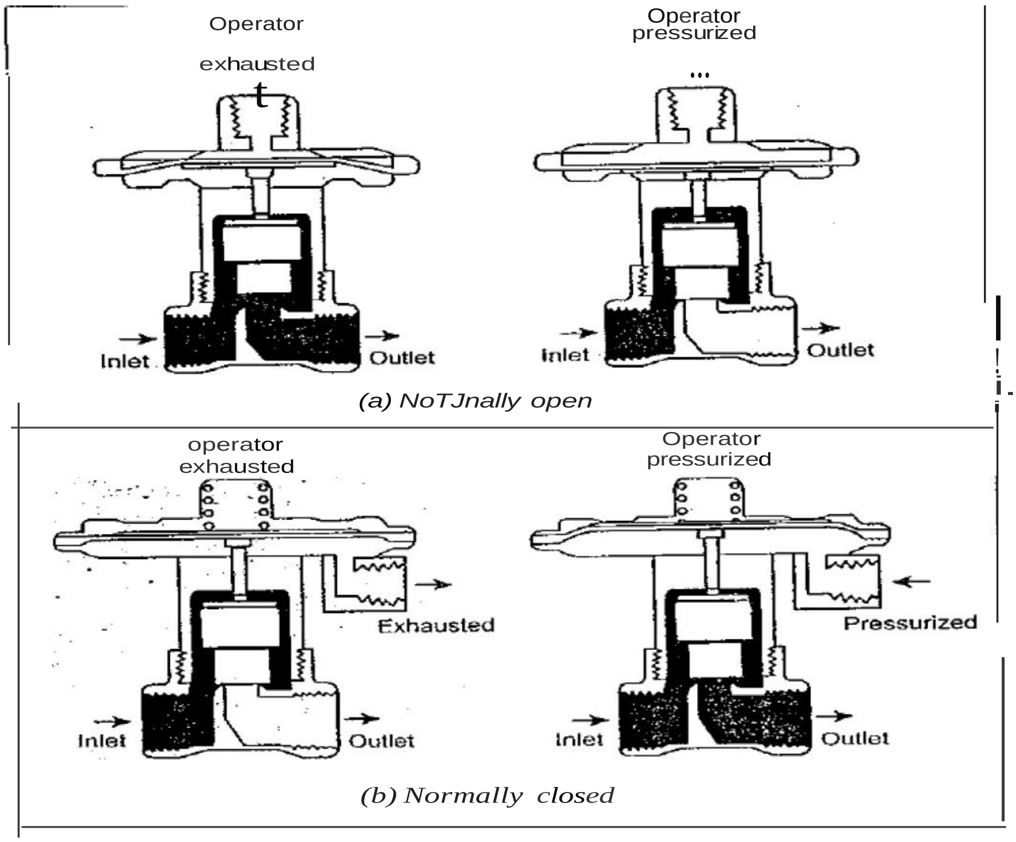


Fig. / 2.2. Two-way, air-pilote1/ vctlve

124.3. Three-Way Valves

The th.-ee-way type .:..atves have three ports an inlet, an exhaust, and a cylinder port.

12431. Construction and Operation

The construct1011 and operation of a typ1caI poppet-type three-way two-posit_ion *(i.e.,* 312) pneumatic valve i illustrated in Fig. 12.3(a). Fig. 12.J(b) shows the graphic symbol- of the 312 way valve.

As cotild be seen from Fig.12.3(a) that one flO'\.v port is connected to eithe1-of the other two ports. This valvemay aiso be used to pressurise one port and exhaust the other por:t. Thus these valves can-be usd as a pilotelay to operate the other valves.

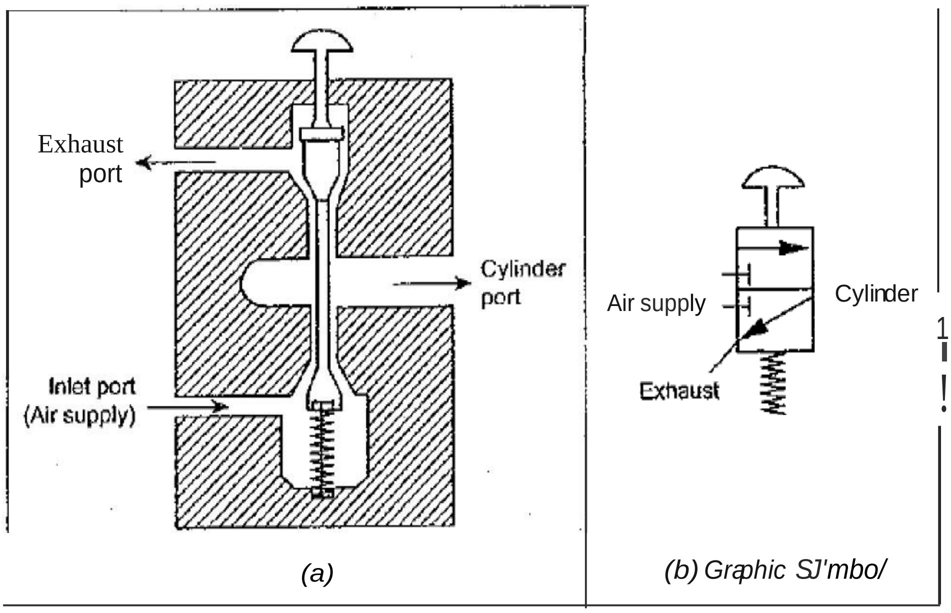


Fig. 123.312 way DC valve

12.4.4. Four-Way Valves

The four way type valves have four ports-an inlet, an exhaust. and two cylinder ports.

12.4.4.1. Construction and 013eration

The construction and operation .of a typical valve-seat type four-way two-position *(i.e.,* 4/2) pneumatic valve is illustrated in Fig.12.4(a). Fig.l*2.4(b)* shows the graphic symbol of the 4/2 way valve.

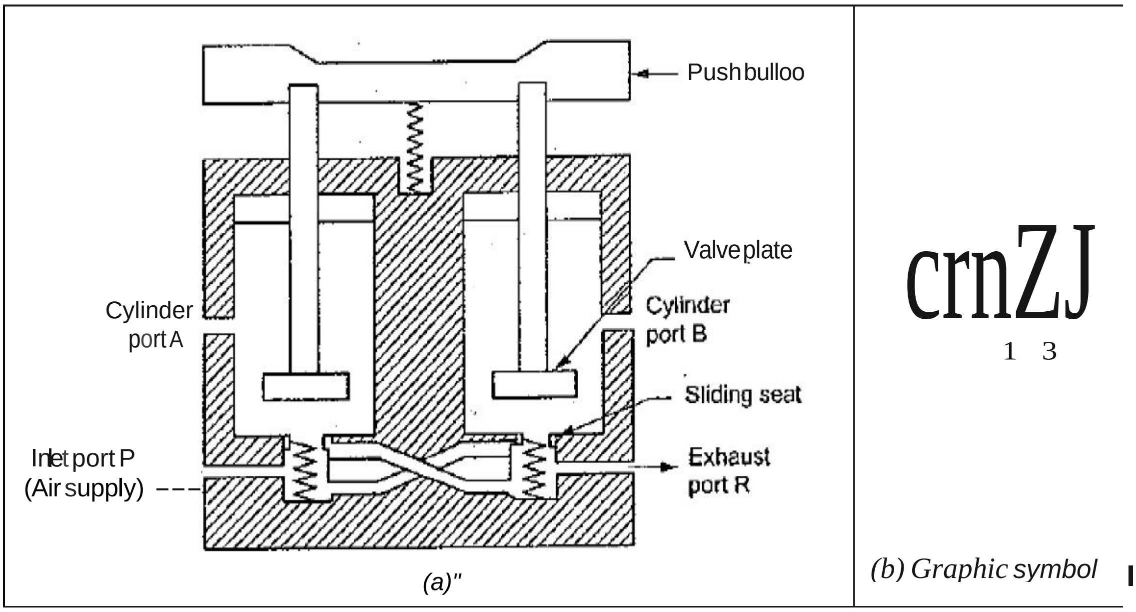


Fig. I2.4. 41 WflY DC valve

As shown in Fig.12-4. the inlet port P connects to cylinder ports A and B to exhaust port R. When the va1ve clements are actuated by means of the push button, they are unseated and port P connects to cylinder ports .B and A to exhaust port R.

[Note |Generally two way DC valves are used as on-off type valves; thne way DC valves are used to control single-acting linear acluator5: and four way DC valves are used to control double-acti11g actuators.

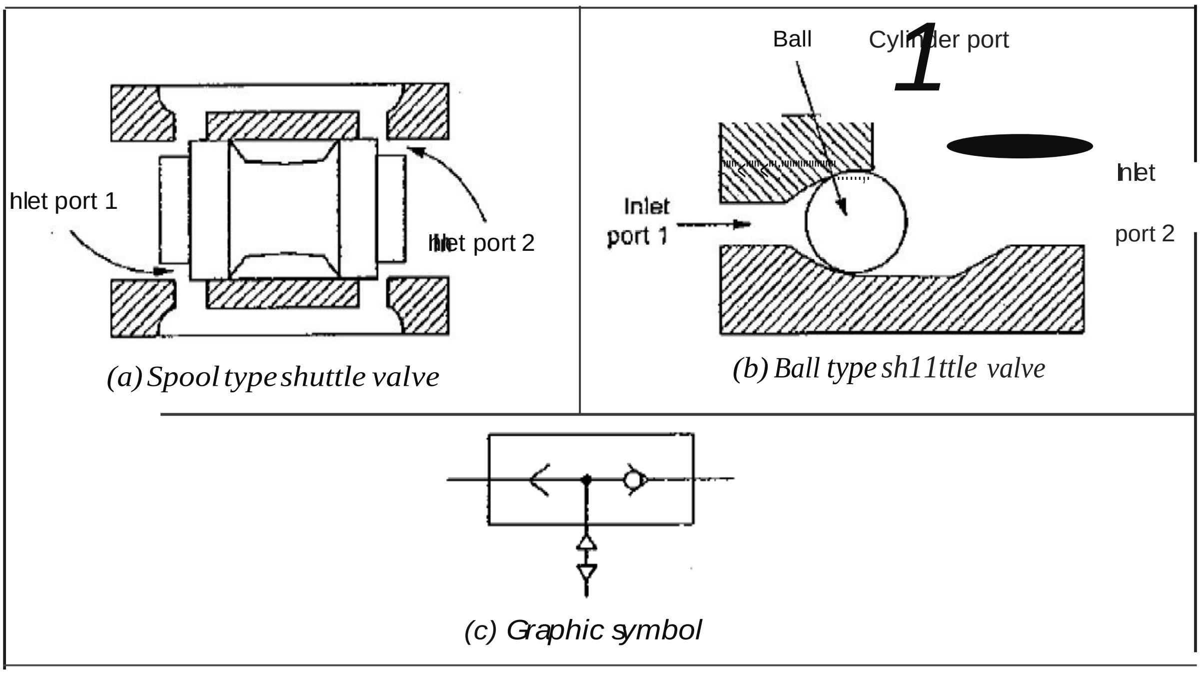
12:5. SHUTI EVALVES

12.5.1 What are Shuttle Valves'?

- *Shuttle valves; also knqwn as double c/1e,ck valves, are used when conlrol is required from more than one pmver source.*
- In other words, shuttle valves are used to select the higher of the two input pressures automatically and c0n11e to output port. This valve is a"tso known as 'OR GATE'_

1252. Construction an Operaion

The construction and operation of a typical three port spool-type shuttle valve is illustrated in Fig.12.S(a). The alternaive ball-type shuttle valve for the same purpose is sl1bwn in Fig.12.S(b).



(a) Spool type shuttle valve (b) Ball type sh11ttle valve (c) Graphic symbol

Fig. 125. Slluttle vall•e

As shown in Figs. I2.5(a) and (b), this val\.'.e consists of two inlet pots and one outlet port. As long as pressure in the right inlet port is greater than tile left, the spool (or ball) closes the left port. When pressure at the left port becomes greater than at the right, the spool (or ball) moves to the right, closing the right port and opening the left.

Quick Exhaust Valves

A quick exhaust valve is a typical shuttle valve. The quick exhaust valve is used to exhaust the cylinder air quickly to atmosphere. Schematic diagram of quick exhaust valve is shown in Figure 1.38. 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. The higher speed of the piston is possible by reducing the resistance to flow of the exhausting air during the motion of cylinder. The resistance can be reduced by expelling the exhausting air to the atmosphere quickly by using Quick exhaust valve.

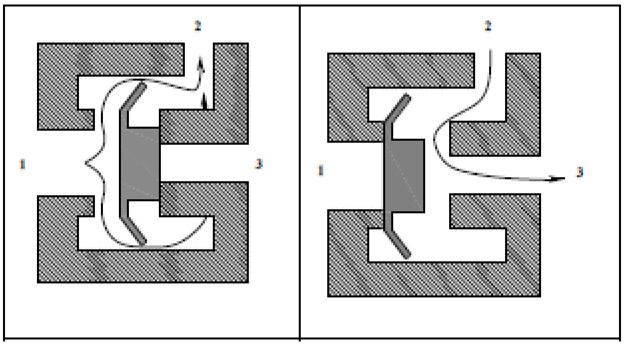


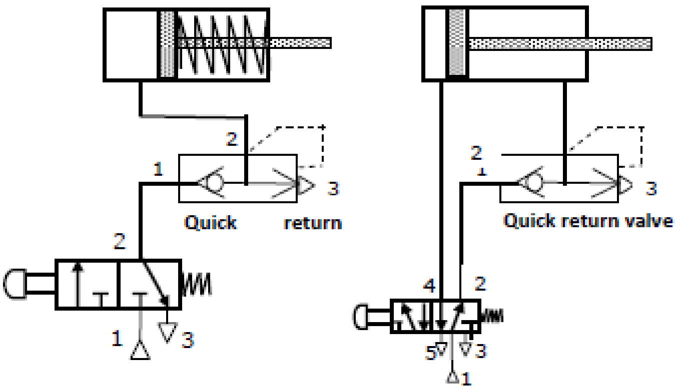
Figure 1.38 Functional diagram of quick exhaust valve.

The construction and operation of a quick exhaust valve is shown in Figure 1.38. It consist of a movable disc (also called flexible ring) and three ports namely, Supply port 1, which is connected to the output 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

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.

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

Typical applications of quick exhaust valves for single acting and double acting cylinders are shown in Figure 1.39



1.2.3 FLOW CONTROL VALVES

Function of a flow control valve is self –evident from its name. A flow control valve regulates the rate of air flow. The control action is limited to the air flow passing through the valve when it is open, maintaining a set volume per unit of time. Figure 1.41(a) shows a variable restrictor type flow control valve (manifold type). Figure 1.41(b) shows a variable restriction type flow control valve (inline type). Figure 1.42 shows another design of Flow control valve, in which flow can be set by turning the knob.

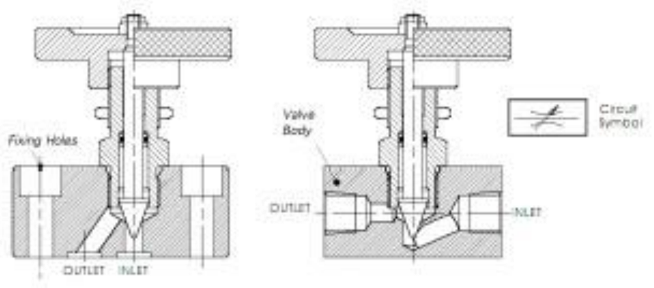


Figure 1.41 Flow control valve a) manifold b) inline

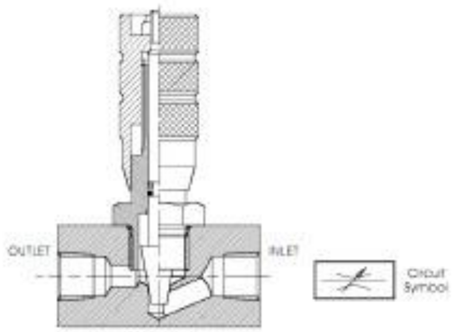


Figure 1.42 Flow control valve (adjustable)

1.2.4 PRESSURE CONTROL VALVE.

Compared with hydraulic systems, few pressure control valves are brought into use in pneumatics. Pressure control valves control the pressure of the air flowing through the valve or confined in the system controlled by the valve.

There are three types of pressure control valves

1. Pressure limiting valve
2. Pressure sequence valve
3. Pressure regulator or pressure reducing valve

A.Pressure limiting valve.

Prevents the pressure in a system from rising above a permissible maximum. Construction feature of pressure limiting valve is shown in Figure 1.43. It is a standard feature of compressed air production plant but is hardly ever used in pneumatic controls. These valves perform a safety relief function by opening to the atmosphere if a predetermined pressure is exceeded in the system, thus releasing the excess pressure. As soon as the pressure is thus relieved to the desired figure, the valve closed again by spring force.

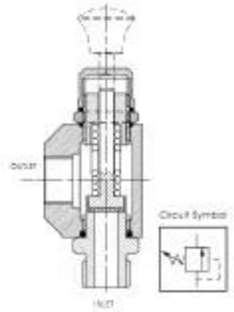


Figure 1.43 Pressure limiting valve

B.Pressure sequence valve

Function of the sequence valve is very similar to that of a pressure limiting valve. It is however used for a different purpose. Outlet of the pressure sequence valve remains closed until pressure upstream of it builds up to a predetermined value. Only then the valve opens to permit the air from inlet to outlet. Sequence valve must be incorporated into a pneumatic control where a certain minimum pressure must be available for a given function and operation is not be initiated at any pressure lower than that. There are also used in systems containing priority air consumers, when other consumers are not to be supplied with air until ample pressure is assured.

C.Pressure reducing valve or regulator

Pressure regulators, commonly called pressure-reducing valves, maintain constant output pressure in compressed-air systems regardless of variations in input pressure or output flow. Regulators are a special class of valve containing integral loading, sensing, actuating, and control components. Available in many configurations, they can be broadly classified as general purpose, special purpose, or precision. Three dimensional view of pressure reducing valve is shown in Figure 1.44

General-purpose or utility regulators have flow and regulation characteristics that meet the requirements of most industrial compressed-air applications. Such regulators provide long service life and relative ease of maintenance at competitive prices. Precision regulators are for applications where regulated pressure must be controlled with close tolerances. Such regulators are used when the outcome of a process or the results of a test depend on accurate pressure control.

Special-purpose regulators often have a unique configuration or special materials for use with fluids other than compressed air. Regulator construction can range from simple to complex, depending on the intended application and the performance requirements.

However, the principle of operation and the loading, actuating, and control components are basic to all designs. Most regulators use simple wire coil springs to control the downstream pressure. Various size springs are used to permit regulation of the secondary pressure within specific ranges. Ideally, the required pressure should be in the center one-third of the rated outlet pressure range. At the lower end of the pressure range, the spring loses some sensitivity; at the high end, the spring nears its maximum capacity.

Regulators can use either a piston or diaphragm to sense downstream pressure. Diaphragms are generally more sensitive to pressure changes and react more quickly. They should be used where sensitive pressure settings are required (less than 0.0025 bar). Pistons, on the other hand, are generally more rugged and provide a larger effective sensing area in a given size regulator. The functional difference between precision and general-purpose regulators is the degree of control accuracy of the output pressure. Output pressure accuracy is determined by the droop due to flow changes (regulator characteristics).

Pressure droop is most pronounced when the valve first opens. Factors contributing to droop are: load change with spring extension, effective area change with diaphragm displacement, and unbalance of area forces on the valve. The amount that output pressure changes with variations in supply pressure is called the regulation characteristic and is influenced by the ratio of diaphragm area to valve area and the degree of valve unbalance.

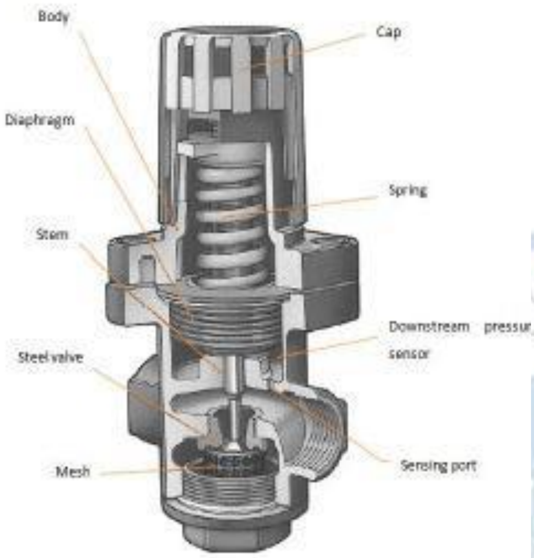


Figure 1.44 Three dimensional figure of pressure regulating valve

SERVO SYSTEMS:

14.2.1. What is a Servo System ?

- ✓ In general, a system in which a small input force is capable to control a larger output force is called as a servo system.
- ✓ ***Definition :*** *A servo control systems is one in which a comparatively large amount of power is controlled by small impulses or command signals and any errors are corrected by feedback signals.*
- ✓ As stated in the above definition, a servo system should provide both signal amplification and automatic correction of any deviation that may take place between the output quantity and quantity set by the command signal.
- ✓ Basically most of the servo systems are closed-loop systems.

14.2.2. Elements of a Basic Closed-Loop Servo System

Fig.14.1 shows a block diagram of a basic closed-loop servo circuit.

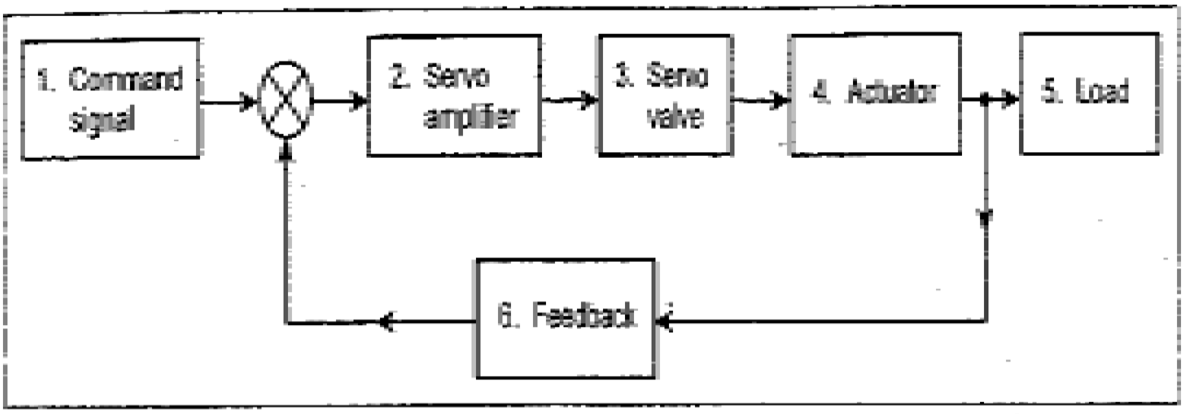


Fig. 14.1. A block diagram of a basic closed-loop servo circuit

*1. **Command signal :*** The command signal may be derived from a punched card, a tape, a tachometer, a potentiometer, or some other device.

*2. **Servo amplifier :*** The servo amplifier receives a low-power input signal and amplifies it to a higher power level.

*3. **Servo valve :*** The servo valve receives the output signal from the amplifier to actuate the servo valve torque motor.

*4. **Actuator :*** The actuator could be linear (hydraulic/pneumatic cylinder) or rotary (hydraulic/air motor).

*5. **Load***

*6. **Feedback transducer :*** The feedback transducer can be a linear variable differential transformer (LVDT), a tachometer, a potentiometer, or a synchro. This device measures the results at the load and sends a feedback signal to the amplifier unit. The feedback signal is compared with the command signal. If there exists a difference (also called 'error'), a hydraulic/pneumatic correction is automatically made that will bring the output signal into correspondence with the input.

The difference between the output signal and the command signal is called the ***'error signal'***. When the error signal is zero, the ideal condition exists. The purpose of the servo system is to bring the error signal to zero.

14.2.3. Servomechanism

A system having a servo valve, servo amplifier and actuator connected together providing a closed loop feedback is known as a servomechanism.

INTRODUCTION TO FLUIDICS

Fluid logic A means of implementing logic functions, not by the normal use of electronic circuitry but by the flow of incompressible fluids (liquids) or gases through tubing containing intersections and constrictions. The logic gates so formed are useful in situations in which high electromagnetic interference prevents the use of electronic components. If the working medium is a gas, the term pneumatic logic is often used.

15.3. PRINCIPLE OF FLUIDIC LOGIC CONTROL ('Coanda Effect' or 'Wall-Attachment' Effect)

15.3.1. What is a 'Coanda Effect' ?

✓ The 'Coanda† effect', also known as ***'Wall-Attachment effect'***, is the basis for functioning of many fluidic components and the fluidic technology itself.

✓ ***'Coanda effect' defined :*** *"When a stream of fluid meets other stream, the effect is to change its direction of flow and effect is the fluid sticks to the wall."*

15.3.2. Illustration of Coanda Phenomenon

Figs.15.1(a), (b) and (c) illustrate the wall-attachment phenomenon.

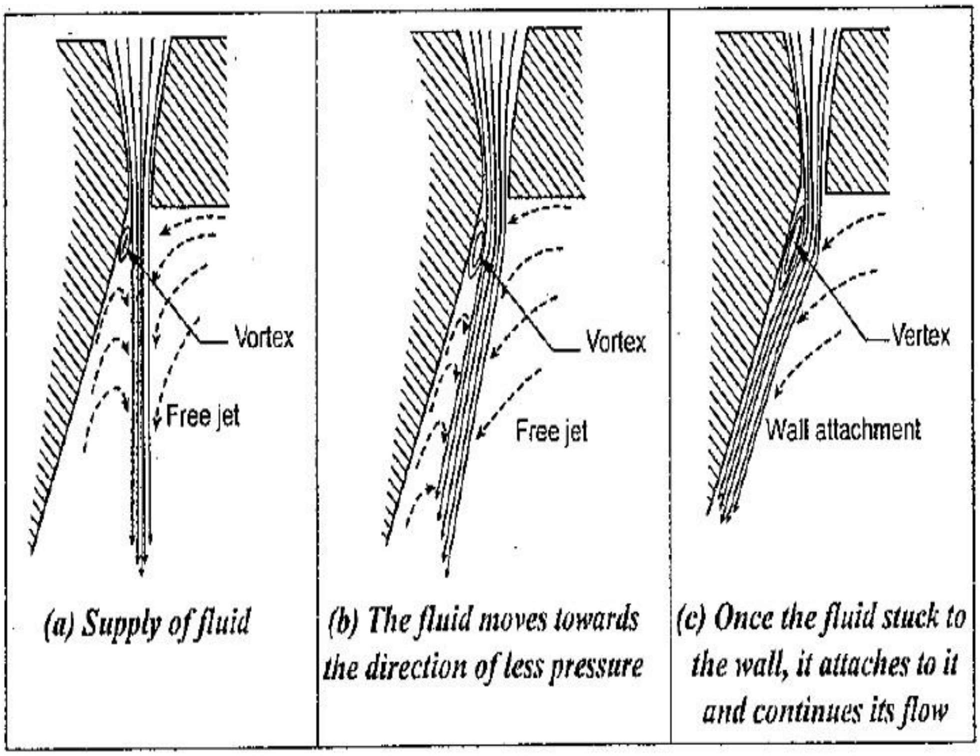


Fig. 15.1. Illustration of the wall-attachment phenomenon

15.3.3. Visual Demonstration of Coanda Effect

Fig.15.2 illustrates a simple self-explanatory, visual demonstration of Coanda effect. When a finger is held near the stream of water flowing at from the water-tap, then one can see that the water attaches itself to the figure as shown. This is clearly due to the Coanda effect.

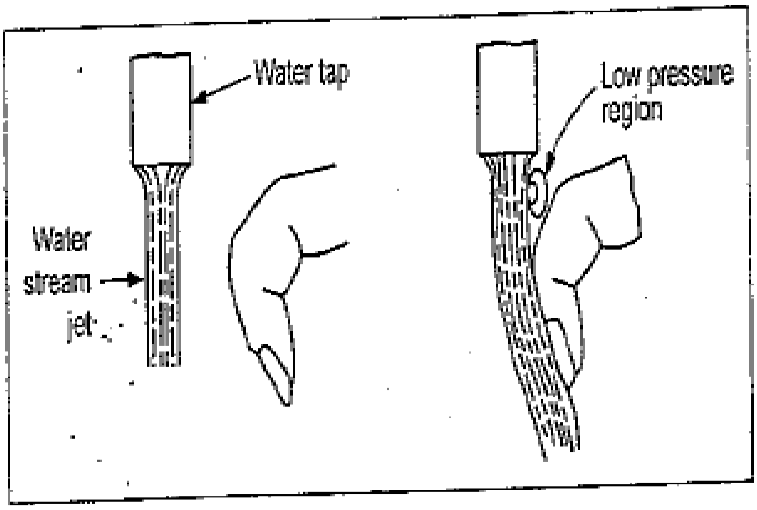
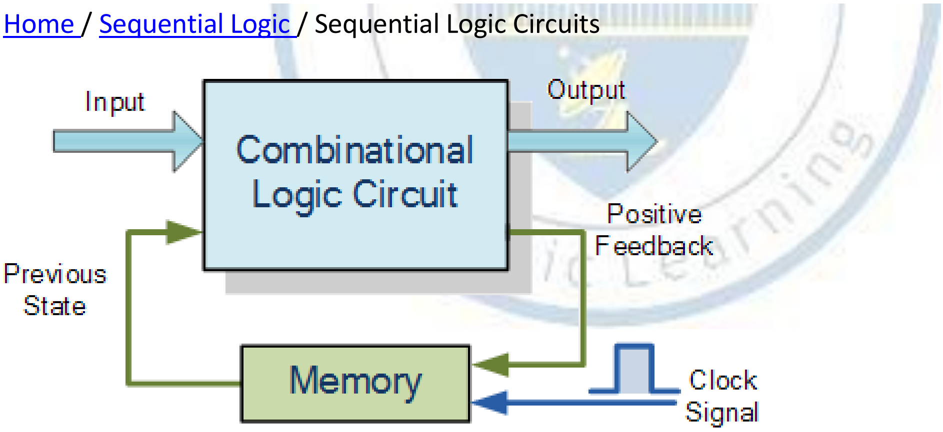


Fig. 15.2. Visual demonstration of the Coanda effect

Home / Sequential Logic / Sequential Logic Circuits



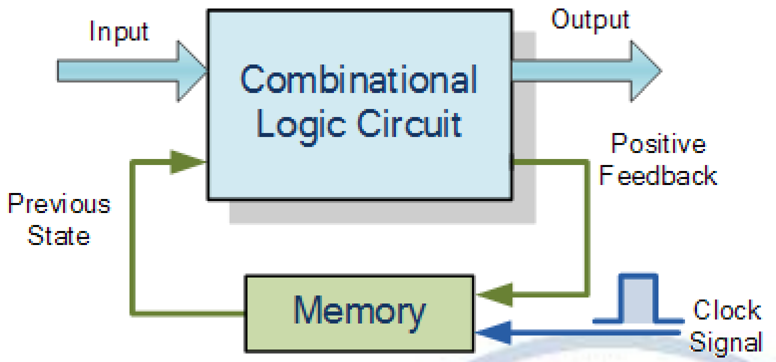
Sequential Logic Circuits

Unlike Combinational Logic circuits that change state depending upon the actual signals being applied to their inputs at that time, **Sequential Logic** circuits have some form of inherent "Memory" built in.

In other words, the output state of a "sequential logic circuit" is a function of the following three states, the "present input", the "past input" and/or the "past output". *Sequential Logic circuits* remember these conditions and stay fixed in their current state until the next clock signal changes one of the states, giving sequential logic circuits "Memory".

Sequential logic circuits are generally termed as *two state* or Bistable devices which can have their output or outputs set in one of two basic states, a logic level "1" or a logic level "0" and will remain "latched" (hence the name latch) indefinitely in this current state or condition until some other input trigger pulse or signal is applied which will cause the bistable to change its state once again.

Sequential Logic Representation



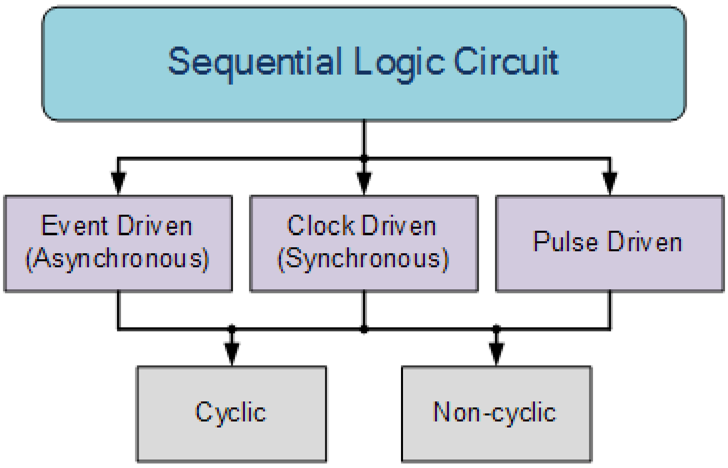
The word "Sequential" means that things happen in a "sequence", one after another and in **Sequential Logic** circuits, the actual clock signal determines when things will happen next. Simple sequential logic circuits can be constructed from standard **Bistable** circuits such as: Flip-flops, Latches and Counters and which themselves can be made by simply connecting together universal NAND Gates and/or NOR Gates in a particular combinational way to produce the required sequential circuit.

Related Products: Direct Digital Synthesizer

Classification of Sequential Logic

As standard logic gates are the building blocks of combinational circuits, bistable latches and flip-flops are the basic building blocks of sequential logic circuits. Sequential logic circuits can be constructed to produce either simple edge-triggered flip-flops or more complex sequential circuits such as storage registers, shift registers, memory devices or counters. Either way sequential logic circuits can be divided into the following three main categories:

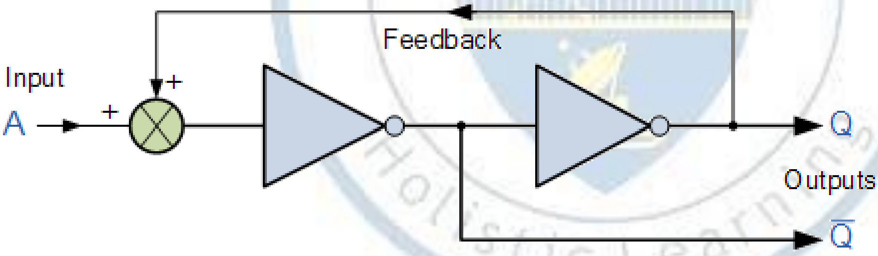
- 1. Event Driven – asynchronous circuits that change state immediately when enabled.
- 2. Clock Driven – synchronous circuits that are synchronised to a specific clock signal.
- 3. Pulse Driven – which is a combination of the two that responds to triggering pulses.



As well as the two logic states mentioned above logic level "1" and logic level "0", a third element is introduced that separates **sequential logic** circuits from their **combinational logic** counterparts, namely *TIME*. Sequential logic circuits return back to their original steady state once reset and sequential circuits with loops or feedback paths are said to be "cyclic" in nature.

We now know that in sequential circuits changes occur only on the application of a clock signal making it synchronous, otherwise the circuit is asynchronous and depends upon an external input. To retain their current state, sequential circuits rely on feedback and this occurs when a fraction of the output is fed back to the input and this is demonstrated as:

Sequential Feedback Loop



The two inverters or NOT gates are connected in series with the output at Q fed back to the input. Unfortunately, this configuration never changes state because the output will always be the same, either a "1" or a "0", it is permanently set. However, we can see how feedback works by examining the most basic sequential logic components, called the SR flip-flop.

SR Flip-Flop

The **SR flip-flop**, also known as a *SR Latch*, can be considered as one of the most basic sequential logic circuit possible. This simple flip-flop is basically a one-bit memory bistable device that has two inputs, one which will "SET" the device (meaning the output = "1"), and is labelled S and another which will "RESET" the device (meaning the output = "0"), labelled R.

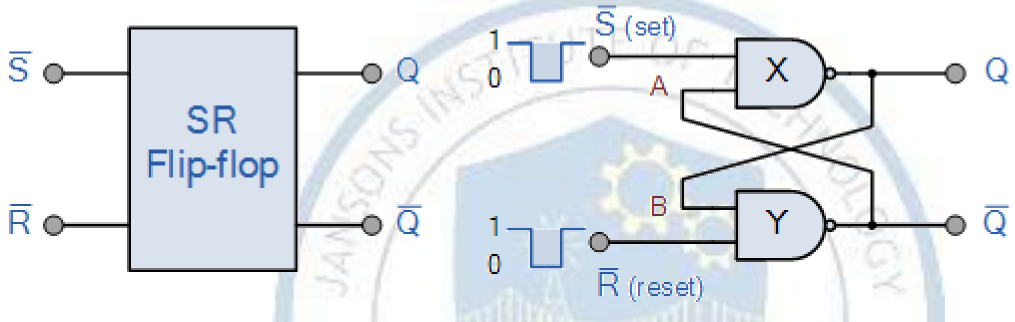
Then the SR description stands for "Set-Reset". The reset input resets the flip-flop back to its original state with an output Q that will be either at a logic level "1" or logic "0" depending upon this set/reset condition.

A basic NAND gate SR flip-flop circuit provides feedback from both of its outputs back to its opposing inputs and is commonly used in memory circuits to store a single data bit. Then the SR flip-flop actually has three inputs, Set, Reset and its current output Q relating to it's current state or history. The term "Flip-flop" relates to the actual operation of the device, as it can be "flipped" into one logic Set state or "flopped" back into the opposing logic Reset state.

The NAND Gate SR Flip-Flop

The simplest way to make any basic single bit set-reset SR flip-flop is to connect together a pair of cross-coupled 2-input NAND gates as shown, to form a Set-Reset Bistable also known as an active LOW SR NAND Gate Latch, so that there is feedback from each output to one of the other NAND gate inputs. This device consists of two inputs, one called the *Set*, S and the other called the *Reset*, R with two corresponding outputs Q and its inverse or complement Q (not-Q) as shown below.

The Basic SR Flip-flop



Symbol Circuit

The Set State

Consider the circuit shown above. If the input R is at logic level "0" (R = 0) and input S is at logic level "1" (S = 1), the NAND gate *Y* has at least one of its inputs at logic "0" therefore, its output Q must be at a logic level "1" (NAND Gate principles). Output Q is also fed back to input "A" and so both inputs to NAND gate *X* are at logic level "1", and therefore its output Q must be at logic level "0".

Again NAND gate principals. If the reset input R changes state, and goes HIGH to logic "1" with S remaining HIGH also at logic level "1", NAND gate *Y* inputs are now R = "1" and B = "0". Since one of its inputs is still at logic level "0" the output at Q still remains HIGH at logic level "1" and there is no change of state. Therefore, the flip-flop circuit is said to be "Latched" or "Set" with Q = "1" and Q = "0".

Reset State

In this second stable state, Q is at logic level "0", (not Q = "0") its inverse output at Q is at logic level "1", (Q = "1"), and is given by R = "1" and S = "0". As gate *X* has one of its inputs at logic "0" its output Q must equal logic level "1" (again NAND gate principles). Output Q is fed back to input "B", so both inputs to NAND gate *Y* are at logic "1", therefore, Q = "0".

If the set input, S now changes state to logic "1" with input R remaining at logic "1", output Q still remains LOW at logic level "0" and there is no change of state. Therefore, the flip-flop circuits "Reset" state has also been latched and we can define this "set/reset" action in the following truth table.

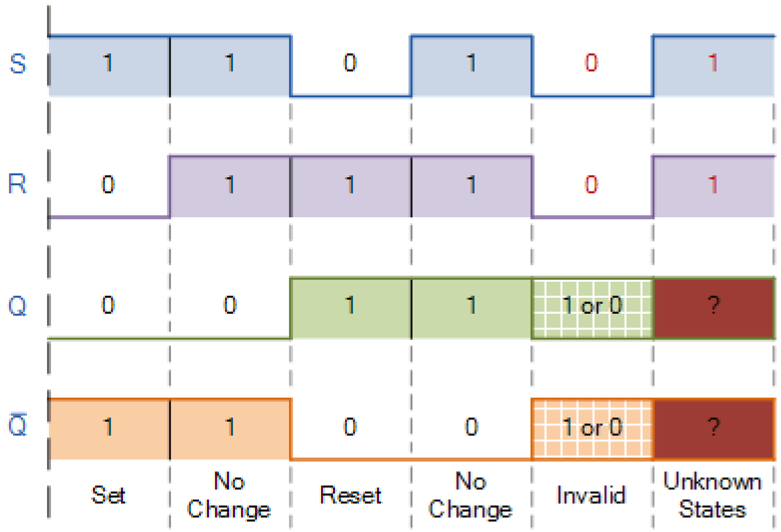
Truth Table for this Set-Reset Function

State	S	R	Q	Q	Description
Set	1	0	0	1	Set Q » 1
	1	1	0	1	no change
Reset	0	1	1	0	Reset Q » 0
	1	1	1	0	no change
Invalid	0	0	1	1	Invalid Condition

It can be seen that when both inputs S = "1" and R = "1" the outputs Q and Q can be at either logic level "1" or "0", depending upon the state of the inputs S or R BEFORE this input condition existed. Therefore the condition of S = R = "1" does not change the state of the outputs Q and Q.

However, the input state of S = "0" and R = "0" is an undesirable or invalid condition and must be avoided. The condition of S = R = "0" causes both outputs Q and Q to be HIGH together at logic level "1" when we would normally want Q to be the inverse of Q. The result is that the flip-flop looses control of Q and Q, and if the two inputs are now switched "HIGH" again after this condition to logic "1", the flip-flop becomes unstable and switches to an unknown data state based upon the unbalance as shown in the following switching diagram.

S-R Flip-flop Switching Diagram

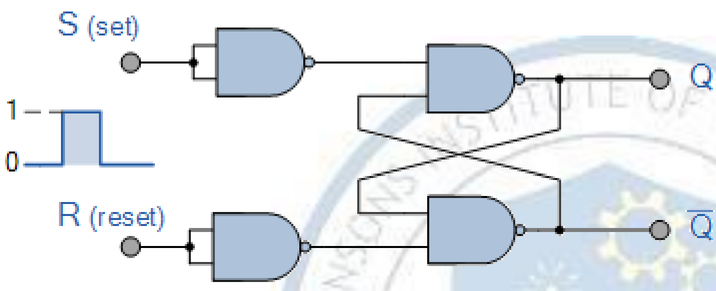


This unbalance can cause one of the outputs to switch faster than the other resulting in the flip-flop switching to one state or the other which may not be the required state and data corruption will exist. This unstable condition is generally known as its **Meta-stable** state.

Then, a simple NAND gate SR flip-flop or NAND gate SR latch can be set by applying a logic “0”, (LOW) condition to its Set input and reset again by then applying a logic “0” to its Reset input. The SR flip-flop is said to be in an “invalid” condition (Meta-stable) if both the set and reset inputs are activated simultaneously.

As we have seen above, the basic NAND gate SR flip-flop requires logic “0” inputs to flip or change state from Q to Q and vice versa. We can however, change this basic flip-flop circuit to one that changes state by the application of positive going input signals with the addition of two extra NAND gates connected as inverters to the S and R inputs as shown.

Positive NAND Gate SR Flip-flop

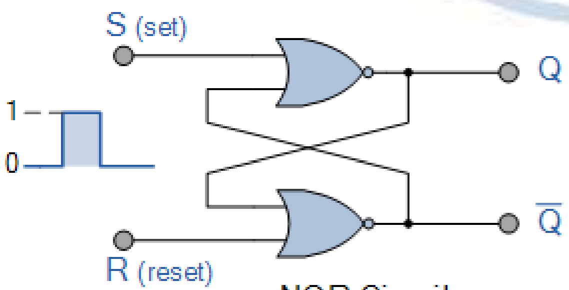


NAND Circuit

S	R	Q	$\overline{Q}$
0	0	No change	
0	1	0	1
1	0	1	0
1	1	X	X (Invalid)

As well as using NAND gates, it is also possible to construct simple one-bit **SR Flip-flops** using two cross-coupled NOR gates connected in the same configuration. The circuit will work in a similar way to the NAND gate circuit above, except that the inputs are active HIGH and the invalid condition exists when both its inputs are at logic level “1”, and this is shown below.

The NOR Gate SR Flip-flop



NOR Circuit

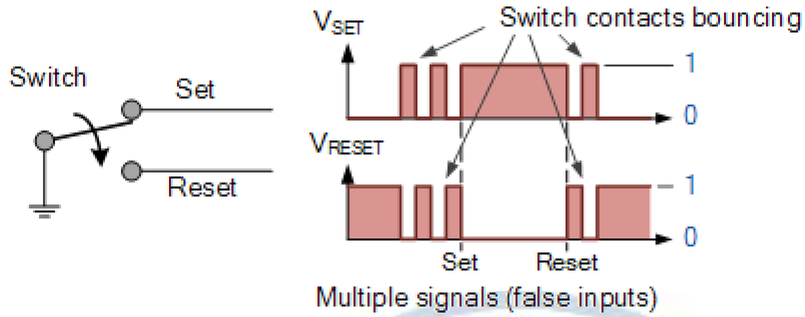
S	R	Q	$\overline{Q}$
0	0	No change	
0	1	1	0
1	0	0	1
1	1	X	X (Invalid)

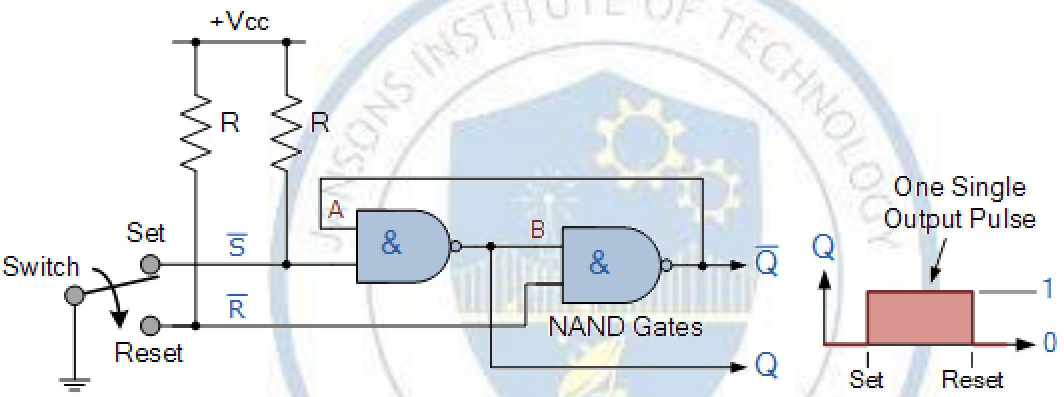
Switch Debounce Circuits

Edge-triggered flip-flops require a nice clean signal transition, and one practical use of this type of set-reset circuit is as a latch used to help eliminate mechanical switch “bounce”. As its name implies, switch bounce occurs when the contacts of any mechanically operated switch, push-button or keypad are operated and the internal switch contacts do not fully close cleanly, but bounce together first before closing (or opening) when the switch is pressed.

This gives rise to a series of individual pulses which can be as long as tens of milliseconds that an electronic system or circuit such as a digital counter may see as a series of logic pulses instead of one long single pulse and behave incorrectly. For example, during this bounce period the output voltage can fluctuate wildly and may register multiple input counts instead of one single count. Then set-reset SR Flip-flops or Bistable Latch circuits can be used to eliminate this kind of problem and this is demonstrated below.

SR Flip Flop Switch Debounce Circuit





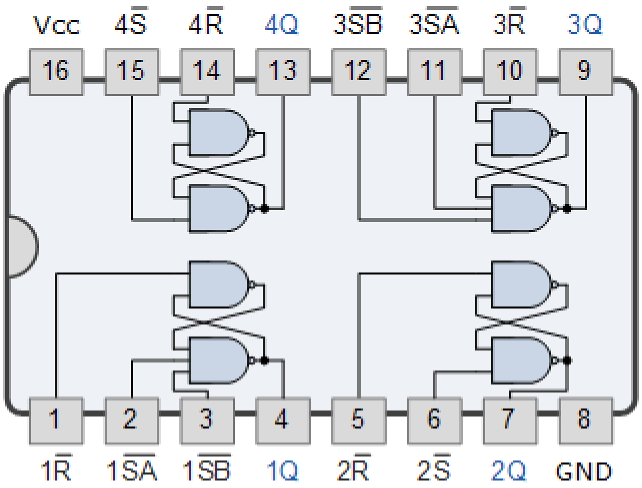
Depending upon the current state of the output, if the set or reset buttons are depressed the output will change over in the manner described above and any additional unwanted inputs (bounces) from the mechanical action of the switch will have no effect on the output at Q.

When the other button is pressed, the very first contact will cause the latch to change state, but any additional mechanical switch bounces will also have no effect. The SR flip-flop can then be RESET automatically after a short period of time, for example 0.5 seconds, so as to register any additional and intentional repeat inputs from the same switch contacts, such as multiple inputs from a keyboards "RETURN" key.

Commonly available IC's specifically made to overcome the problem of switch bounce are the MAX6816, single input, MAX6817, dual input and the MAX6818 octal input switch debouncer IC's. These chips contain the necessary flip-flop circuitry to provide clean interfacing of mechanical switches to digital systems.

Set-Reset bistable latches can also be used as Monostable (one-shot) pulse generators to generate a single output pulse, either high or low, of some specified width or time period for timing or control purposes. The 74LS279 is a Quad SR Bistable Latch IC, which contains four individual NAND type bistable's within a single chip enabling switch debounce or monostable/astable clock circuits to be easily constructed.

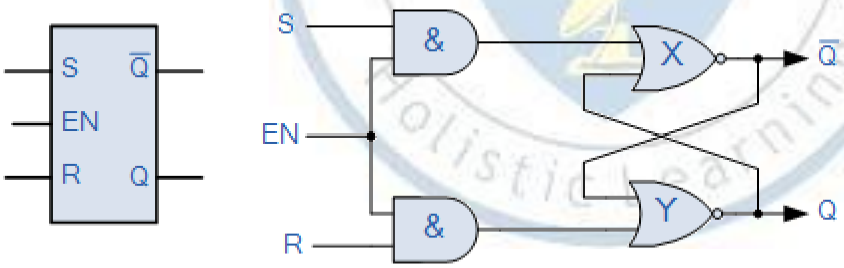
Quad SR Bistable Latch 74LS279



Gated or Clocked SR Flip-Flop

It is sometimes desirable in sequential logic circuits to have a bistable SR flip-flop that only changes state when certain conditions are met regardless of the condition of either the Set or the Reset inputs. By connecting a 2-input AND gate in series with each input terminal of the SR Flip-flop a Gated SR Flip-flop can be created. This extra conditional input is called an "Enable" input and is given the prefix of "EN". The addition of this input means that the output at Q only changes state when it is HIGH and can therefore be used as a clock (CLK) input making it level-sensitive as shown below.

Gated SR Flip-flop



When the Enable input "EN" is at logic level "0", the outputs of the two AND gates are also at logic level "0", (AND Gate principles) regardless of the condition of the two inputs S and R, latching the two outputs Q and Q into their last known state. When the enable input "EN" changes to logic level "1" the circuit responds as a normal SR bistable flip-flop with the two AND gates becoming transparent to the Set and Reset signals.

This additional enable input can also be connected to a clock timing signal (CLK) adding clock synchronisation to the flip-flop creating what is sometimes called a "Clocked SR Flip-flop". So a **Gated Bistable SR Flip-flop** operates as a standard bistable latch but the outputs are only activated when a logic "1" is applied to its EN input and deactivated by a logic "0".

Fluidics Circuit:

15.6.1. Control of Air Cylinder Using Preferenced Flip-Flop

15.6.1.1. Circuit

Fig.15.14 illustrates a fluidic logic circuit that can provide the push-button start and air limit switch reversal of an air cylinder. This circuit uses two pilot-actuated 3/2 control valves (V1 and V2), a preference flip-flop, a normally closed (NC) limit switch (V3), a shuttle valve (V4), and an air cylinder.

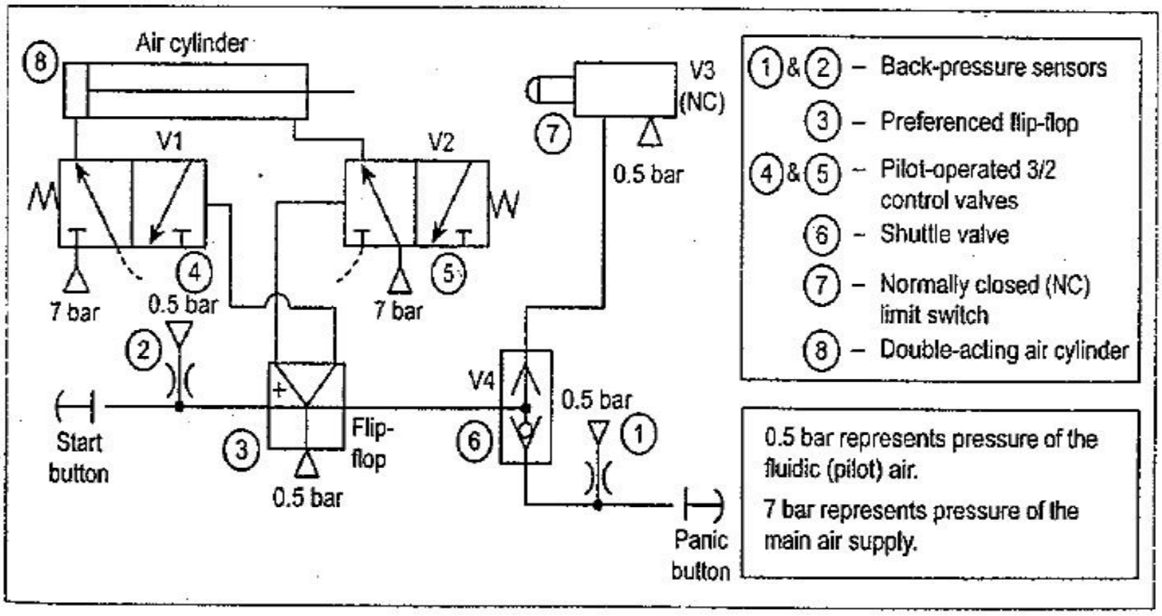


Fig. 15.14. Control of air cylinder using preferenced flip-flop

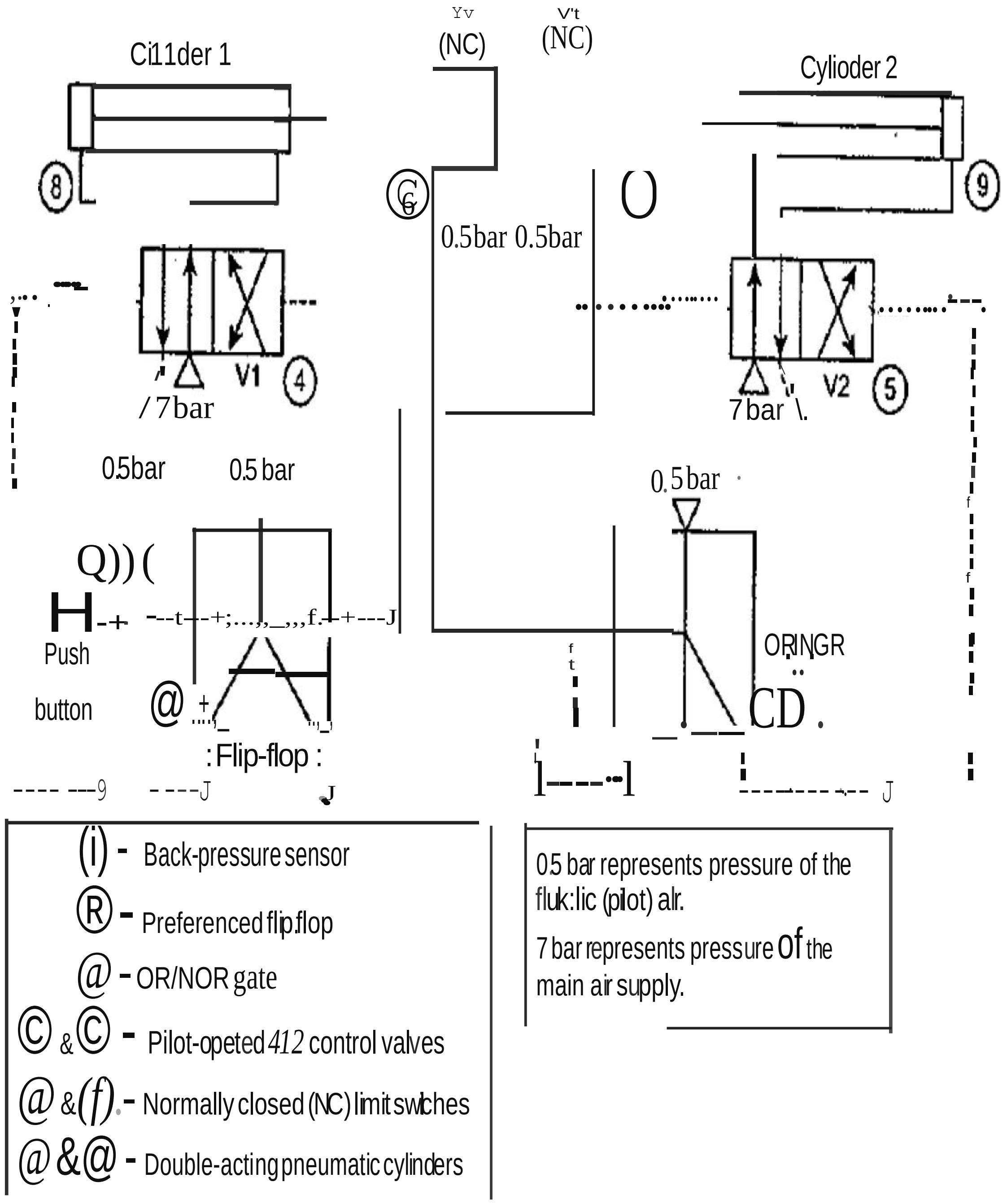


Fig. 15.15. Fluitfic sequenci11g control of two pneumatic cylinders

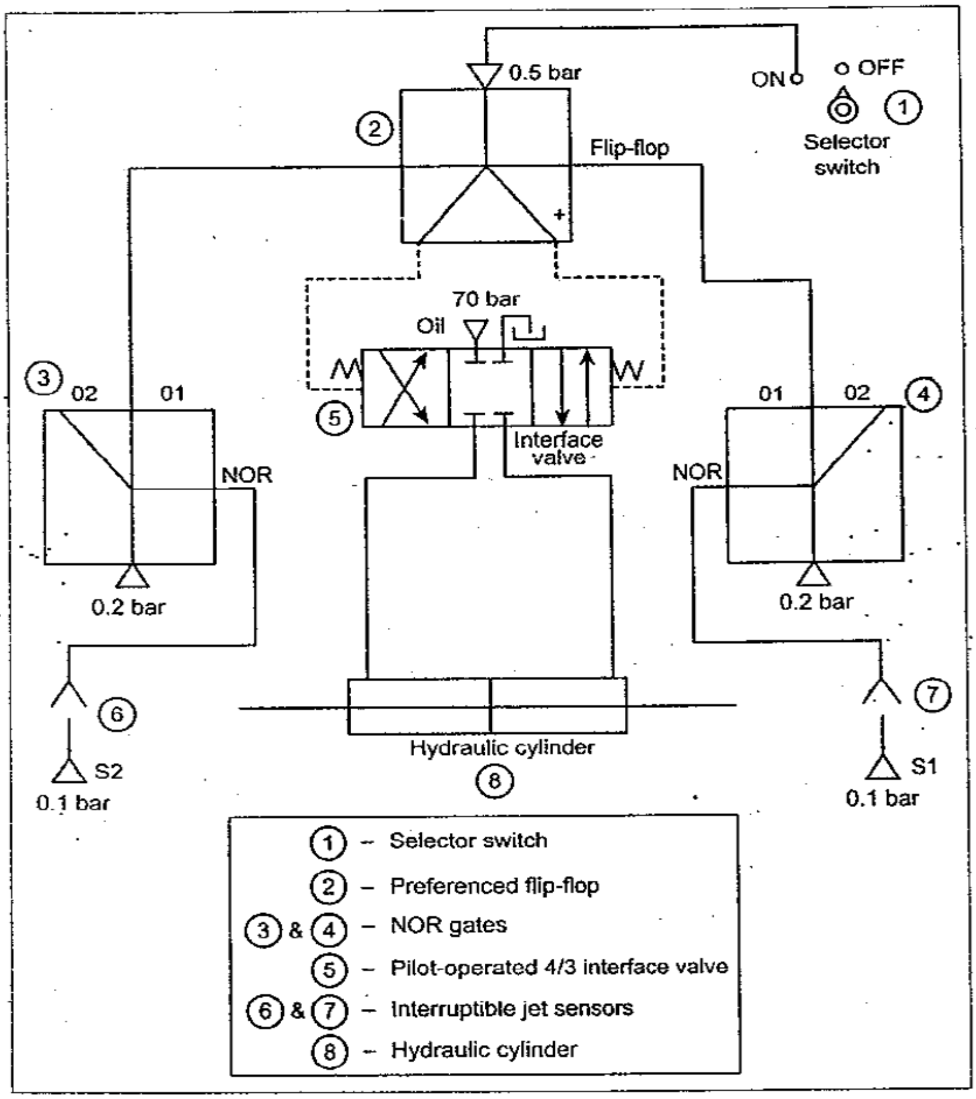
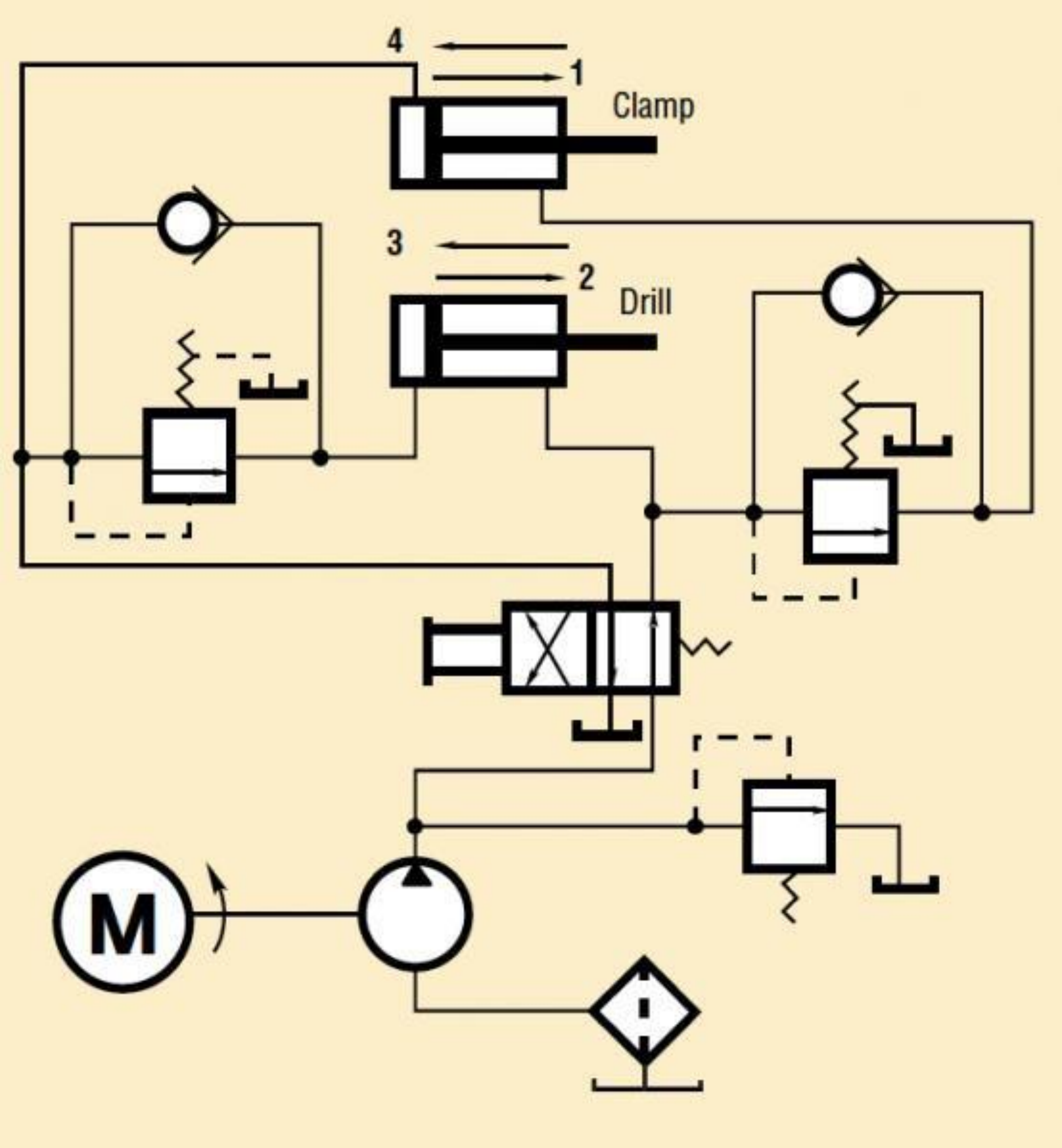


Fig. 15.16. Continuous reciprocation of a hydraulic cylinder using fluidic controls

UNIT V TROUBLE SHOOTING AND APPLICATIONS

Design of circuits using the components of hydraulic system for Drilling, Planning, Shaping, Punching Press. – Selection, fault finding and maintenance of hydraulic components Sequential circuit design for simple application using cascade method, Electro pneumatic circuits. Selection criteria of pneumatic components – Installation fault finding and maintenance of pneumatic components. Microprocessor and PLC- Applications in Hydraulic and Pneumatics- Low cost Automation – Hydraulic and Pneumatic power packs.

Design of circuits using the components of hydraulic system for Drilling:



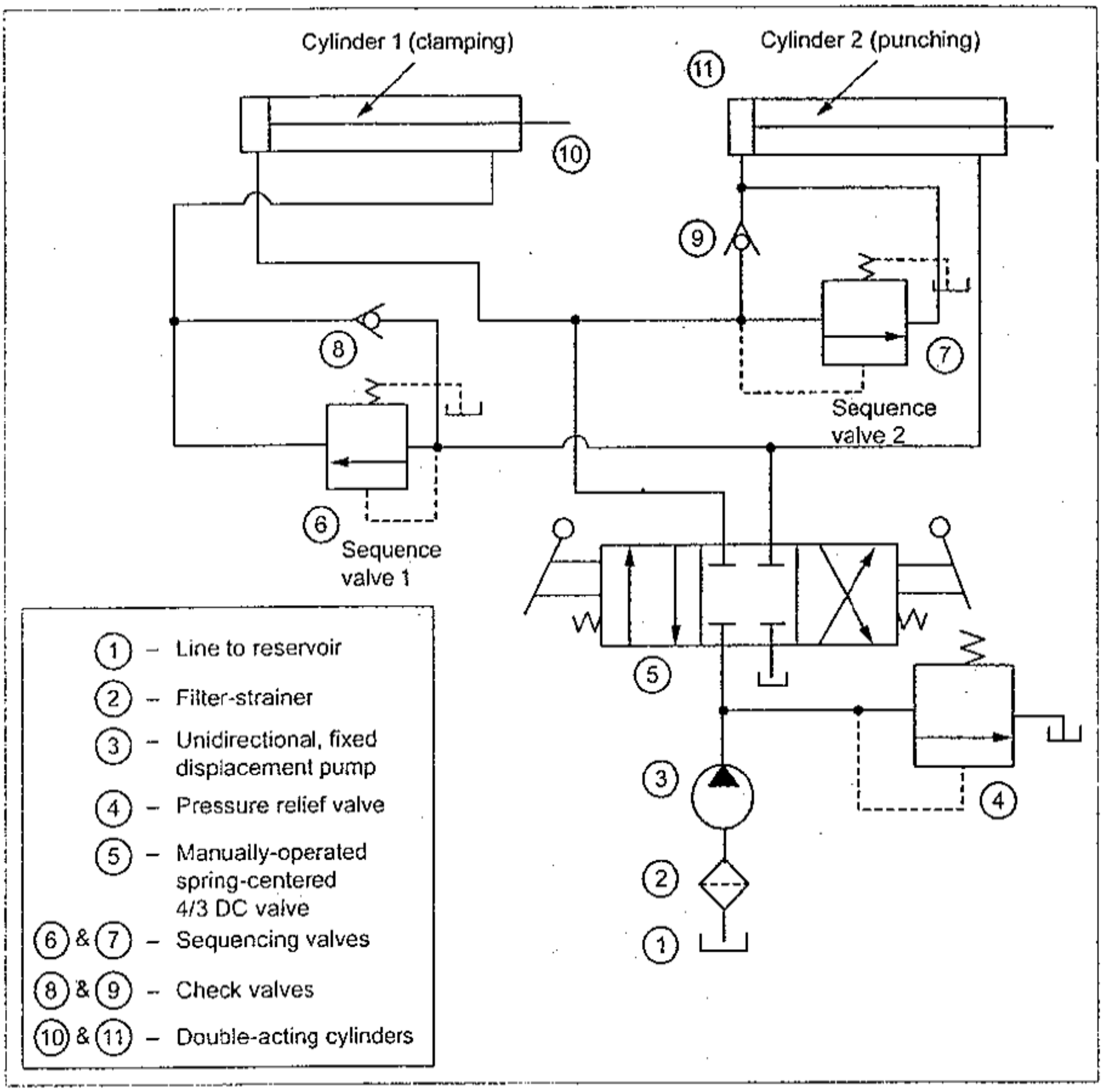


Fig. 13.5. Hydraulic cylinder sequence circuit (for clamping and punching operations)

Circuit: The hydraulic press circuit employing double pump unloading principle is shown in Fig.1.

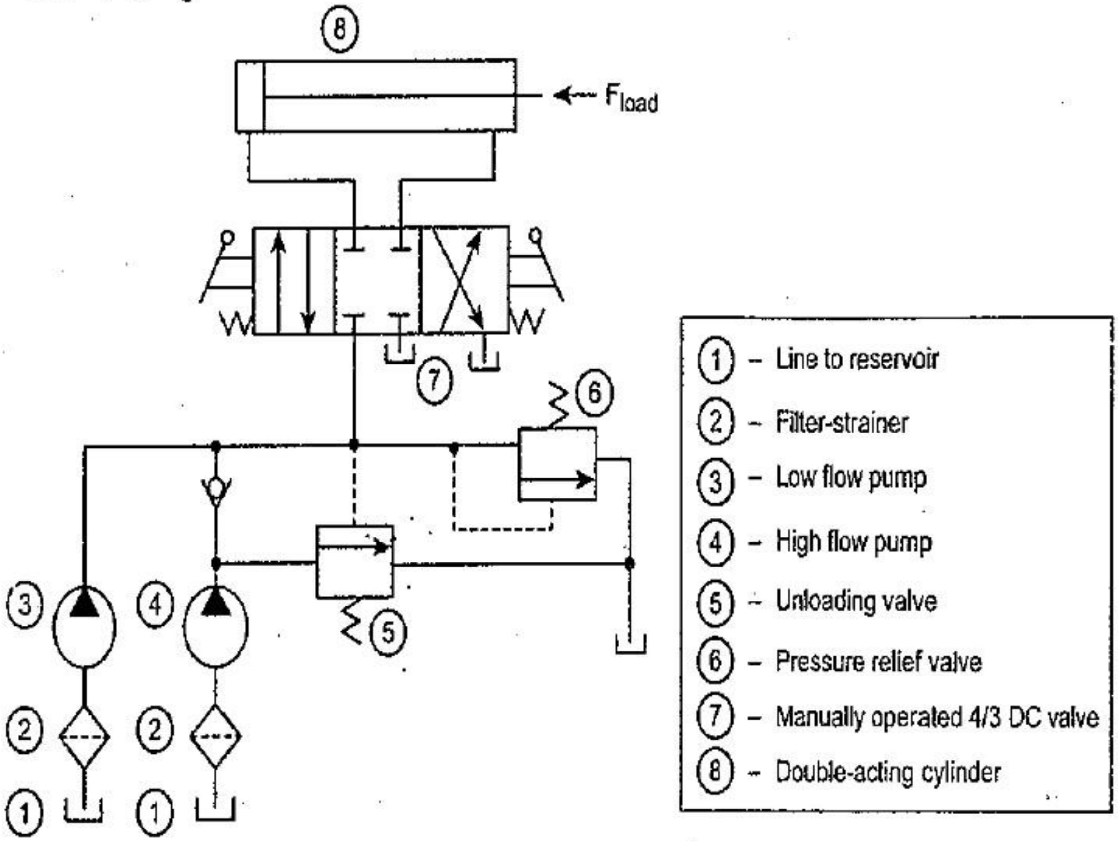


Fig.1. Double-pump hydraulic press circuit

Operation: When the pressing/punching operation starts, the increased pressure opens the unloading valve to unload the low-pressure pump. When the DC valve is in its spring-centered mode, the relief valve protects the high-pressure pump from overpressure at the end of the cylinder stroke. During the punching operation, the check valve protects the low-pressure pump from high pressure.

13.26. DESIGN OF PNEUMATIC LOGIC CIRCUITS

In the preceding sections, we have discussed few basic pneumatic circuits. It should be noted that a pneumatic circuit for a particular application can be designed in various methods. The five methods commonly used by engineers are :

1. Cascade method,
2. Classic or intuitive method,
3. Step-counter method,
4. Karnaugh-Veitch (K-V) mapping method, and
5. Combinational circuit design.

However, the design of pneumatic logic circuits using cascade method is more important from our subject point of view.

13.26.1. Cascade Method of Pneumatic Circuit Design

The cascade method is found to be the simplest and easiest method of designing pneumatic logic circuits.

13.26.1.1. Procedure

The following step by step procedure may be followed while using the cascade method.

Step1 : Each cylinders are given, for convenience, individual letters (say A, B, C, *etc.*). The given sequence is written first with '+' representing extension (forward) stroke of the cylinder and '–' representing retraction (return) stroke of the cylinder. (For example A^+, B^+, A^-, B^-, *etc.*)

Step 2 : The given sequence is split into miniml1m number of groups. The grouping can be done as below *:*

(i) The tirst group is split where the change in stroke occurs.

(ii) The second, third and subsequent groups are formed such that maximum of one change occurs within the group.

(ii0 No letter should be repeated within any group.

(iv) The groups are identified by letters like I, II, III, *etc.*

illustration : Let us assume .the sequence A+ B+ B- C+ C- A-. This sequence can be splitted into three groups as shown below :

A+ S+ S C+ C- A-
1 ll" .' III

Step 3 : Each group is.assigned a pressure manifold line which must be pressurised only during the time the partfoulaF group is active.

∴ Number of pressur llne1 = Number of groups

Step 4 : Selectio11 of vall;es : : :

(i) Each cylinder is..provided with a pilot operated 412 DC valve.

∴ Number of pilot co11tro/ valvs = Number of cylinders

(ii) Limit valves are positioned at either end actuated by the piston rod to identify the extension and retraction of cylinders. The limit valves are denoted .by a_0, a_1, h_0; b_1, *etc.,* where the suffix (0' corresponds to valves which are actuated at the end of return stroke and the suffix '1' corresponds to valves which are actuated at the end of forward stroke. Each cylinder requires two limit valves.

∴ Number of limit valves = 2 x Number of cy/i1id_ers

Each manifold line supplies air pressure to those limit valves within its particular gr<?up.

(iii) In order to pressurize the various manifold lines in the proper order, one or more group changing valves or cascade valves are used.

∴ Number of cnscal/e (or group clianging) valves ;;; Number of gro1Jps –I

Step J : The valve connections are made as follows ;

(i) The output of each limit valve is connected to the pilot input corresponding to the next sequence step.

(ii) The limit valve corresponding to the last step of the given group is 'not' connected to the pilot actuation of the DC valve of next cylinder. Instead, it is. connected to the pilot line of the grup changing or cascade valves? as to press1,1dze the manifold of the subsequent group.

This manifold rine is then connected to the pilot line corresponding:to the first step of the next group.

13.26.2 Advantages of Cascade Method

1. Circuit design, drawing and checking can be accomplished very quickly.
2. Fault diagnosis and trouble-shooting are ve1y simple.
3. Requi red task by each cylinder and their signal elements is fully ensured.
4. This avoids a problem that may occur because of air becoming trapped in the pressure iine to control a valve and so preventing the valve. frorn switching.

| *Example 13.2* | *·Three pneltmatic cy/i11ders A, B, tmtl C are usetl in 011 automutic ·equence of operation. A cylinder extends, B cylinder extends, B cyli,,der retracts and tllen A cyli1tder retrt1cts, cylintler extemls (JIU/ C cylintler retr(lcts. Develop pne11matic circ1tils by cascade metltotl.*

©*Solutimi :* The steps involving during the design of this circuit is explained as below :

Step I : Given sequence is A+ S+ B-A- C C-

Step 2 : The given sequence can be initially splitted into three groups as

A+ S+ B- A- c+ c-
(LI · IH

In order to keep the number of groups minimal, the C- can be assigned to group I. So the ideal grouping is as follows :

c- A+ s+ S- A- c+
I u

Step 3 : Number of pressure lines == Number of groups = 2

Step 4 : Selection of valves :

(i') Number of pilot operated 4/2 DC valve == Number of cylinders ;;;: 3

Thus three cylinder actuation-VA, VB, VC-are provided.

(ii) Number of limit valves = 2 *x* Number of cylinders = 2 x 3 == 6

Thus six limit valves-$a_0, a_1, b_0, b_1, c_0, c_1$-are provided.

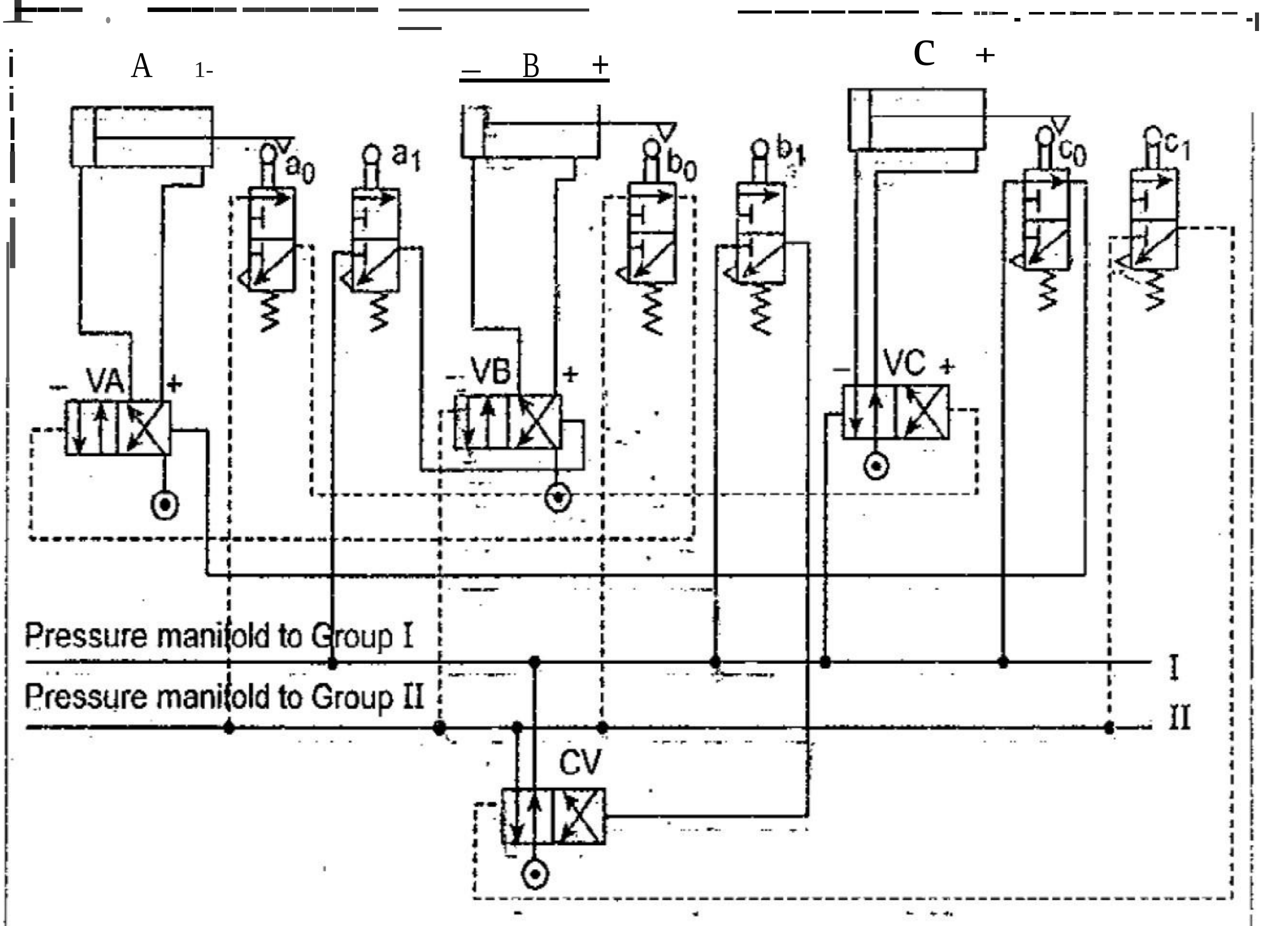
(iii) Number of cascade (or group changing) valves = {Number of grou} − 1 = 2 − 1 ::: I.

So. for this circuit, only one cascade valve is sufficient.

Step 5 : The valve connections are made as follows ;

(i) The cascade valve CV is shifted to its teft envelop tlow path configuration so that the pressure manifold to group I is pressurized. First line I is connected directly to the pilot line (-) of 4/2 DC valve VC. So retraction of C (C-) starts when group I is pressurized.

At the end cf rctr\tion of C, the lii:nit valve c_0 is actuated. Now \h_c pressure from manifoN Hnt; ' pas through co, t_o rh.e pilot l ine (+) of 4/2 DC xale VA. As a re_ sul yliger A eJtends. (A+) and actuates limit valve $_1$• Pressure. then passes from manifold H1w I rough a_1tC? the pHot line. (+) of 4/2_DC val VB; \lis causes cyl inder to tend rr) and actuatr. limit valv. b_1• ThLis the sc_qu. ncing o,\G rou p I is complet -



--:. represnts operC!-tions or oup I

--- ---represents operatoins or group 1l

A, 6. arid C – Doublle acting peumatic cyltq rs

CV :Cascade {or group changing} villv

VA, VB, nd VC .:_ 4/2 direction !control valves fof the cylinders A, 8, and C respectively

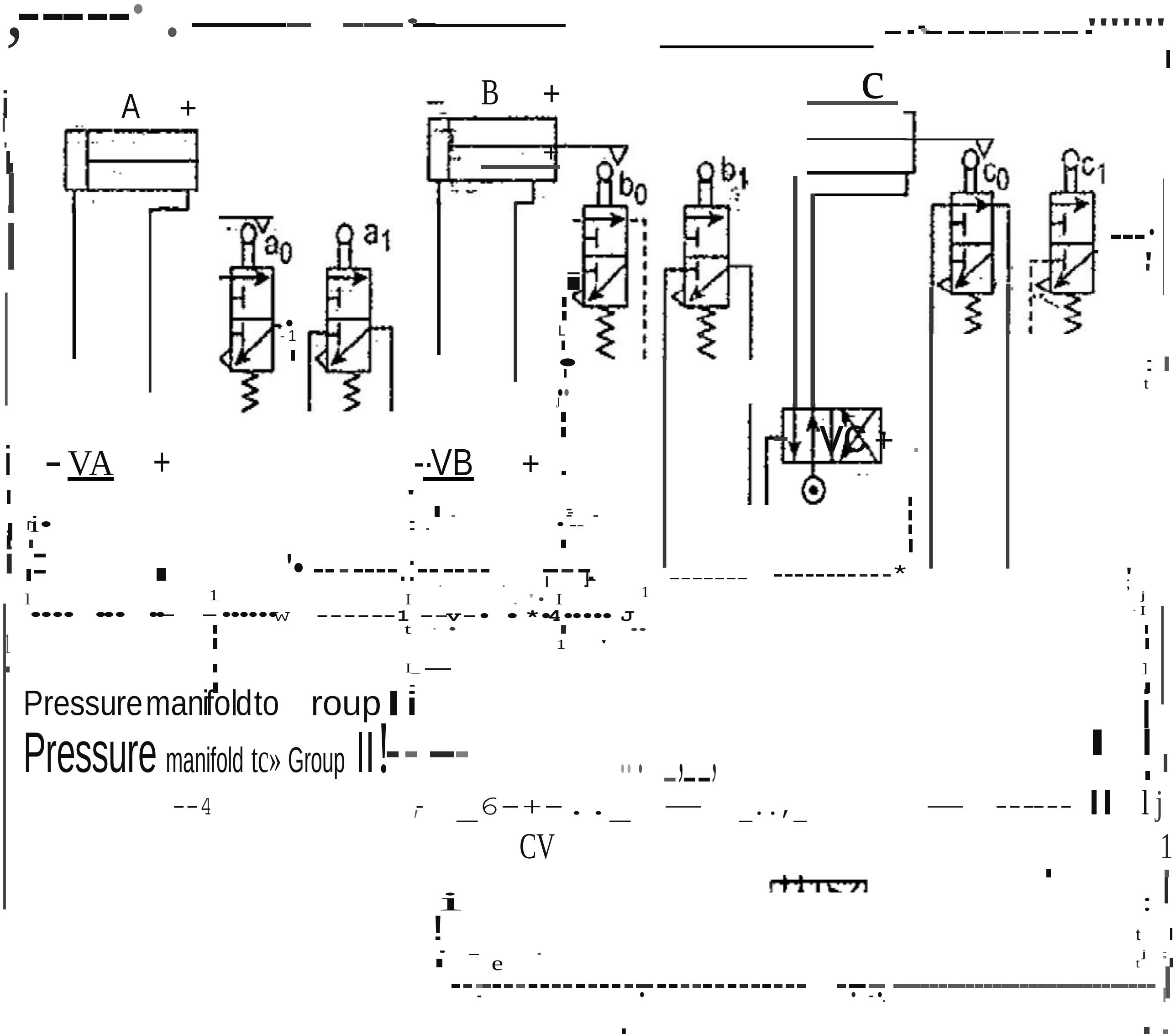
for cylinder A

a_0 nd a_1 – Limit valvs

bo nd b_1 – Limit valve$ for cylinder B

:co_an....1 - Limit valves for cymnder c

At the en of rctr \ tion of C, the liulit valve c_0 is actuated. Now _c pressure from manifo_, Hn \ pa s through *co*, t_o rh.e pilot Iine (+) of 4/2 *DC* ale VA. As a rsult f yl er A etends (A+) and actuates Hmit valve a_1• Pressure. then passes from nanifold H1wI 1rough a.$_1$tC:> the pHot line (+) of 4/2_DC valv VB; Hlis causes cylinder *to* etend (f-) and actuatP. limit valv.b_1• ThLis the seqLI;ncing o,{Group Iis compl_et -



represnts oper'!-ons of oup I

represents operaloins of group 11

A, B. arid C :- Double-acting pneumatic cylin

CV - Cascade {or group changing) valyt1

VA, VB, nd VC 412 directiona_f control valves fof lhe cy)inders A, 8, and C r pectivety

a_0 nd a_1 - Limit valvs for cylinder A

bo nd b_1 - Limit valve$ for cylinder B

:co a,.. ... - -1mit valve for cynnder c

CHAPTER 16

FLu10 POWER C1Rcu1Ts: FAILURE AND TROUBLESHOOTING

16.1. INTRODUCTION

The new applications of hydraulic and pneumatic power system are being found and adopted every day in all fields. Also fluid power is considered as the muscle of automation because the future automated industries will largely depend on fluid power for their operations. So we cannot afford the failure of these systems. Like any other systems, fluid power systems also develop various types of faults and defects which need periodic and routie maintenance. Therefore in order to enhance the operational reliabiUty 11J1d maintainability of the fluid power system, it is highly required to take up various maintenance and repair measures to prevent failure of components and stoppage of the system.

It is also found that the maximum trouble free life of the fluid power systems mainly depend on the following four basic requirements :

I. Properly installed equipments,
2. Properly trained personnel,
3. Planned preventive maintenance, and
4. Effiqient troubleshooting.

In this chapter, we shall describe how to troubleshoot fluid power circuits effectively, depending on the symptoms of the problem involved:

FAILUR"E AND TRdUBLESHoa>rING OF HYDRAULIC <SYSTEM

16.2. FAILURE AND TROUBLESHOOTING OF HYDRAULIC SYSTEM

16.2.1. Common Faults in Hydraulic Systems

Table 16.l lists the most common type of defects that can be found in hydraulic systems.

Table 16.1. Commonfaidts in hydraulic systems

1. Reduced speed of travel of machine tool elements.
2. Slow response to control.
3. Excessive loss of system pressure.
4. Excessive leakage in the system.
5. Rise in the oil temperature.
6. Non-uniform or jerky movement of tables, carriages, *etc.*, especially at low feed rates.

7. Increased noise in the system.
8. No supply or less supply from pump.
9. CaVitation of seal failure.
10. High rate of seal failure.
11. Poor oil life.
12. High degree of contamination level of system medium.

16.2.2. Common Causes of Hydraulic System Breakdown

Table 16.2 lists the most common causes of-hydraulic system breakdown.

Table 16.2. Common causes of hydraulic system breakdown

1. Inadequate supply of oil in the reservoir.
2. Clogged or dirty oil filters.
3. Leaking seals.
4. Loose inlet lines that cause the pump to take in air.
5. Incorrect type of oil.
6. Excessive oil temprature.
7. Excessive oil pressure.

16.2.3. Fault Finding Using Troubleshooting Charts

The term troubleshooting refers to an organised and systematic study of the problem and a logical approach tthe difficultyfaced in a system.

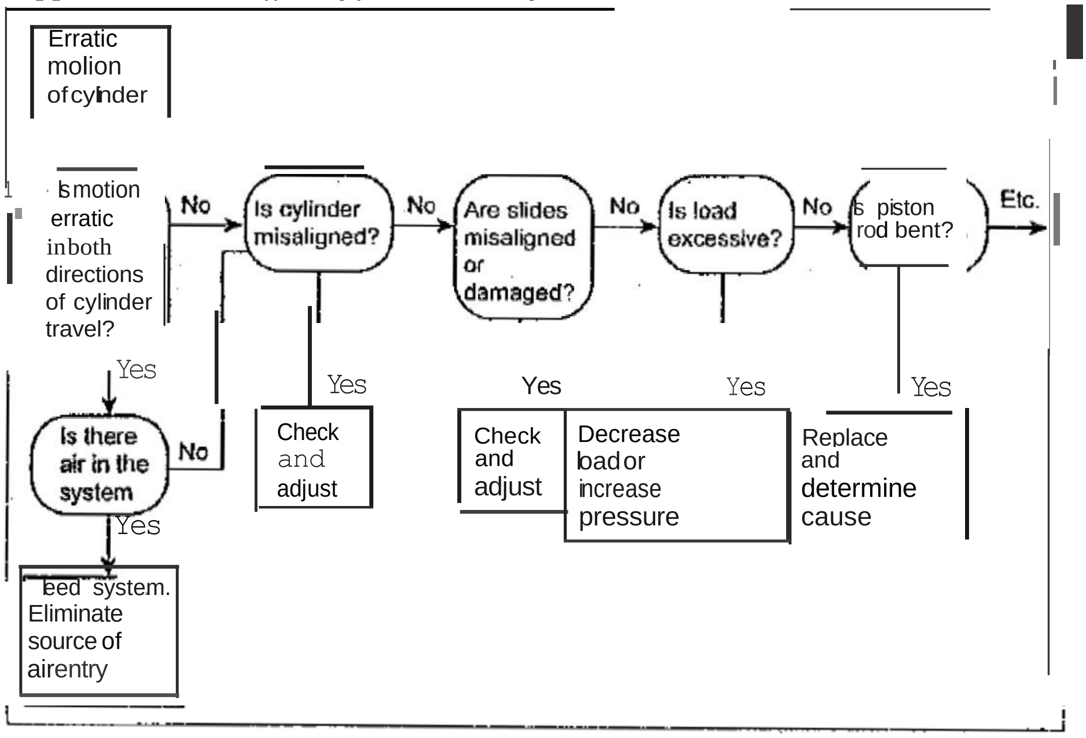


Fig. 16.1 Tree-branching chartfor a hydra11Jic system

Maintenance engineers often use a fault finding chart, also known as *tree-bąnchi11g chart,* to simplify the complex fault finding process in a hydraulic circuit.· A typicat tree-branching chart is illustrated in Fig.16.1.

As could be seen from the chart•.it asks a question which has answers only in the 'yes' or 'no' type. This answer will determine the. next step to be taken. Thus, this tree-branching chart technique helps the maintenance personnel in developing a logicaJ and rapid approach to fault diagnosis.

162.4. FaultDiagnosis of Hydraulic System

Table 16.3 presents the various faults, their symptoms, probable causes, and also the remedia actions that can be taken to prevent them in hydraulic systems.

·Table 16.3 Variousfatti ts,possible carlses and remedies of a hydrauľre system and its components

'(rouble/Fault	Probable causes	Remedial actions
I.PUMP ·		
l. Pl1mp deJivedng insuflicient or no oil	Wrong direction of shaft	Must be rversed immediately to prevent seizure and breakage of parts due to lack of oil
	Pump shaft turning too slowly to prime itself	Check minimum speed recommendation and momentarily increase rpm, to rectify
	Clogged strainer or-suction pipe line	Clean strainer or suction pipe line.Remove foreign matter
	Strainer capacity insufficient	Replace with a strainer whose capacity is more than twice the maximunt flow rate
	Air leak in suction line	Add oil and check oil level in reservoir. Check for leaks and repair
	Faulty rot.ating part in tne pump body	Check by listening to the sound. Remove the cover and check the internal mechanism. Replace, *il* necessary
	Oil leak inpump casing due to seizureor wear of pump sliding parts	Check the sliding parts
	Low level of oil in the reservoir	Add the oil recommended as per the indicator line
	Oil viscosity too heavy to pick up prime or too light causing excessive slippage	Use oil as per recommendation

Troublault	Probable causes	Remedial actions
2. Pump developing unstable .or zero pressure	Pump not delivering oil for itny of the above .reasons	Apply the above remedies
	Relief valve setting not high enouh	Correct valve setting by using pressure gauge
	Relief valve sticking open	Check relief valve. If necessary, dismantle and clean valve
	Clogged orifice of the relief valve	Overhaul and dean relief valve
	Mis-assembly, mis-connection or mis-operation of various valves in the circuit	Must be corrected
	Faulty performance of various valves or excessive oil leakages in the circuit through actuators and valves *etc.*	Test each component separately and repair
	Faultv pressure gauge	Check and replace if necessary
	Partially clogged suction line or suction strainer	Clean and remove foreign matter
3. Pump making noise	Misalignment of pump a.nd prime mover	Check and rectify
	Strainer capacity insufficient	Replace with a strainer whose capacity is more than twice the maximum flow rate
	Air leak at pun,p's suction pipe joints or from shaft packing of the pump	Pour oil on suspected joints while listening for chat1ge in sound. [f sound stops, tighten the joint
	Air remains in pump casing	Elimina te air through the air breather
	Small size of suction pipe	Replace so that the flow velocity on the suction side will be approximately 0.5 to 1 m/s
	Couplin11: misalignment	Re-a lifm properly
	Pump bolts very loose	Tighten
	Resonance noises irl the system	Reinforce by installing supports to eliminate resonance
	Air bubble or too much foam in suction oil.	Check to be certain that the return lines are below oil level and well separated from suction lines.
	Verv high viscosity .	Use recommended oiL
	.Pump running too fast.	Check the recommended inaxiiuum speed.

Trouble/fault	Probable causes	Remedial actiops
4: Pump oil over-heated	Faulty oil cooler	Repair
	Insufficient size of oil reservoir	Increase capacity or install an oil cooler
	Pump pressure too high	Readjust relief valve setting
	Excessive flow velocity	Replace piping
	Seizure of pump's sliding parts	Dis-assemble and repair. Check for foreign matter in oil and see if the pump casing is filled with oil
5. Internal leakage arour\d pump	Shaft packing worn out	Replace
	Top cover packing damaged	Change the packing and apply clamping torque on the cover as pr manufacturer's tecommendation
6. Excessive wear	Abrasive matter in the hydraulic oil being circulated through	Instal an adequate filter or replae oil more often
	Viscosity of oil very low at working conditions	Check pump manufacturer's recommendatfons or consult your hydraulic engineer
	Sustajned high pressure above the maximum pump rating	Check maximum setting of the relief valve
	Misaligned drive or tight belt drive	Check and rectify
	Air recirculation causing chatter in the system	Remove air from the system
7. Breakage of parts inside pump hous1ng	Excessive pressure above maximum pump rating	Adjust relief valve properly
	Seizure due to lack of oil	Check oil level in reservoir and cleanness of stl'ainer and any other possible restrictions in suction lines
	Solid matter wedged in the pump	Install a filtir in the system. Clean suction strainer more often
	Excessive tighh1ess of head screws	Follow manufacturer's recommendations
U. RELIEF VALVES		
1. Erratic pressure	Dirt in oil	Clean strainer and flush the system
	Worn poppet or seat	Lap the poppet or replace
	Piston sticking in the main bod .	Check and rectify

Trouble/Fault	Probable causes	Remedial actions
2. No or low pressure	Vent connection open	Check and rectify
	Balancehole plugged	Check and rectify.
	Poppet not seating properly	Check,lap and repair
3. Excessive noise or chatter	High oil velocity	Check and rectify
	Faulty or worn poppet or seat	Check, lap or replace
	Excessive tank line pressure	Check and rectify
	Long vent line or pressure setting too dos to that of another valve in the circuit	Check and rectify
	Valve setting too dose to the system operating pressure	Set relief valve at least 10 bar higher than the required working pressure of the system
III. DIECTIONAL CONTROL VALYES (DCVs)		
1. Faulty or incomplete shifting	Worn out control linkage, shift pin, *etc.*	Check and repair
	Insufficient pilot pressure	Check and rectify
	Burned out solenoid	Check and replace
	Worn spring centering mechanism	Check and replace
2... Cylinder creeping or drifting	Valve spool not centering properly	Check and rectify
	Valve spool not shifting completely	Check and i:eplace
	Valve spool or body worn out	Check and rectify
	Leakage past the piston in the cylinder	Check and overhaul the cylinder
IV. SEQUENCCNG VALVES.		
1. Premature movement of secondary operation	Valve set too low	Ch.eek and set it hiJ?her
	Excessive load on primary cylinders	Check and adjust accordingly
	High inertia load on primary cylinder	Check and make sequence valve remote controlled
2. No movement or slow secondary operation	Sequence valve setting too hih	Check and adjust again
	Relief valve setting too dose to that of sequence valve	Should have at least 10 bar differential
	Valve spool bindin in body	Check and repair
V. UN()i:NGVALVES		
1. Fails to completely unload pump	Valve setting too high	Set correctly
	Remote pressure setting too low	Adjust properly
	Valve spool binding in *body*	Overhaul valve

Trouble/Fault	Probable causs	Remedial actions
VI CQiJN'tER;E J4\Na,:VALVES		
1. Will not support load	Valve setting too low	Set properly
	Dirt under jnteID"al check valve	Flush the system
	Valve spool and body worn out	Replace worn out parts
	Leakage past the piston in the cylinder	01eck and overhaul the cylinder
VII..FLO.W.CON fROLVEVES.		
1. Variation in feed	Sticking-hydrostat	Overhaul valve
	Cvlinder or motor leakag-e	Overhaul cylinder or motor
	Cha1\ge jn oil viscosity	Check and replace oil
	Improper pressure drop across valve	Adjust correctly
	Inadequate lubrication of machine parts	Check and do the 1e essary rectifications
Vlll. REMOTE FLOW CONTROL VALVES		
1. External leakage	Back pressure in drain line or defective seals	Drain directly to reservoir or replace seals
2. Feed rate variation	Hydrostatic pressure compensator inoperative or sticking hydrostat	Clean valve anrl nu h system. PpHsh hydrostat and metering spool. Replace defective seals
3. Maximum flow not obtainable	Contaminants in the throttling orifice.Meterg spool binding or not shifting fully. Insufficient voltage in torque motor	Clean valve. Check torque motor coils and input current. Re-align properly
4. Check valve-inoperative	Dirt lodged between the matin faces or finished faces	Disassemble and flush thoroughly
IX.HYDRAULIC :MOTORS		
1. Motor turning inwrong direction	Incorrect piping between control valve and fluid motor	Check circuits to det-ermine correct piping
2. Abence of proper speed and torque	System overload, relief valve adjus_h11ent not set high enough	Check required system pressure and reset relief valve
	Relief valve sticking open	Inspect and overhaul relief valve, set correctly
	Free recirculation of oil to reservoir	Identify the exact point of fault and rectify
	Driven mechanism binding, because of mis-alignment	Remove fluid motor and check the torque required for drive shaft
	Pump not delivering sufficient volume or pressure	Check pump delivery and pressur:e

Trouble/fault	Ptobable causes	Remedial actions
3. External oil leakage from fluid motot	Gasket leaking (may be due to drain not connected to the reservoir when requfred)	Replace gasket. If drain line is required, it must be connected directly to reservoir.
4. Times of operation longer than specified	Air in system	Bleed
	Internal leakage inactuating cylinder or directional vaive	Repair anq replace worn out parts
	Worn out pump	Repair
	Action is sluggish c-nly" on startup and becoes alright after warming up and vice-versa	Itis due to wrong selection of hydraulic oil. Consult manu facturer's reconunendations for correct hydraulic oil viscosity
	Low auxiliary £onlrol_pressure	Control lines may be too small particularly if they are very long
X.HYDRAULIC CYUNPERS		
1. Piston packing failing too often	Defective or poor quality of packing	Check and consult a hydraulic engineer for the correct solution
	Packing retainer bent	Check and rectify
	Piston bearing worn out	Check and replace
	Cylinder wall surface excessively worn out or badly scored	Check, smoothen and replace if necessary
	Getting damaged during assembling	Check itnd take care during assembling
	Packing might be facing very high pressures.	Adjust relief valve correctly
	Too rnuc::h contaminants inthe hydraulic oil	Flush system
	Design defects j.n. mounting	Consult hydraulic engineer
	Defective rod wiper	Check and chattge rod wiper
2. Reduced speed	Oil bypassing the piston	Check and overhaul cylinder. Replace defective parts
	Wrong setting of the control valve	Adjust properly
	Less delivery from pump	Check and rectify
	Directional valve not shifting fully	Check directional valve as discussed before
	Low setting or any defect in relief valve	Check and correctly setas mentioned before

Trouble/Fault	Probable causes	Remedial actions
3; Insufficient force available or no movement at all	Defective or very low set relief valve	Check and correctly set as mentioned·before
	Oil bypassing the piston	Check and overhaul the cylinder
	Pump not delivering oil ·	Check and overha\ll the cylinder
	Defective directional valve (specially solenoid operated or hydraulically operated)	Check and rectify
XI. ACCUMULATORS		
1. Sudden drop of pressure .when position of selector valve is changed	Internal or exrnal leak in accumulator	Check and repair leak
2. No prsure available after pump is stopped	Leaking gas valve or leaking check valve in the line	C_heck and replac valve
3. Sluggish response	Gas pre-charge not sufficient	Pre-charge according to manufacturer' s instructions and check for gas leak, if any.
XII.GENERAL CIRCUIT PROBLEMS		
1. Insufficient-pressure in system	Very low relief valve setting	Reset
	Leakage of full pump delivery within circuit	Delect and rectify
	Pump slipping its entire volume	Check and rpair
2. Slow operations	Leakage lhrough cylinder or fluid motors	Ch&k and repair ·
	Valve not closing or shifting properly	Check and repair
	Relief valve set at a. much higher pressure than necessa1y. Excess oil dissipated through increased slippage in various parts or throµgh relief . valve or through throttle valve	Reset relief valve slightly above the maximum pressure required for the work stToke. Follow manufacturer' s recommendations for niaximum pressure setting.
	Internal oil leakage due to wear in pump or in other places .	:Replace or repair pu mp and rectify other faul after detecting
	Viscosity of oil is very high	Follow manufacturer's recommendation'i for the correct viscosity grade to be used at various temperatures

Trouble/Fault	Probable causes	Remedial actions
3. Excessive heating of oil in system	Pump assembled too tightly after overhaul. This reduces clearanc and increases rubbing friction.	Follow manufacturer's instructions while tcying to reassemble
	Leaking check valves and relief valves in the pump	Repair
	Improper functioning of oil cooler or supply of cooling water cut-off	Check and repair
	Automatic unloading control inoperative	Check and repair
	Restricted lines	If lines are crimped, replace. If partially plugged for any reason remove obsbuction
	Large pump deliveries not unloaded properly	Study circuits and rectifi the fault
	Insufficient radiation	Use artificial cooling
	Reser\roir too small to provide adequate cooling	Replace with larger reservoir or install cooler
	Undersized valves or pipings	Check and repair

FAILURE AND TROUBLESHOOTING OF PNEUMATIC SYSTEM

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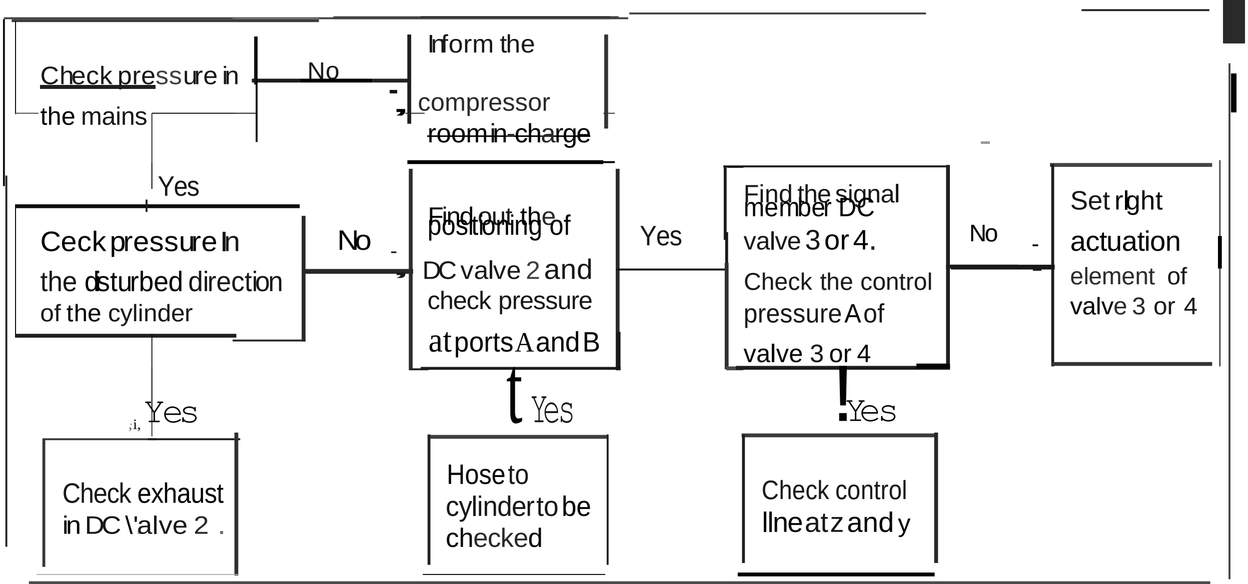
16.3.1. Fault Finding using Troubleshooting Charts

Similar to hydraulie systems, a tree_branching chart shown iFig.'16.2 can be used to find the faults.in pneumatic systems.



16.3.2. Fault Diagnosis of Pneumatic System

Table 16.4 presents the various faults, t_heir symptoms, probable causes, and also the remedial actions that can be taken to prevent them in pneumatic systems.

Table 16.4. Variousfaults, possible causes, and remedies of a pneumatic system and its components

Tlouble/Fault	Probable causes	Remedial actions
I. COM(>RESSORS		
1. Unusual noise	Leakin2 cylinder valve	Adjust and stop leakae
	Loose belt in compressor wheel, motor pulley	Adjust the belt as recommended .
	.t'1otor with excessive end play in shaft	Adjust the end play
	Carbon on top of the piston	De-carbonise
	. Leaking, broken or worn out . constant speed unloader parts	Adjust or replace
	Valve seats wom	Recondition valve seat
	Wot.n-or scored connecting rod, p]ston pin or crank pin beari{lgs	Recondition the connecting rod, replace OI' condition gudgeon pin and crank pin bearings
	Defe!=tive ball beal"ings on crank shaft or on motor shaft	Replace bearings
	Loose motor fan	Ti_ghten the motor fan
	Cylinders or pistons scratched, worn or scored	Rebore cylinder and replace piston
2.Inadequate performance	Dirt in suclion filter	Clean filtering plate and filter disc. Do not use gasoline for danger of explosion
	Defective sealing of cylinder ad	Mount fresh packing of the qrlinder head
	Valve interference through dislocated valve seat and valve guide	Exchange valve insert plate
	Worn out pistons and piston rings as well as worn out cylinder	Exchange iston with rings and also the cylinder if necessary
	Piston rings broken or not sealed	Replace piston rings as per manufacturer's instructions
	End gap not staggered in rooves	Stagger the end gaps, make the rings free in the gtooves
	Rough, scratched or excessive end gaps	Replace
	Cylinders or pisto scratched, worn or scored	Replace or repair

Trouble/Fault	Probable causes	Remedial actions
II. FILTERS		
1. Excessive pressure drop throi.agh filter	Dirty filter element	Replace filter element
	Filter is undersized	Consult manufacturer's flow charts; consider both body, size and port sizes when specifying
2. Contaminants carried through the filter	Elements omitted during servicing	Replace missing elements
	Elements not tightened enough	Tighten elements to prevent bypass
	Broken elements	Replace broken elements
	Element too coarse	Replace with finer graded elements
	Broken end cap from increased pressure drop.caused by dirt build-up on entry side	InstalJ standard pa rticle filter ahead of the coalescing filter
3. Moi!lture in downstream air	Sump of filter bowl has collected too much water and water is re-entering the system	Drain bowl or install automatic drain
	Installation is wrong	Correct installation
	Location is incorrect :filter too dose to the after cooler or.too high in the plant ceiling	Relocate filter or install a dryer
	Body size is too large, causing low velocity and inefficient operation	Consult manufacturer's data
	Dew point of air is too high	install a dryer
4. Plastic bowl crazed and breaking	Incompalible chemicals in contact with the plastic	Unless exact cause can be identified. substitute with metal bowls
	Excessive temperatures, pressures or sunlight	Unless damaging agent can be identified aa.d eliminated, substitute metal bowls
III. REGULATORS.		
1. Regulator cannot reach high set point	Pressure gaugs are inaccurate	Ensure that gauge calibration is a regular maintenance function
	rn5'uffident upstream pressure	Meast.fre and compare inlet pressure with outlet pressure
	Incorrect control spring range	check model number for type used and replace

Trouble/Fault	Probable causes	Remedial actions
	Leakage in downstream circuit	Chee fittings,valves, cylindecs and regulators, correct as required
	Incorrect adjusting technique	To achieve reduced pressure, tum handle counter-clockwise below desire set point, then clockwise back up
2. Set point pressure becomes too high	External loads imposing a higher pressure	Use pressure relief valves, circuit changes or a.venting regulator
	leakage from inlet side :worn out poppet sea'l, seat or balancing seal	Check for lea1'ageai:'d replace parts as necessary
	Non-yenting regulator can aggrevate pressure increase from other causes	Replace witli venijng regulator
3. Air often.escaping from vent hole	External loads imposing a higher pressure	Use pressure relief valves, circuit chang or a ventilating regulator
	Leakage from inlet side :worn out poppet seal, seat, or balancing seal	Check for leakage and replace parts as n cessary
4. Pressure too low when air is flowing	Incorrect adjusng technique	To achieve reduced pressure, tum handle counter-cl<><;kwise below the desired set point then clockwise back up
	Setting altered through vibration	Re-position adjustments and use locking features to secure position
	Leakage in downstream system	Check connections, component seals and correct as required
	Flow reqirement is too high for regulator rating and/or plumbing	Install a larger regulator and/or larger plum.bing
5. Chatter and vibration	Load insmbility from friction, turning over-center or reaching a natural frequency	Requires systein analysis
	Regulator response to load changes is too fast or too slow	Change control springs, poppet return springs or the set-point
	Regulator design has an inherent instability in this application	Change in springs or set-point may help or it may be necessary to switch regulators

Trouble/Fault	Probable causes	Remedial actions
6. Delay or lack of reverse flow	Regulator is not designed for reverse flow	Check manufacturer's specifica lions
	Inlet pressure exhausts too slowly	Check exhaust path for adequate capacity; check path for restricting flow control valves
	Downstream pressure is above the set-points, regulator is exhausting through vent path rather than reverse flow	Alter system conditions to keep downstream pressure at or below set-point before reverse flow starts
IV..LUBRICATORS		
1. Oil not delivered from the lubricator	Empty reservoir bowl	Institute progra1n of regular refilling, or use an automatic refiH system
	Clogged passage ays	Disassemble and dean
	Closed needle valve	Check adjustment
	Tom restrictor	Replace the broken restrictor
	Internal parts incorrectly assembled	Disassembled and reassemble carefully
	Clogged pick-up tube inlet	Clean away debris
	Nonvertical positioning	Reposition and/or relocate the lubricator
2. Oil delivery is delayed	Initial st<irt up delays are natural	Allow a few minu tes of sustained air flow to fill internal passageway in the lubricator with oil
	.lnternal leilkage in oil passageways	Disassemble a11d inspect for missing, damaged or improperly assembled parts
	Clogged pick-up tube inlet	Clean away debris
3. Too much oil ctelivery	Improper needle valve adjustment	Readjust as necessary
	Reverse flow.through the' lubricator	Use a quick exhaust valve at the cylinder port or locate the lubricator just upstream of the quick exhaust
4. Poor component performance even with oil delivery	Tortuous flow path from lubricator	Relocate the lubricator
	Incorrect oil type	Use recommendations of the component manufacturer
	Decrease in oil delivery rate	Periodic variation of flow rate

Trouble/Fa.ult	Probable causes	Remedial actions
	Water condensation inthe oil reservoir may occur in systems left unoperated . for long periods	Manua lly drain from the bottom of the bowl reservoi r
5. Reservoir bowl crazed	(ncompatible oil with plastic material; excessive temperatures. pressures or sunlight	Use only mineral based oils or use metal bowls
V. AIR CYLINDERS		
1. Cylinder fails to move the load when valve is actuated	Binding inmachine linkage	Check linkage to ensure that excessive friction loads are not pre.sent
	Pressuce too low	Check the pressu're at the cylinder to make certain that it is in accordance with circuit requirements
	CyJinder undersized for loads	Re-calc;u late force needs and install appropriate sized cylinders to carry the load
	Piston rod broken at piston end	Disassembled and replace piston rod
2_ Erratic cylinder action	Valve sticking or binding	ca> Check for dirt or gummy deposits (b) Check for wom parts
	Cylittd.er sticking or binding	(a) Check for overtightened packing on rod seal or piston (b) Check for mis-alignment or worn parts
3. Cylinder body seal leak	l,oose tie rods	Tighten the tie rods according to manu facturer's recommendations
	Excessive pressure	Reduce the pressure to the rated limits
	Pinched or extruded seal	Replace the cylinder body seal
	Seal deterioration	Check the compatibility of seal material with the lubricant used
4. Rod gland seal leak	Torn or worn seal	Exarnine the piston rod for dents and nicks. Replace the piston rod if the surface is rough

Trouble/Fault	Probable causes	Remedial actions
5. Excessive or rapid piston seal wear	Seal installed incorrectly	Check installation instructions and make necessary corrections
VI. AIR MOTORS		
1. Motor won't run	Air pressure too low	Check leaking air lines, small capacity hoses and compressor adequacy
	Insufficient lubrication	Proper lubrication by inline oilers or lubricators
	Rotor rubbing	Check the bearing wear
2. Lack of power	Internal air leakage and low air pressure	Check leaking air lines
	Worn vanes	Chipped, cracked, loose or rough edged vanes should be replaced
	Worn bearing plates	(a) If galling is only slight, sanding the plate to remove the burns (b) If wear is excessive replacement is necessary
3. Excessive vane wear	Dirty air	Strainers should be located at the inlet ports to prevent particles of dirt and rust from entering the motor
VII. VALVES		
1. Valve blows to exhaust	Inlet poppet not seating properly	(a) Poppet is damaged, it must be replaced (b) Dirt in poppet seats, clean it (c) Poppet seat damaged. Replace the entire valve body assembly
	Nicked, torn or swelling seals	Replace it
	Cylinder leaks	Leakage in the packing of the air cylinder connected to the valve. Replace the packings
	Damage spools	Replace it
	Air supply pressure too low and causes the valve to actuate partially	Inspect the system for undersized supply lines, sharp bends, fittings and clogged filter elements or a defective pressure regulator and adjust

Trouble/Fault	Probable causes	Remedial ctions
	Water or oil contamination	Ensure that the air is dry and that the air filter is drained frequently
2. Poppet chatb!rs	Low pilot or signal pre:.sure	Check the valve specification for minimum pilot or signal pressme required
3. Spool valve action is sluggish	Swollen seals	Replace it
	Varnish deposi in spool valve	Remove varnish using a water soluble dergent or solvent such as kerosene
	Air supply pressure low	Inspect the system
	Low pilot or signal pressure	Check tha valve specification for minimum pilot or signal pressure requirements
	Poor or no lubrication	Check the system lubricator to see that it is working as it should
	Faulty silencer/ muffler	(u) Remove the silencer to see if valve performance has improved. (b)· Clean the silencer to see if valve performance has improved. (c) Verify if the silencer is of adequate *size*
	Water or oil contamination	Ensure tliat the supply air is dry
4. Air flow is normal only in. actuated position	Broken return spring ·	Replace the return spring
S. Solenoid buzzes	Low voltage at solenoid	Voltage should be checked at the solenoid coil and repaired
6. Solenoid bums out	High transient voltage	Isolate solenoid circuits from main power circuits
7. Sequence valve gives erratic timing .	Faulty piston seal	R.eplace it
	Excessive lubrication	Check the system lubrication
	Fluctuating air pressure set	Install a pressure reguletor at the systems lowest expected pressure
	Ac\.Umulated water	Re-route the pilot supply lines to eliminate low points
8. Flow control valve does not respond to adjustment	Excessive lubrication	Check the system lubrication
	Incorrect installation	[nstaJl properly
	Dirt in valve	Clean the valve·

Trouble/Fault	Probable causes	Remedial actions
VIII. PIPELINES AND HOSES		
1. Pressure drop due to leakage of compressed air	Loose joints, fittings or glands	Tighten them
	Ruptured pipes and hoses	Replace the pipes and hoses
2. Pressure rises at specific points	Pipes, hoses are blocked	Clean and remove dirt
	Pipes, hoses are bent	Change them
3. Noise level is high	Silencer stops working	Clean it

15.8.1. htroduction

Program mable logic controller (PLC) is one of the important micro-processor based controller. As we aware, microprocessor has a tremendous impact on industrial control and instrumentation due to its high rnliability and flexibility at the design and impiementation stages. The decreasing cost of microprocessors with increa_sing facilities in them are acting as catalyst in their ':"idening scope of applications. In recent years. PLCs are being used in plce of electro-mechanical relays or cam-ope!"ated logic controllers to control fluid power systems.

15.8.2. What s a Programmable Logic Controller (PLC) ?

./ *Defi11ilion : A programmable logic controller (PLC) _can be defined as a digital electronic device that uses a programmable memory to store instructions and to implement functions such as logic, seq_uencing, timing, counting, and arithmetic in order to control machines and processes.*

./ ln simple terms, a PLC is a user-friendly electronic computer designed to perform logic functions such as AND, OR, and NOT for controllng the operation of industrial equipment and processes.

./ Thus a PLC consists of solid-state digital logic elements for making logic decisions and providing corresponding outputs.

./ Basically, PLCs are designed as a replacement for hard-wired electro-mechanical relays to control fluid power systems.

15.8.3. PLCs Vs Computers

PLCs are similar to genel,"al-purpose compute1s. But PLCs have certain features which are specific to their use as controllers. Some of the important features of PLCs are :

1. PLCs are rugged and designed to withstand vibrations. temperature, humidity, and noise.
2. The interfacing for inputs and outputs is inside the controller.
3. They are easily programmed and have an easily understood programming language. Programming is primarily concerned with logic an switching operations.

15.8.4. Advantages of PLCs over Electromechanical Relays

The PLCs replace electr':'mechanical relays due to their following advantages :

1. PLCs are more reliable and faster in operation.
2. They are smaller in size and can be more readily expanded.
3. They require less electrical power.

4. They are less expensive when .compared to electromecha,nic I relays for the same number of control functions.
5. Hard-wired electromechanical relays lack flexibility. For instance when system operation requi rements change, then the relays have to be rewired.
6. PLCs have very few hardware failure when compared to electro-mechanical relays.
7. Special flinctions such as time-delay actions and counters. can be easily performed using PLCs.

15.9. MAJOR UNITS OF A PLC

A PLC consists ote_tree major elements,, as-shown in Fig.15J7. They are:

1. Central processing unit (CPU),
2. Programmer/mo itor (PM). and
3. Input/output module (1/0).

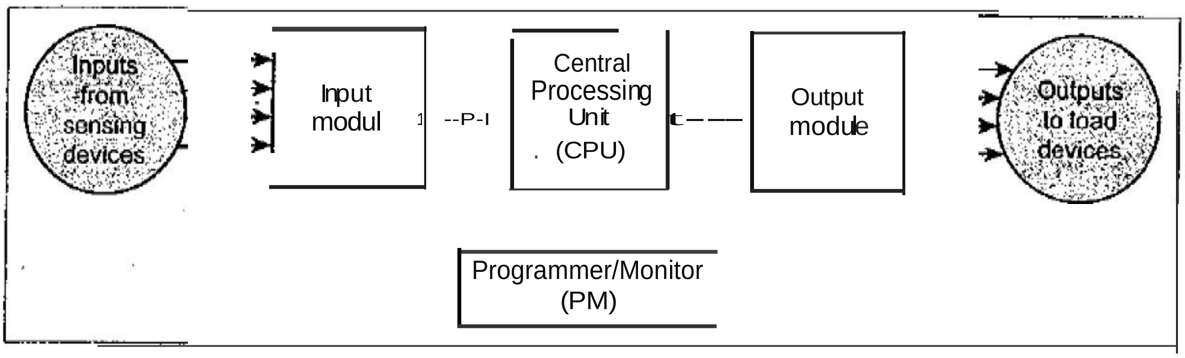


Fig. i5.17. Block diagram of a PLC

15.9.1. Central Processing Unit (CPU)

./ The CPU controls and processes an the operations within the PLC, that's why this uni is referred as the 'brain' of the PLC.

./ *F1111ction :* The CPU (z) receives input data from various sensing devices such as switches, (ii) executes the stored program, and *(iii)* delivers correspondin g output signals to various load .control devices such as relay coils and solenoids.

,..{ It consists a microprocessor with a fixed memory (ROM-'re.ad only memory') and a variable memory (RAM 'random access memory').

:5;9.2. Programmer/Monitor (PM)

./. The programmer/monitor unit allows the user to enter th desired programme into t11e RAM.

:-1' The programme which is entered in relay logic (in RAM) determines the sequence of operation of the system to be controlled.

15.9.3. Input/Output Module (1/0)

- This module interfaces between the fluid power system input sensing and output load devices and the CPU.
- *Function :* The purpose of the 1/0 module is to transform the various signals received from or sent to the fluid power interface devices (such as push-button switches, pressure switches, limit switches, solenoid coils, motor relay coils, and indicator lights).

?flQ:E;e.a'G .M Mf t:f [i/::_:.;:<.: :< .:.:.;._ ·:' ·:;·, ::(,):/;..:>L\r.;:::1:: :\Jh'h.ff{J:Jf 1&£ N!;f\i

15.10.1. What is mean by Ladder Programming ?

- The basic fonn of programming commonly used with PLCs is *ladder programming*.
- PLC programming based on the use of ladder diagrams involves writing a program in a similar manner to drawing a switching circuit.
- The ladder diagram consists of two vertical lines representing the power Jines. Circuits are connected as horizontal lines. *i.e.*, the rungs of the ladder, between these two verticals.

15.10.2. PLC Ladder Symbols

- Fig. 15.18 shows the basic standard symbols that are used.
- Fig. 15.19 shows an example of rungs in a ladder diagram.

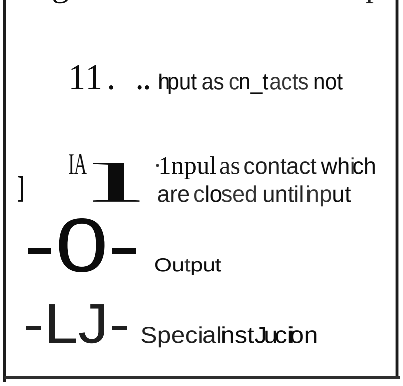


Fig. lS.18. Symbol

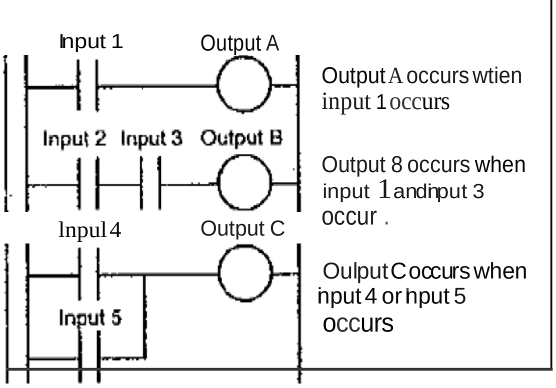


Fig. 15.J9. £xomple of ru11gs i11 a ladder diagram

15.10.3. Construction

[n drawing the circuit line for a rung, inputs must always precede outputs and there must be at least one output on each line. Each rung start with an input or a series of inputs and end with an output.

The inputs and outputs are numbered, the notation used depending on the manufacturer. For example, the Mitsubishi F series of PLCs precedes input elements by an X and output elements by a Y and uses the following numbers :

Inputs X400–407,410-413

X500–507, 510–513

: (24 possible inputs)

Outputs Y430-437

Y530–537

(16 possible outputs)

15.10.4. Illustration of Drawing a PLC Ladder Diagram

Consider an example of a solenoid valve which opens to allow water to enter a vessel. This situation, where the output from the PLC is to energise a solenoid wi1en a normally open start switch connected to the input is being closed, is shown in Fig. 152(a). The PLC ladder diagram for the situation is shown in Fig.15.20(b).

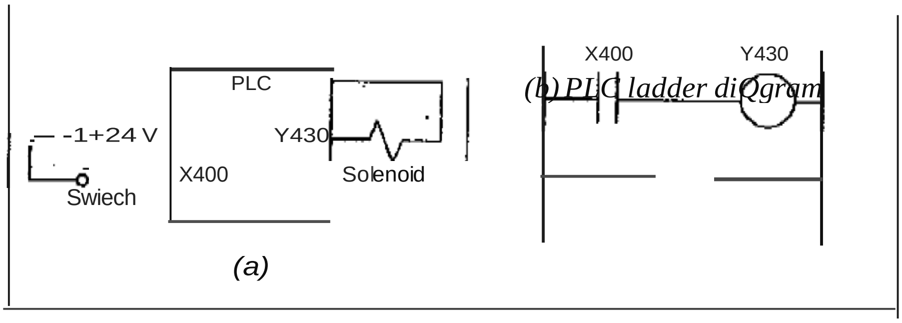


Fig. 15.10. Illustration of 1ritwi1rg ≮ PLC lmlder dillgram

Starting with the input, we have the normally open symbol 11. This might have an input address X400. The Une terminates with the output, the solenoid, with the symbol O. Thjs might have the output address Y430. To indicate the end of the program the end rung is marked. When the switch is closed the solenoid is activated.

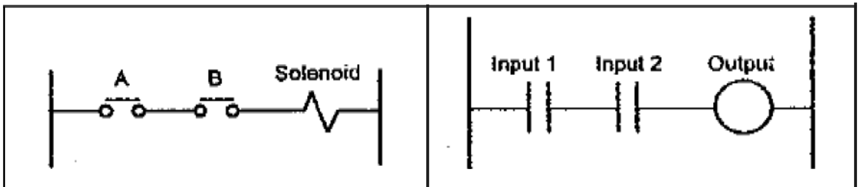
15.11. PLC LADDER PROGRAMS FOR LOGIC FUNCTIONS

The logic functions (such as AND, OR, NOR, *etc.)* can be obtained by combinations of switches (such as limit switches, solenoid coils, *etc.).* The following sections show how we can write PLC Jadder programs for such combinations.

1611.1. AND Logic Function

Fig.15.21(a) shows a situatiqn where a coiI is not energized unless two, normally open, switches are both closed. Switch A and switch B have both to be c1osed, which thus gives an A.ND logic situation.

Fig.1521*(b)* shows the PLC ladder diagram for the AND logic function shown in Fig.J 5.21(a). In Fig.15.2l(b), the ladder diagram starts with II,labelled Input i-, to represent fWitch A and in series with it 11, labelled Input 2, to represent switch B. The line then n?inates with O to represent the output.

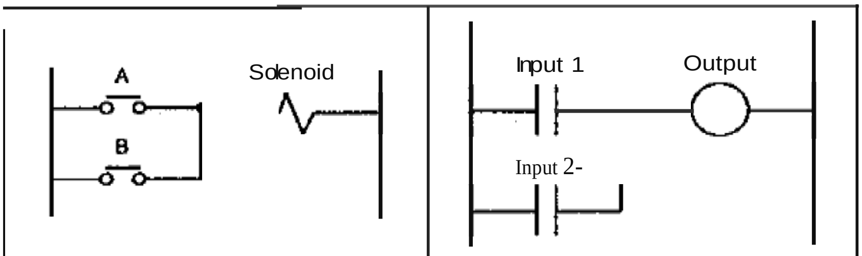


(a)AND logic situation (b) PLC ladder diagram

Fig. 15.21.A11 AND system

15.11.2. OR Logic Function

Fig.15.42(a) shows a situation where a__coil is not energized until either, normally open, switch or B is closed. This situation is an OR logic gate.



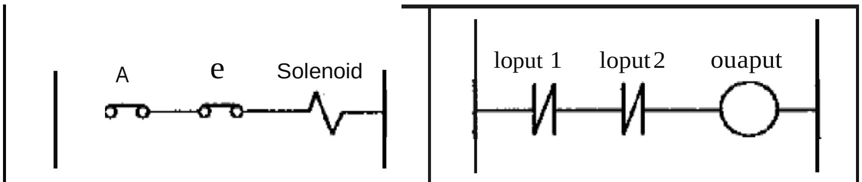
(a) OR logic situatio1t (b) PLC ladder diagram

Fig. 15.22.Ari OR system

Fig.15.22(b) shows the PLC ladde diagram for the OR logic gate shown in Fig.15.22(a). In Fig.15.22(b), the ladder diagram starts with 11. labelled Input 1, to represent A and in parallel with it 11 labelled Input 2, to represent switch B. The line then terminates with O to represent the output.

15.11.3. NOR Logic Function

Fig.15.23(a) shows a NOR logic gate situation. Fig.15.23(b) shows the PLC ladder program for the NOR gate shown in Fig.l 5.23(a). Since there has to be an otput when neithr A nor B have an input and when there is an input to A or B the output stops, the ladder program shows Input 1 in parallel with Input 2, with both being represented by normally closed contacts.

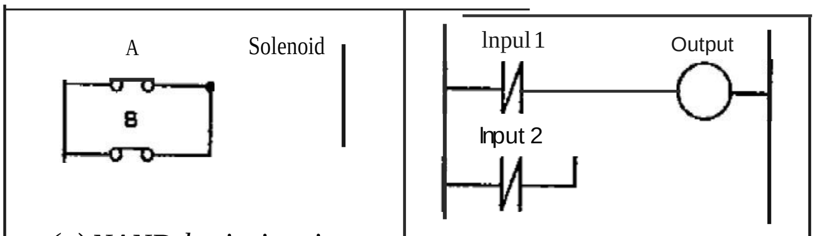


(a)NOR logic sit11alion (b) PLC ladder diagram

Fig.J5.23. A NOR system

15.11.4. NANO Logic Function

Fig.15.24(a) shows a NANO logic gate situation. Fig.15.24{b) shows the PLC ladder program for the NANO gate shown in Fig.15.24(a). There is no output when both A and B have an input. Thus for the ladder program line to obtain we require no inputs to Input t and fo'' [nput 2.



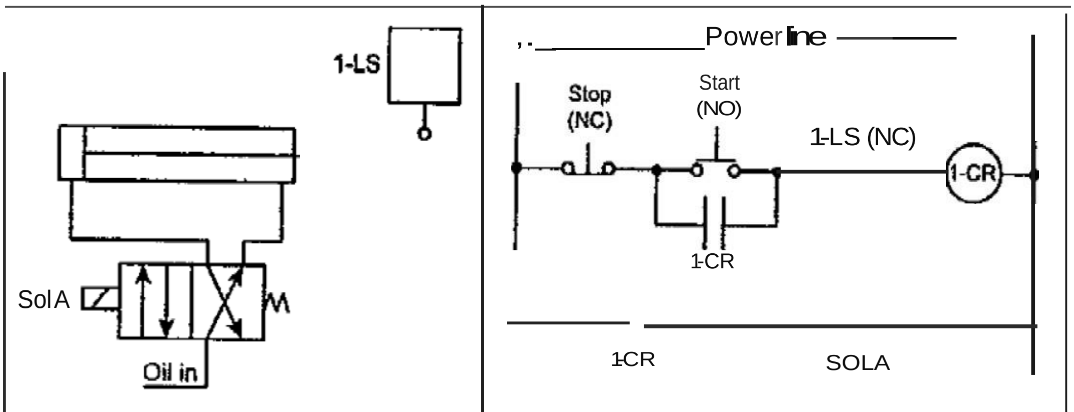
(a) NAND logic situation (b) PLC ladder diagram

Fig. 15.14. A NAND system

15.12. PLC CONTROL OF A HYDRAULIC CYLINDER

15.12.1. Circuit and Relay Ladder Diagram

Consider a system, shown in Fig.15.25, which' is used to control a double-acting hydraulic cylinder usi ng a single limit switch. Fig.15.25(b) shows the hard-wired relay ladder diagran for system shown in Fig. l5.25(a).



(a) Hydralilic circuit (b) Hard-wired relay ladder diagram

Fig.15.25. Control of a ltytlrau/ic cylincler 11si11g a single limit swltcli

15.12.2. PLC Ladder Logic Diagram

Fig. 15.26 shows a PLC ladder logic diagram for the equivlent hard-wired relay ladder iagram shown in Fig.l5.25(b). It may be noted that the layout of both diagrams are similar. The two rungs of the relay ladder diagram are converted to two rungs of the PLC ladder logic 4iagram.

: Since the input modules act like relays, the relay contacts are substituted for original switch contacts (with the prefix X followed by a umber) and output modules are substituted by relay coils (with the prefix Y followed by a number).

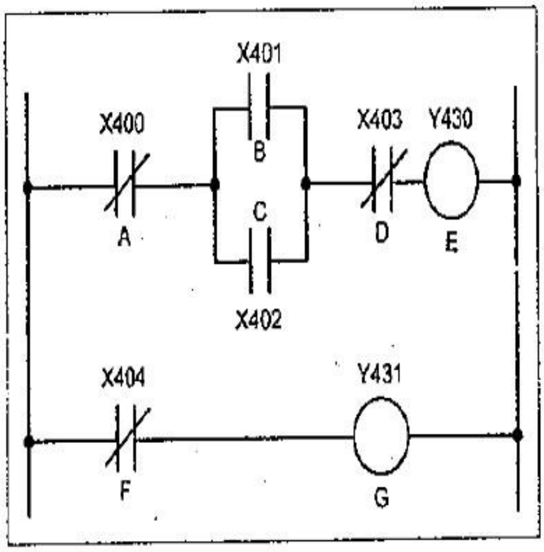


Fig. 15.26. PLC ladder logic diagrams

15.12.3. Boolean Equations

We know that the PLC performs operations based on logic functions. Each rung of a ladder diagram be represented by a Boolean equation. For this purpose, the capital letters A, B, C, *etc.* are used to represent each electrical component in the Fig.15.36. Now the Boolean equations can be written for each rung as follows :

Top Rung : $\bar{A} \cdot (B + C) \cdot \bar{D} = E$

This equation can be read as : NOT A AND (B OR C) AND NOT D EQUALS E. We know that OFF state can be represented by 0 and ON state by 1. This equation means that E is energized when A is NOT actuated AND B OR C is actuated AND D is NOT actuated.

Bottom rung : $F = G$

This means that G is energized when F is actuated.

LOW COST AUTOMATION

Low Cost Automation promotes cost effective reference architectures and development approaches for production and transportation that properly integrates human skill and technical solutions, includes shop floor production support and decentralized process control strategies, addresses automation integrated with information processing as well as automation of non-sophisticated and easily handled operations for productive maintenance.

Low Cost Automation is not an oxymoron like military intelligence or jumbo shrimps. It opposes the rising cost of sophisticated automation and propagates the use of innovative and intelligent solutions at affordable cost. The concept can be regarded as a collection of methodologies aiming at exploiting tolerance for imprecision or uncertainties to achieve tractability, robustness and in the end low cost solutions. Mathematically elegant design of automation systems are often not feasible because of neglecting the real world problems, i.e. they are failure-prone and therefore often very expensive for their users. Low Cost Automation does not mean basic or poor performance control. The design of automation systems considers its life cycle with respect to cost: **cost oriented automation**. Batch processing in manufacturing with decreasing lots, but increasing part complexity as well as mixed parts to be manufactured, demands for intelligent automation integrated with human capabilities of experience and knowledge regarding shop floor control and maintenance to save cost: **cost effective automation**. Soloman (1996) points to shortening product life cycles that need more intelligent, faster and adaptable assembly and manufacturing processes with reduced set-up, reconfiguration and maintenance time. Machine vision, despite partly of costly components, properly applied can reduce manufacturing cost (Lange & Hirzinger, 2002). In order to survive in a competitive market it is essential that manufactures have the capability to deploy rapidly affordable automation with minimum downtime. This capability to adapt to a changing manufacturing environment results in cost saving and increased production. The concept of low cost automation or **affordable** automation is the provision of the human mind (Soloman, 1996).

The reliability of low cost automation is independent on the grade of automation, i.e. to cover all possible circumstances in its field of application. Often it is more suitable to reduce the grade and involve human experiences and capabilities to gap the bridge between theoretical findings and practical requirements. On the other hand, theoretical findings in control theory and practice foster intelligent solutions with respect to saving cost. Anyway, reliability is a must of all automation systems, but this requirement has no one-to-one relation to cost. As an example one may consider Computer Integrated Manufacturing (CIM). The original concept connected the design of parts automatically to the machines at the workshop via shop floor planning and scheduling software, thereby using a lot of costly components and instruments. After a while this kind of automation turned out to be very costly, because of a centralized control had to fight against uncertainties and unexpected events. A decentralization of the control and the involvement of human experience and knowledge along the added value chain of the production process required less sophisticated hard- and software and reduced the manufacturing cost and got CIM to its breakthrough even in small and medium sized enterprises (SMEs).

Low cost automation concerns also the implementation of an automation system. This should be as easy as possible and besides facilitate the maintenance. Maintenance is very often the crucial point and an important cost-factor to be considered. A standardization of components of automation systems could also be very helpful to reduce cost, because it fosters the usability, the distribution and innovation in new applications, i.e. fieldbus technology in manufacturing and building automation.

Low Cost Automation as a cross-sectional field in automatic control mostly not develops new control concepts but uses combinations of it and an integration of information technology.