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POLLACHI INSTITUTE OF ENGINEERING AND TECHNOLOGY

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Department of Mechanical Engineering

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III Year – V Semester

ME3492 HYDRAULICS AND PNEUMATICS

HYDRAULICS AND PNEUMATICS

UNIT I FLUID POWER PRINICIPLES AND HYDRAULIC PUMPS
Introduction to Fluid power – Advantages and Applications – Fluid power systems – Types of fluids– Properties of fluids and selection – Basics of Hydraulics – Pascal's Law – Principles of flow – Friction loss – Work, Power and Torque Problems, Sources of Hydraulic power : Pumping Theory – Pump Classification – Construction, Working, Design, Advantages, Disadvantages, Performance, Selection criteria of Linear and Rotary – Fixed and Variable displacement pumps – Problems.

UNIT II HYDRAULIC ACTUATORS AND CONTROL COMPONENTS
Hydraulic Actuators: Cylinders – Types and construction, Application, Hydraulic cushioning – Hydraulic motors – Control Components: Direction Control, Flow control and pressure control valves – Types, Construction and Operation – Servo and Proportional valves – Applications – Accessories: Reservoirs, Pressure Switches – Applications – Fluid Power ANSI Symbols – Problems.

UNIT III HYDRAULIC CIRCUITS AND SYSTEMS
Accumulators, Intensifiers, Industrial hydraulic circuits – Regenerative, Pump Unloading, Double- Pump, Pressure Intensifier, Air-over oil, Sequence, Reciprocation, Synchronization, Fail-Safe, Speed Control, Hydrostatic transmission, Electro hydraulic circuits, Mechanical hydraulic servo systems.

UNIT IV PNEUMATIC AND ELECTRO PNEUMATIC SYSTEMS
Properties of air – Perfect Gas Laws – Compressor – Filters, Regulator, Lubricator, Muffler, Air control Valves, Quick Exhaust Valves, Pneumatic actuators, Design of Pneumatic circuit – Cascade method – Electro Pneumatic System – Elements – Ladder diagram – Problems, Introduction to fluidics and pneumatic logic circuits.

UNIT V TROUBLE SHOOTING AND APPLICATIONS
Installation, Selection, Maintenance, Trouble Shooting and Remedies in Hydraulic and Pneumatic systems, Design of hydraulic circuits for Drilling, Planning, Shaping, Surface grinding, Press and Forklift applications. Design of Pneumatic circuits for Pick and Place applications and tool handling in CNC Machine tools – Low cost Automation – Hydraulic and Pneumatic power packs.

TEXT BOOKS

1. Majumdar S.R., "Pneumatic systems – Principles and maintenance", Tata McGraw Hill, 1995

2. Anthony Lal, "Oil hydraulics in the service of industry", Allied publishers, 1982.

3. Anthony Esposito, "Fluid Power with Applications", Pearson Education 2000.

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3. Majumdar S.R., "Pneumatic systems – Principles and maintenance", Tata McGraw Hill, 1995

4. Anthony Lal, "Oil hydraulics in the service of industry", Allied publishers, 1982.

5. Harry L. Stevart D.B, "Practical guide to fluid power", Taraoeala sons and Port Ltd. Broadey, 1976.

6. Michael J, Prinches and Ashby J. G, "Power Hydraulics", Prentice Hall, 1989.

7. Dudelyt, A. Pease and John T. Pippenger, "Basic Fluid Power", Prentice Hall, 1987.

UNIT I
FLUID POWER PRINICIPLES AND HYDRAULIC PUMPS

FLUID POWER:

Fluid power is the technology that deals with the **generation, control, and transmission of power** – using pressurized fluids. It is used to push, pull, regulate, or drive virtually all the machines of modern industry.

For example, fluid power steers and brakes automobiles, launches spacecraft, move earth, harvests crops, mines coal, drives machine tools, controls airplanes, processes food, and even drills teeth.

Since a fluid can be either a liquid or a gas, fluid power is actually the general term used for hydraulics and pneumatics. *Hydraulic systems use liquids such as petroleum oils, water, synthetic oils, and even molten metals the first hydraulic fluid to be used was water because it is readily available. However, water has many deficiencies. It freezes readily, is a relatively poor lubricant, and tends to rust metal components.* Hydraulic oils are far superior and hence are widely used in lieu of water. Pneumatic systems use air as the gas medium because air is very abundant and can be readily exhausted into the atmosphere after completing its assigned task.

FLUID SYSTEMS:

Two different types of fluid systems: **fluid transport and fluid power.**

Fluid transport systems have as their sole objective the **delivery of a fluid** from one location to another to accomplish some useful purpose. Examples include pumping stations for pumping water to homes, cross- country gas lines, and systems where chemical processing takes place as various fluids are brought together.

Fluid power systems are designed specially to **perform work.** The work is accomplished by a **pressurized fluid bearing directly on an operating cylinder or fluid motor**, which, in turn, provides the muscle to do the desired work. Of course, control components are also needed to ensure that the work is done smoothly accurately, efficiently, and safely.

Liquids provide a very rigid medium for transmitting power and thus can provide huge forces to move loads with almost accuracy and precision. On the other hand, pneumatic systems exhibit spongy characteristics due to the compressibility for air. However, pneumatic systems are less expensive to build and operate. In addition, provisions can be made to control the operation of the pneumatic actuators that drive the loads.

Fluid power equipment ranges in size from huge hydraulic presses to miniature fluid logic components used to build reliable control systems.

Advantages of Fluid Power

1. **Ease and accuracy of control.** By the use of simple levers and push buttons, the operator of a fluid power system can readily start, stop, speed up or slow down, and position forces that provide any desired horsepower with tolerances as precise as one ten-thousandth of an inch. A fluid power system that allows an air craft pilot to raise and lower his landing gear. When the pilot move a small control valve in one direction, oil under pressure flows to one end of the cylinder to lower the landing gear. To retract the landing gear, the pilot move the valve lever in the opposite direction, allowing oil to flow into the other end of the cylinder.

2. **Multiplication force.** A fluid power system (without using cumbers some gears, pulleys, and levers) can multiply forces simply and efficiently form a fraction of an ounce to several hundred tons of output. A rugged, powerful drive is required for handling huge logs. In this case, a turntable, which is drive by a hydraulic motor, can carry a 20,000 – 1b load at a 10ft radius under rough operating conditions.

3. **Constant force or torque.** Only fluid power systems are capable of providing constant force or torque regardless of speed changes. This is accomplished whether the work output moves a few inches per hour, several hundred inches per minute, a few revolutions per hour, or thousands of revolutions per minute. An application in oceanography that involves the exploration and development of the ocean's resources for the benefit of humankind. In this instance, it is important for the operator to apply a desired constant grabbing force through the use of the grappling hooks.
4. **Simplicity, safety, economy.** In general, fluid power systems use fewer moving parts than comparable mechanical or electrical systems. Thus, they are simpler to maintain and operate. This, in turn, maximizes safety, compactness, and reliability, power steering control designed for off – highway vehicles. The steering unit.

Additional benefits of fluid power systems include instantly reversible motion, automatic protection against over loads, and infinitely variable speed control. Fluid power systems also have the highest horse power per weight ratio of any known power source.

DISADVANTAGES:

In spite of all these highly desirable features of fluid power, it is not a panacea for all power transmission problems. Hydraulic systems also have some draw backs. Hydraulic oils are messy, and leakage is impossible to eliminate completely. Hydraulic lines can burst, possibly resulting in human injury due to flying objects, if proper design is not implemented. Also, most hydraulic oils can cause fires if an oil leak occurs in an area of hot equipment. Therefore, each application must be studied thoroughly to determine the best overall design. It is hoped that this book will not only assist the reader in developing the ability to make these types of system selection decisions but also present in a straight forward way the techniques for designing, analyzing, and troubleshooting basic fluid power systems.

Applications of Fluid Power

1. **Fluid power drives high-wire over head tram.** Most overhead trams require a haulage or low cable to travel up or down steep inclines. However, the 22 passenger, 12,000 –lb hydraulically powered and controlled sky tram is unique. It is self- propelled and travels on a stationary cable. Because the tram moves instead of the cable, the operator can stop, start, and reverse any one car completely independently of any other car in the tram system. Integral to the design of the Sky tram drive is a pump (driven by a standard eight – cylinder gasoline engine), which supplies pressurized fluid to four hydraulic motors. Each motor drives two friction drive wheels.

2. **Fluid power is applied to harvest corn.** The world's dependence on the United States for food has resulted in a great demand for agricultural equipment development. Fluid power is being applied to solve many of the problems dealing with the harvesting of food crops.

3. **Hydraulics power brush drives. F**luid power-driven brush drive used for cleaning roads, floors, etc., in various industrial locations. Mounted directly at the hub of the front and side seep- scrub brushes, compact hydraulic motors place power right where it's needed. They eliminate bulky mechanical linkages for efficient, light weight machine design. They eliminate bulky mechanical linkages for efficient, lightweight machine design. The result is continuous, rugged industrial cleaning action at the flip flop of a simple valve.

4. **Fluid power positions and holds part for welding.** Welding operation in which a farm equipment manufacturer applied hydraulics for positioning and holding parts while welding is done. It is a typical example of how fluid power can be used in manufacturing and production operations to reduce costs and increases production.
5. **Fluid power performs bridge maintenance.** A municipality used fluid power of years as a means for removing stress from structural members of bridges, making repairs, and replacing beams.

6. **Fluid power is the muscle in industrial lift trucks. H**ydraulic lift truck having a 5000 – 1b capacity. The hydraulic system includes dual – action tilt cylinders and a hoist cylinder. Tilting action is smooth and sure for better load stability and easier load placement. A lowering valve in the hoist cylinder controls the speed of descent even if the hydraulic circuit is broken. Hydrostatic power steering is available as an optional feature.
7. **Fluid power drives front- end loaders. F**ront – end loader filling a dump truck with solid scooped up by a large hydraulic – powered bucket. Excellent load control is made possible with a specially designed flow control valve. The result is low effort and precise control; this keeps the operator working on the job longer and more efficiently. Thus, reduced operator fatigue is accompanied by increased production.
8. **Fluid power preserves the hear beat of life.** Dr. Robert Jarvik made medical history with the design of an artificial, pneumatically actuated heart, which sustained the life of Dr. Barney Clark for over 100 days. Other health applications include artificial kidneys and valve –assisted bladders, which employ fluid power principle of pressure and flow. Miniature, oxygen-tight pumps are implanted in patients to provide continuous medication. These micro delivery pumps can either be permanent for internal use or disposable for external infusion of medicine.

9. **Hydraulics power robotic dexterous arm. A** hydraulically powered robotic arm that has the strength and dexterity to torque down bolts with its fingers and yet can gingerly pick up an eggshell. This robotic arm is adept at using human tools such as hammers, electric drills, and tweezers and can even bat a base ball. The arm has and with a thumb and two fingers, as well as wrist, elbow, and shoulder. It has ten degrees of freedom, including a three – degree of freedom end effecter (hand) designed to handle human tools and other objects with human like dexterity. The servo control system is capable of accepting computer or human operator control inputs. The system can be designed for carrying out hazardous applications in the subsea, utilizes, or nuclear environments, and it is also available in a range of sizes from human proportions 6 ft long.

Types of Fluid power control systems

Fluid power systems are also classified by the type of control system utilized. There are five basic types of fluid power control systems; closed-loop, open-loop electrical, fluid logic, and programmable logic. The following is a brief description of each of these five control systems.

1. **Closed – loop control system.** A closed – loop system is one that use feedback. This means that the state of the output from the system is automatically sampled and compared (feedback) to the input or command signal by means of a device called a feedback transducer. If there is a difference between the command and feedback signals, action is taken to correct the system output until it matches the requirement imposed on the system. Closed-loop systems are frequently called servo systems, and the valves used to direct fluid to the actuators are typically called servo valves.

2. **Open – loop control system.** An open – loop system does not use feedback. The output performance of the system: therefore depends solely on the characteristics of the individual components and how they interact in the circuit. Most hydraulic circuits are of the open-loop systems. This is because any errors such as slippage (oil leakage past seals, the magnitude of which depends on system pressure and temperature) are not compensated for in open-loop type, which are generally not so complex or as precise as closed –loop systems. This is because any errors such as slippage (oil leakage past seals, the magnitude of which depends on system pressure and temperature) are not compensated for in open loop systems. For example, the viscosity of a hydraulic fluid decreases (fluid becomes thinner) as its temperature rises. This increases oil leakage past seals inside pumps, which, in turn causes the speed of an actuator, such as a hydraulic motor, to drop. In a closed –loop system, a feedback transducer (for example, a taco meter, which generates a signal proportional to the speed at which it is rotated) would sense this speed reduction and feed a proportional signal back to the command signal. The difference between the two signals is used to control a servo valve, which would then increase the fluid flow rate to the hydraulic motor until its speed is at the required level.

3. **Electrical control system.** This type is characterized by the fact that the fluid power system interacts with a variety of electrical components for control purposes, and relays can be used to operate electrical solenoids to control the operations of valves that direct fluid to the hydraulic actuators. An electrical solenoid control system permits the design of a very versatile fluid power circuit. Automatic machines such as those used in the machine – tool industry rely

principally on electrical components control the hydraulic muscles for doing the required work. The air craft and mobile equipment industries have also found that fluid power and electricity work very well together, especially where remote control is needed. By merely pressing a simple push-button switch, an operator can control a very complex machine to perform hundreds of machinery operations to manufacture a complete product. An electrically controlled fluid power system can be either of the open –loop or closed –loop type, depending on the precision required.

4. **Fluid logic control system.** This type is characterized by the fact that the fluid power system interacts with fluid logic device instead of with electrical devices for control purposes. Two such fluid logic systems are called moving-part logic (MPL) and fluidics, which perform a wide variety of sensory and control functions. Among these control functions are AND/NAND, OR/NOR, and FLIPFLOP, logic capability. Fluid logic devices switch a fluid, usually air, from one outlet of the device to another outlet. Hence an output of a fluid logic device is either ON or OFF as it rapidly switches from one state to the other by the application of a control signal.

5. **Programmable logic control system.** In this type, programmable logic controllers (PLCs) are used to control systems operation. In recent years. PLCs have increasingly been used in lieu of electromechanical relays to control fluid power systems. A PLC is a user –friendly electronic computer designed to perform logic functions such as AND, OR, and NOT for controlling the operation of industrial equipment and processes. A PLC consist of solid – state digital logic elements for mating logic decision and providing corresponding outputs. Unlike general- per-pose computers, a PLC is designed to operate in industrial environments where high ambient temperature and humidity levels may exists. PLCs offer a number of advantages over electromechanical relay control systems. Unlike electromechanical relays, PLCs are not hard – wired to perform specific functions. Thus, when system operation requirements change, a software program is readily changed instead of having to physically rewire relays. In addition, PLCs are more reliable. Faster in operation, smaller in size, and can be readily expanded.

General types of fluids.

The first major category of hydraulic fluids is the petroleum-based fluid, which is the most widely used type. If the crude oil is quality-refined, it is generally satisfactory for light services. However, additives must be include to meet with the requirements of good lubricity, high viscosity index and oxidation resistance. Most of the desirable properties, if not already present in the petroleum oil, can be obtained by the addition of additives. The primary disadvantage of a petroleum- based fluid is that it will burn.

The second category of fluids has been developed: the fire – resistant fluid. This greatly reduces the danger of a fire. However, fire – resistant fluid generally have higher specific gravity than do petroleum – based fluids. This may cause cavitations problems in the pump due to excessive vacuum pressure in the pump inlet line unless proper design steps are implemented. Also most fire – resistant fluids are more expensive and have more compatibility problems with seal materials. Therefore, fire – resistant fluids should be used only if hazardous operating conditions exist. Manufacturer's recommendations should be followed very carefully when changing from a petroleum – based fluid to fire – resistant fluid and vice versa. Normally, thorough draining, cleaning, and flushing are required. It may even be necessary to change seals and gaskets on the various hydraulic components.

A third category is the conventional MS (most severe) engine – type oil, which provides increased hydraulic system life due to better lubricity. This is due to the antiwar additives used to prevent engine wear on cams and valves. This improved lubricity also provides wear resistance for the heavily loaded hydraulic components such as pumps and valves.

The fourth category of fluid is air itself. Air is the only gas commonly used in pneumatic fluid power systems. The reason is that air is inexpensive and readily available. One of the significant advantages of air is that it will not burn. Air can easily be made clean by the use of a filter, and any leaks are not messy since they simply dissipate into the atmosphere. Air can also be made a good lubricant by the introduction of a fine oil mist using a lubricator. Also, the use of air eliminates return lines since the spent air is exhausted into the atmosphere. Disadvantages of air include its compressibility and subsequent sluggishness and lack of rigidity. Finally, air can be corrosive since it contains oxygen and water. However most of the water can be removed by the use of air dryers.

In summary, the single most important material in a fluid power system is the working fluid. No single most important material in a fluid power system is the working fluid. No single fluid possesses all the ideal characteristics desired. The fluid power designer must select the fluid that comes the closer to being ideal over all for a particular application. Only if a fire hazard is present should a fire resistant fluid be used. The most expensive fluid is not necessarily the best one to use.

Properties of Hydraulics fluids

VISCOSITY:

Viscosity is probably the single most important property of a hydraulic fluid. It is a measured of the sluggishness with which a fluid moves. When the viscosity is low, the fluid flows easily because it is thin and has low body. A fluid that flows with difficulty has a high viscosity for a given hydraulic system is a compromise. Too high a viscosity results in

1. High resistance to flow, which causes sluggish operation.
2. Increased power consumption due to frictional losses.
3. Increased pressure drop through valves and lines.
4. High temperatures caused by friction.

On the other hand, if the viscosity is too low, the result is

1. Increased leakage losses past seals.
2. Excessive wear due to breakdown of the oil film between moving parts. These parts may be internal components of a pump or even sliding valve spool inside its valve body.

Viscosity is often expressed in the CGS metric system. In the CGS metric system. The units are

$$\mu = \frac{T}{v/y} = \frac{dyne/cm^2}{(cm/s)/cm} = dyne.s/cm^2$$

Where a dyne is the force that will accelerate a 1-g mass at a rate of $1cm/s^2$. The conversions between dynes and newton's and between centimeters (cm) and meters (m) are as follows:

$1N=10^5$ dynes
1m=100cm

A viscosity of 1 dyne's/cm^2 is called a poise.

Calculations in hydraulic systems often involve the use of kinematic viscosity rather than absolute viscosity. Kinematic viscosity (v) equals absolute viscosity (μ) divided by mass density (ρ):

$$\nu = \frac{\mu}{\rho}$$

Checking units for ν in the English system, we have

$$\nu = \frac{dyne.s/cm^2}{g/cm^2} = \frac{dyne.s/cm^2}{\left(dyne/cm^2\right)/\left(cm/s^2\right)} = cm^2/s$$

Where 1 kilogram (kg) equals 1000 grams (g).

The viscosity of a fluid is usually measured by a sysbolt viscosimeter basically, this device consists of an inner chamber containing the sample of oil to be tested. A separate outer compartment, which completely surrounds the inner chamber, contains a quantity of oil whose temperature is controlled by an electrical thermostat and heater. A standard orifice is located at the bottom of the center oil chamber. When the oil sample is at the desired temperature, the time it takes to fill a 60-cm^3 container through the metering orifice is then recorded. The time (t), measured in seconds, is the viscosity of the oil in official units called saybolt universal seconds (SUS). Since a thick liquid flows slowly, the SUS viscosity will be higher than for a thin liquid.

A relationship exists between the viscosity in SUS and the corresponding metric system units of centistokes (cS). This relationship is provided by the following empirical equations.

$$v(cS) = 0.226t - \frac{195}{t'} t \le 100SUS \qquad (2\text{-}19)$$

$$v(cS) = 0.220t - \frac{135}{t'} t \le 100SUS \qquad (2\text{-}20)$$

Where the symbol v represents the viscosity in centistokes and t is measured SUS or simple seconds.

VISCOSITY INDEX:

The viscosity index (V.I.) of an oil is a number that indicates the effect of temperature changes on the viscosity of the oil. A low V.I. signifies a relatively large change of viscosity with changes of temperature. In other words, the oil becomes extremely thin at high temperatures and extremely thick at low temperatures. On the other hand, a high V.I. signifies relatively little change in viscosity over a wide temperature range.

Oxidation

Oxidation which is caused by the chemical reaction of oxygen from the air with particles of oil, can seriously reduce the service life of a hydraulic fluid.

Corrosion

Corrosion is the chemical reaction between a metal and acid. The result of rusting (or) corrosion is the "eating away" of the metal surfaces of hydraulic components.

Flammability

Flammability is defined as the case of ignition and ability to propagate a flame.

Flash point

The temperature at which the oil surface given off sufficient vapors to ignite when a flame is passed over the surface

Fire point

The temperature at which the oil will release sufficiency vapour to support combustion continuously for fire seconds when a flame is passed over the surface.

Autogenously ignition temperature (AIT)

The temperature at which ignition occurs spontaneously.

Neutralization number

The neutralization number is a measure of the relative acidity or alkalinity of a hydraulic fluid and is specified by a PH factor.

$$\text{Neutralization number}=\frac{\text{total no.of titrating solution}}{\text{weight of sample used}}\times 5.61$$

Pressure drop

Pressure that was not used directly for doing work is called as pressure drop or resistive pressure. Excessive presume drop results in increased heat generation. This pressure drop should be added to the system pressure to calculate overall pressure requirements during designing a system.

Demulsibility.

The property of a hydraulic fluid to separate rapidly and completely from moisture and to resist emulsification is known as Demulsibility.

Significance: This property is significant because the operati0n of many hydraulic systems are conductive to the forming of moisture or of stable water-in-oil emulsions.

Different types of hydraulic fluids

1. **Water glycol solutions.** This type consists of an actual solution of about 40% water and 60% glycol. These solutions have high viscosity index values, but the viscosity rises as the water evaporates. The operating temperature range runs from -10^0 F to about 180^0 F. Most of the newer synthetic seal materials are compatible with water – glycol solutions. However, metals such as zinc, cadmium, and therefore should not be used. In addition, special paints must be used.

2. **Water-in – oil emulsions.** This type consists of about 40% water completely dispersed in a special oil base. It is characterized by the small droplets of water completely surrounded by oil. The water provides a good coolant property but tends to make the fluid more corrosive. Thus, greater amounts of corrosion in hibitor additives are necessary. The operating temperature range runs form -20^0F to about 175^0F. As is the case with water – glycol solutions, it is necessary to replenish evaporated water to maintain proper viscosity. Water – in – oil emulsions are compatible with most rubber seal materials found in petroleum – based hydraulic systems.

3. **Straight synthetics.** This type is chemically formulated to inhibit combustion and in general has the highest fire – resistant temperature. Typical fluids in this category are the phosphate esters or chlorinated hydrocarbons. Disadvantages of straight synthetics include low viscosity index, incompatibility with most natural or synthetic rubber seals, and high cost. In particular, the phosphate esters readily dissolve paints, pipe thread compounds, and electrical insulation.

4. **High – water-content fluids.** This type consists of about 90% water and 10% concentrate. The concentrate consists of fluid additives that improve viscosity, lubricity. Rust protection against bacteria growth. Advantages of high-water-content fluids include high fire resistance, outstanding cooling characteristics,

and low cost. Which is about 20% of the cost of petroleum- based hydraulic fluids. Maximum operating temperatures should be held to 120^{0}F to minimize evaporation. Due to a somewhat higher density and lower viscosity compared to petroleum- based fluids. Pump inlet conductors should be sized to keep fluid velocities. High –water-content fluids are compatible with most rubber seal materials, but leather, paper, or cork materials should not be used since they tend to deteriorate in water.

Fluid Power Symbols. The study of the operation of a hydraulic or pneumatic system is more convenient if a diagram of the system or circuit is available. The components in an installation and their connections can be determined from such a diagram.

A schematic diagram indicates the functions of the various parts. A schematic diagram of a hydraulic system or a pneumatic system is similar to geographical road map. The symbols can be used to trace the action of oil or air through a system.

There are three main groups of symbols:

1. Symbols that are used for both hydraulic and pneumatic devices.
2. Symbols that are used only for hydraulic devices.
3. Symbols that are used only for pneumatic devices.

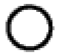
Lines

-continuous line - flow line

-dashed line - pilot, drain

-Envelope - long and short dashes around two or more component symbols.

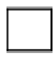
Circular

 -large circle - pump, motor

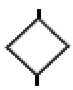
 -small circle - Measuring devices

 -semi-circle - rotary actuator

Square

 -one square - pressure control function
-two or three adjacent squares - directional control

Diamond

 -diamond - Fluid conditioner (filter, separator, lubricator, heat exchanger)

Miscellaneous Symbols

 -Spring

 -Flow Restriction

Triangle

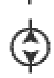
▼ -solid - Direction of Hydraulic Fluid Flow

▽ -open - Direction of Pneumatic flow

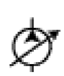
Pumps and Compressors

Fixed Displacement hydraulic pump

 -unidirectional

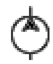
 -bidirectional

Variable displacement hydraulic pump

 -unidirectional

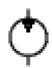
 -bidirectional

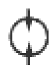
Compressor



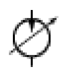
Motors

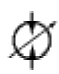
Fixed displacement hydraulic motor

 -unidirectional

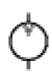
 -bidirectional

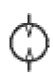
Variable displacement hydraulic motor

 -unidirectional

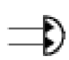
 -bidirectional

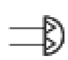
Pneumatic motor

 -unidirectional

 -bidirectional

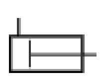
Rotary Actuator

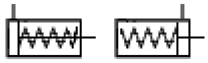
 - hydraulic

 - pneumatic

Cylinders

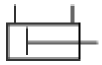
Single acting cylinder

 -returned by external force

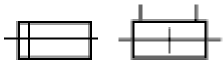


-returned by spring or extended by spring force

Double acting cylinders

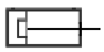


-single piston rod (fluid required to extend and retract)

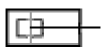


-double ended piston rod

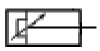
Cylinders with cushions



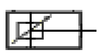
- single fixed cushion



- double fixed cushion



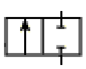
- single adjustable cushion



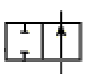
- double adjustable cushion

Directional Control Valves

Directional control valve (2 ports / 2 positions)

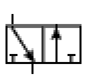


-Normally closed directional control valve with 2 ports and 2 finite positions.

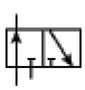


-Normally open directional control valve with 2 ports and 2 finite positions.

Directional control valve (3 ports / 2 positions)

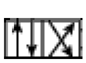


-Normally closed directional control valve with 3 ports and 2 finite positions.



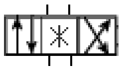
-Normally open directional control valve with 3 ports and 2 finite positions.

Directional control valve (4 ports / 2 positions)



-directional control valve with 4 ports and 2 finite positions

Directional control valve (4 ports / 3 positions)

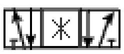


-directional control valve with 4 ports and 3 finite positions
*-(center position can have various flow paths)

Directional control valve (5 ports / 2 positions) normally a pneumatic valve

-directional control valve with 5 ports and 2 finite positions

Directional control valve (5 ports / 3 positions) normally a pneumatic valve

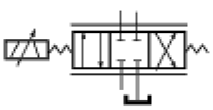


-directional control valve with 5 ports and 3 finite positions

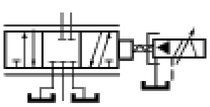
Proportional directional control valve

Electro-hydraulic servo valve

-The spool positions on these valves is variable allowing for variable flow conditions.



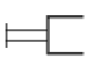
-single-stage **direct operation** unit which accepts an analog signal and provides a similar analog fluid power output



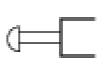
-two-stage with mechanical feedback **indirect pilot operation** unit which accepts an analog signal and provides a similar analog fluid power output

Control Methods

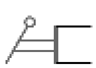
Manual Control



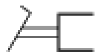
-general symbol (without showing the control type)



-pushbutton

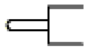


-lever

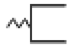


-foot pedal

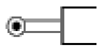
Mechanical Control



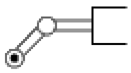
-plunger or tracer



-spring

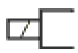


-roller



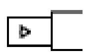
-roller(one direction only)

Electrical Control

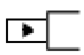


-Solenoid (the one winding)

Pilot Operation

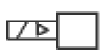


-pneumatic

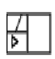


-hydraulic

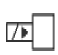
Pilot operated two-stage valve



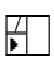
-Pneumatic: Sol first stage



-Pneumatic: Air pilot second stage

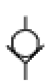


-Hydraulic: Sol first stage

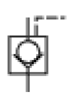


-Hydraulic: Hyd pilot second stage

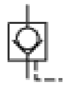
Check valves, Shuttle valves, Rapid Exhaust valves



-check valve -free flow one direction, blocked flow in other direction

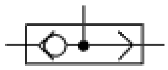


-pilot operated check valve, pilot to close



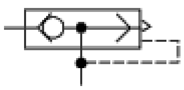
-pilot operated check valve, pilot to open

Shuttle valve



-to isolate one part of a system from an alternate part of circuit.

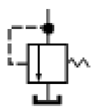
Rapid exhaust valve/Pneumatic



-installed close to an actuator for rapid movement of the actuator.

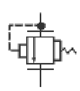
Pressure Control Valves

Pressure Relief Valve (safety valve) normally closed



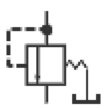
- Line pressure is limited to the setting of the valve, secondary part is directed to tank.

Proportional Pressure Relief



- line pressure is limited to and proportional to an electronic signal

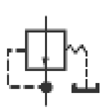
Sequence Valve



- When the line pressure reaches the setting of the valve, valve opens permitting flow to the secondary port. The pilot must be externally drained to tank.

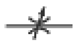
Pressure reducing valve

- pressure downstream of valve is limited to the setting of the valve

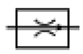


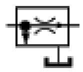
Flow Control Valves

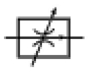
Throttle valve

 -adjustable output flow

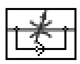
Flow Control valve

 -with fixed output (variations in inlet pressure do not affect rate of flow)

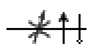
 -with fixed output and relief port to reservoir with relief for excess flow (variations in inlet pressure do not affect rate of flow)

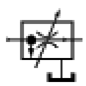
 -with variable output

 -fixed orifice

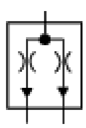
 -metered flow toward right free flow to left

 -pressure compensated flow control fixed output flow regardless of load

 -pressure and temperature compensated

 -with variable output and relief port to reservoir

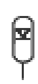
Flow dividing valve

 -flow is divided equally to two outputs.

Shut-Off Valve

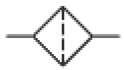
 -Simplified symbol

Accumulators

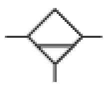


Filters, Water Traps, Lubricators and Miscellaneous Apparatus

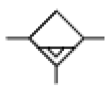
Filter or Strainer



Water Trap

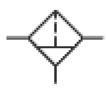


-with manual drain

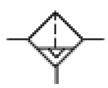


-with automatic drained

Filter with water trap

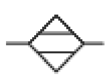


-with manual drain



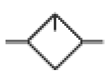
-automatic drain

Air Dryer



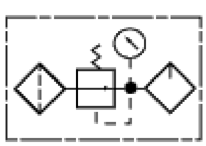
refrigerant, or chemical removal of water from compressed air line

Lubricator

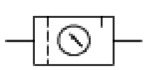


-oil vapor is indicted into air line

Conditioning unit

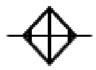


-compound symbol of filter, regulator, lubricator unit



-Simplified Symbol

Heat Exchangers

 <>	-air or water cooled unit designed to remove heat from oil returning to reservoir

Basics of Hydraulics

Hydraulic Basics

Hydraulics is the science of transmitting force and/or motion through the medium of a confined liquid. In a hydraulic device, power is transmitted by pushing on a confined liquid. Figure 1-1 shows a simple hydraulic device. The transfer of energy takes place because a quantity of liquid is subject to pressure. To operate liquid-powered systems, the operator should have a knowledge of the basic nature of liquids. This chapter covers the properties of liquids and how they act under different conditions.

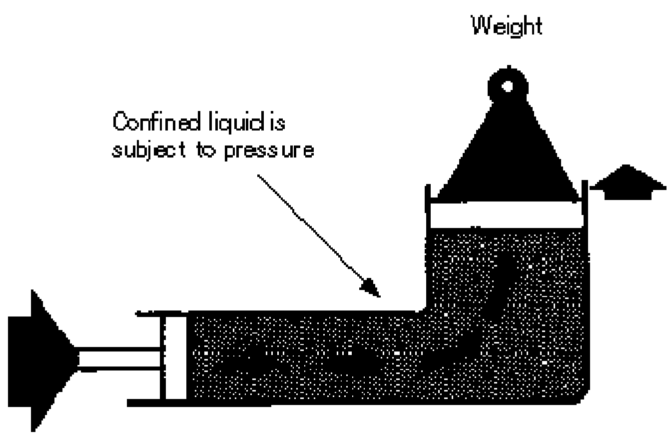


Figure 1-1. Basic hydraulic device

Pascal's Law

Blaise Pascal formulated the basic law of hydraulics in the mid 17th century. He discovered that pressure exerted on a fluid acts equally in all directions. His law states that pressure in a confined fluid is transmitted undiminished in every direction and acts with equal force on equal areas and at right angles to a container's walls.

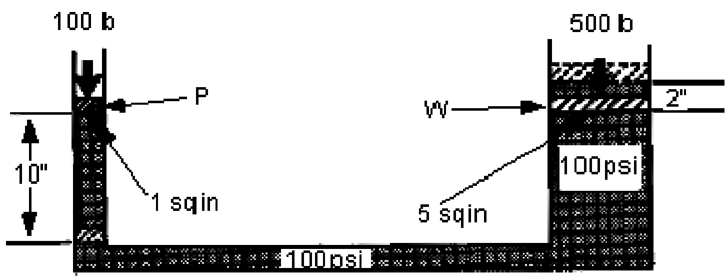


Figure 1-7. Pascal's Law apparatus

Figure 1-7 shows the apparatus that Pascal used to develop his law. It consisted of two connected cylinders of different diameters with a liquid trapped between them. Pascal found that the weight of a small piston will balance the weight of a larger piston as long as the piston's areas are in proportion to the weights. In the small cylinder, a force of 100 pounds on a 1-square-inch piston creates a pressure of 100 psi. According to Pascal's Law, this pressure is transmitted undiminished in every direction. In the larger cylinder, the 100 psi of pressure from the small cylinder is transmitted to an area of 5 square inches, which results in a force of 500 pounds on the second piston. The force has been multiplied 5 times-a mechanical advantage of 5 to 1. Using the same factors, you can determine the distance the pistons move. For example, if the small piston moves down 10 inches, the larger piston will move up 2 inches. Use the following to determine the distance:

$$D_2 = \frac{F_1 \times D_1}{F_2}$$

Where-

F_1 = force of the small piston, in pounds
D_1 = distance the small piston moves, in inches
D_2 = distance the larger piston moves, in inches
F_2 = force of the larger piston, in pounds

Example: Determine D_2

$$D_2 = \frac{F_1 \times D_1}{F_2} \qquad D_2 = \frac{100 \times 10}{500} \qquad D_2 = 2\ in$$

The six basic components of a hydraulic system are:

1. Reservoir (or tank),
2. Pump
3. Prime mover
4. Valves
5. Actuator and
6. Fluid –transfer piping.

Actuator

An actuator is used to convert the fluid energy into mechanical force or torque to do useful work.

Differentiate between a liquid and a gas.

Sl.No	Liquid	Gas
1	Posses a definite volume for a give mass, but conforms to the shape of the container.	Has a definite mass, but does not possess a definite volume and conforms to the shape of the container.
2	Incompressible fluid	Compressor fluid
3	It forms a free surface	It expands and occupies the whole volume of the container.

Applications of Pascal's law.

1. Braham's hydraulic press
2. Air-to-hydraulic pressure booster.

Laminar and Turbulent flow

A fluid flows through pipe, the layer of fluid at the wall has zero velocity. This is due to viscosity, which causes fluid particles to cling to the wall. Layers of fluid at the progressively greater distances from the pipe surface have higher velocities, with the maximum velocity occurring at the pipe centerline.

Actually there are two basic types of flow in pipes, depending on the nature of the different factors that affect the flow. *The first type is called laminar flow, which is characterized by the fluid flowing in smooth layers or laminate.* In this type of flow, a particle of fluid in a given layer stays in that layer. This type of fluid motion is called streamline flow because all the particles of fluid are moving in parallel paths. Therefore, a laminar flow is smooth with essentially no collision of particles. For laminar flow, the friction is caused by the sliding of one layer or particle of fluid over another in a smooth continuous fashion.

If the velocity of flow reaches a high enough value, the flow ceases to be laminar and becomes turbulent. In turbulent flow the movement of a particle becomes random and fluctuates up and down in a direction perpendicular as well as parallel to the mean flow direction. This mixing action generates turbulence due to colliding fluid particles. This causes considerably more resistance to flow and thus greater energy losses than that produced by laminar flow.

<u>Reynolds's Number</u>

It is important to know whether the flow pattern inside a pipe is laminar or turbulent. This brings us to the experiments performed by Osborn Reynolds is 1833 to determine the conditions governing the transaction from laminar to turbulent flow. Reynolds allowed the fluid in the large controlled the flow rate by means of a valve at the end of the tube. A capillary tube, connection to a reservoir of dye, allowed the flow of a fine jet of dye into the main flow stream.

Reynolds applied the dimensional analysis on variables and introduced a dimensional number called Reynolds number (Re)

Reynolds number, $Re = \frac{\rho VD}{\mu} = \frac{VD}{v}$

Where

$\rho =$ Density of the liquid,

V= Velocity of flow,

D=Diameter of the pipe,

μ=Absolute visocity of the fluid, and

v=Kinematic viscosity of the fluid

Reynolds's number is the basis for determining the laminar and turbulent flow. If Re<2000, then the flow is laminar, and if Re> 4000, then the flow is turbulent.

Darcy's equation

Friction is the main cause of energy losses in fluid power systems. The energy loss due to friction is transferred into heat, which is given off to the surrounding air. The result is a loss of potential energy in the system, and this shows up as a loss in pressure or head. The head loss (H_L) in a system actually consists two components:

1. Losses in pipes
2. Losses in fittings

Head losses in pipes can be found by using Darcy's equation:

$$H_L = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2_g}\right)$$

Where f = friction factor (dimensionless)
L = length of pipe (m).
D = pipe inside diameter (m).
V= average fluid velocity (m/s),
g = acceleration of gravity (m/s^2)

Darcy's equation can be used to calculate the head loss due to friction in pipes for both laminar and turbulent flow. The difference between the two lies in the evaluation of the friction factor f.

Frictional Losses in Laminar Flow

Darcy's equation can be used to find head losses in pipes experiencing laminar flow by noting that for laminar flow the friction factor equals the constant 64 divided by the Reynolds number:

$$f = \frac{64}{N_R}$$

$$H_L = \frac{64}{N_R}\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

The following example illustrates the use of the Hagen-Poiseuille equation.

Frictional Losses in Turbulent Flow

Darcy's equation will be used for calculating energy losses in turbulent fluid flow. However, the friction factor cannot be represented by a simple formula as well as the case for laminar flow. This is due to the random and fluctuating movement of the fluid particles.

For turbulent flow, experiments have shown that the friction factor is function of not only the Reynolds number but also the relative roughness of the pipe. The relative roughness is defined as the pipe inside surface roughness (Greek letter epsilon) divided by the pipe inside diameter D:

Relative roughness $\frac{E}{D}$

Absolute Roughness

Type of Pipe	ε(ft)	ε(mm)
Glass Or Plastic	Smooth	Smooth-
Drawn Tubing	0.000005	0.0015
Commercial Steel or wrought Iron	0.00015	0.046
Asphalted Cast Iron	0.0004	0.12
Galvanized Iron	0.0005	0.15
Cast Iron	0.00085	0.26
Riveted Steel	0.006	1.8

Losses in pipe.

1. Major energy losses
This loss is due to friction.
2. Minor energy losses
These losses are due to:

(i) Losses in valves and pipe fittings.
(ii) Sudden enlargement/construction of pipe
(i) Bend in pipe, etc.

Losses in Valves and Fittings.

In addition to losses due to friction in pipes, there also are energy losses in valves and fittings such as tees, elbows, and bends.

For many fluid power applications, the majority of the energy losses occur in these valves and fittings in which there is a change in the cross section of the flow path and a change in the direction of flow. Thus, the nature of the flow through valves and fittings is very complex.

As a result, experimental techniques are used to determine losses. Tests have shown that head losses in valves and fittings are proportional to the square of the velocity of the fluid:

$$H_L = \frac{Kv^2}{2g}$$

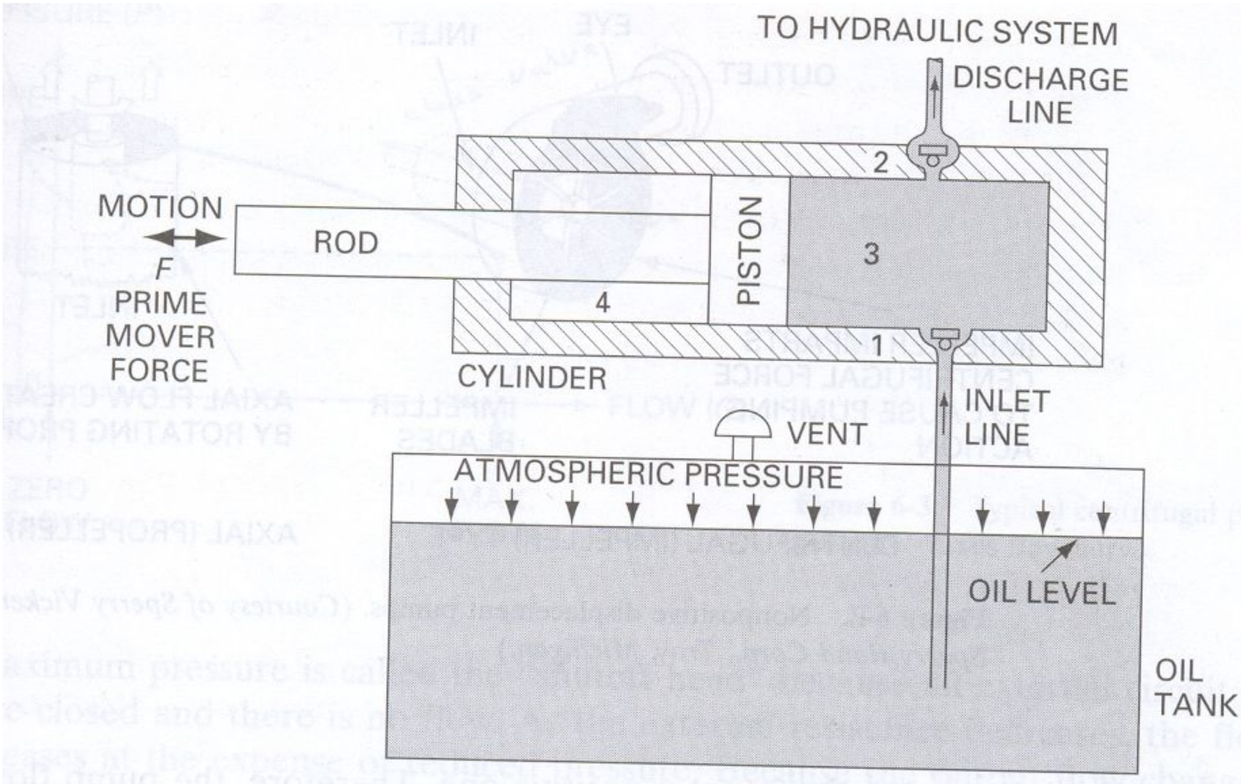
The constant of proportionality (K) is called the K factor of the valve or fitting.

Illustrations of several common valves and fittings are given as follows:

Valve Or Fitting	K Factor
Globe Valve: Wide open	10.0
½ open	12.5
Gate Valve: Wide open	0.19
¾ open	0.90
½ open	4.5
¼ open	24.0
Return Bend	2.2
Standard Tee	1.8
Standard Elbow	0.9
45^0 Elbow	0.42
90^0 Elbow	0.75
Ball Check valve	4.0

HYDRAULIC SYSTEM & COMPONENTS

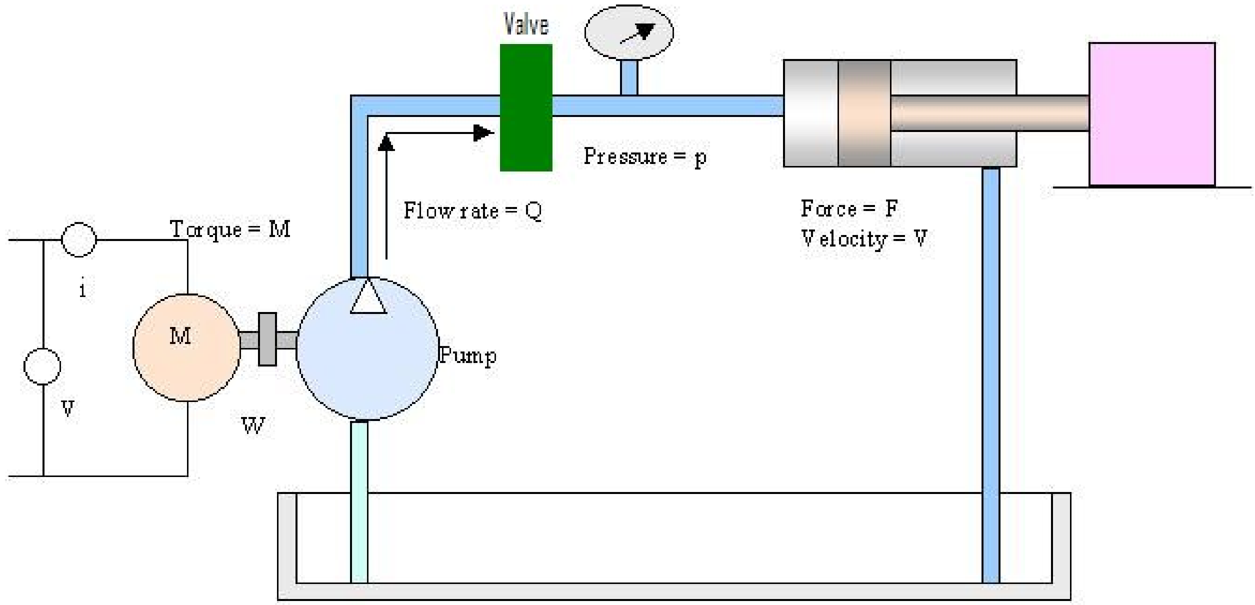
Pumping theory:



The main components of a pumping system are:

- Pumps (different types of pumps are explained in section 2)
- 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



Electric Power
P= V x I

Mechanical Power
P= Torque = M x W
W= Nm x 1/sec.= Nm/s

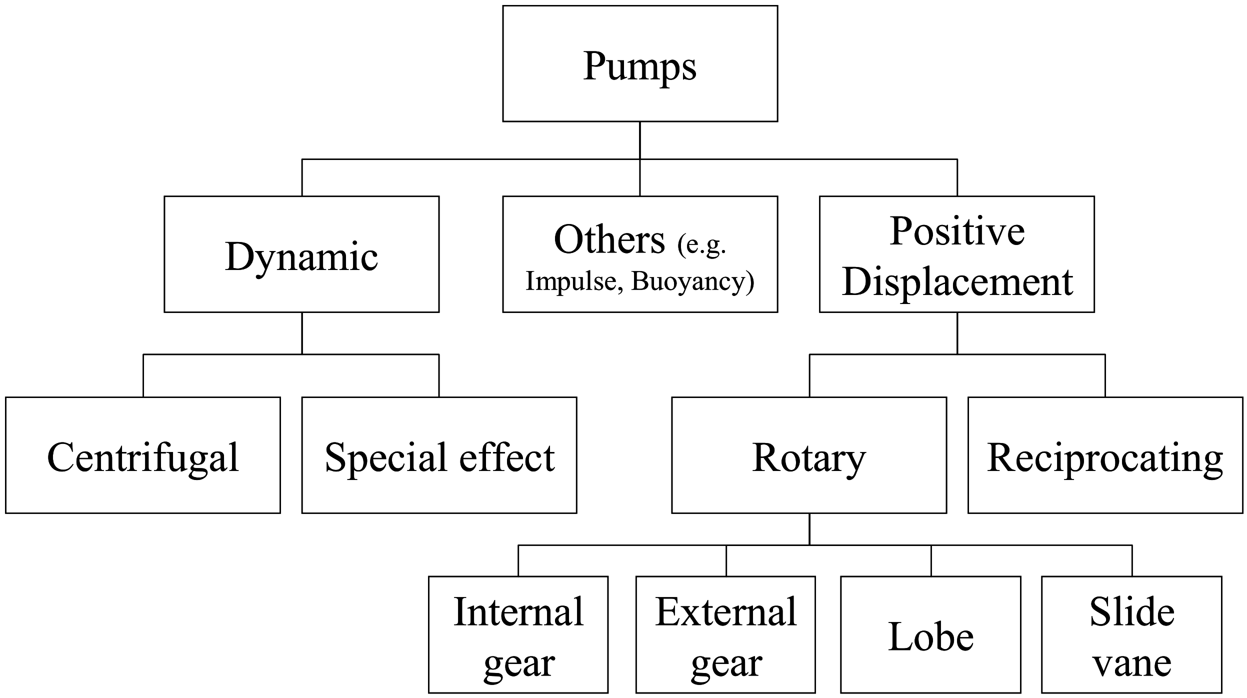
Hydraulic Power
P = p x Q
W= N/sq.m x cubic meter / s.
= Nm / s

Mechanical Power
P = F x V
W = N x m/s
= Nm/s

Pump classification

There are two broad classifications of pumps as identified by the fluid power industry. They are described as follows.

- Hydrodynamic or non-positive pumps
  - They are used for low-pressure, high-volume flow applications.
  - Normally their maximum pressure capacity is limited to 250-300 psi.
- Hydrostatic or positive pumps (Gear, vane, piston pumps)
  - High pressure capability (up to 10,000 psi or higher)
  - Small compact size
  - High volumetric efficiency
  - Small changes in efficiency
  - Great flexibility of performance



1. Hydrodynamic or non positive displacement pumps:

Examples of this type are the centrifugal (impeller) and axial (propeller) pumps in although these pumps provide smooth continuous flow, their flow output is reduced as circuit resistance is increased. In fact, it is possible to completely block off the outlet to stop all flow. Even while the pump is running at design speed. These pumps are typically used for low-pressure, high-volume flow applications.

Since there is a great deal of clearance between the rotating and stationary elements, these pumps are not self-priming. This is because there is too much clearance space to seal against atmospheric pressure. And thus the displacement between the inlet and outlet is not a positive one. Thus the pump flow rate depends not only on the rotational speed (rpm) at which it is driven but also on the resistance of the external system.

As the resistance of the external system starts to increase, some of the fluid slips back into the clearance spaces, causing a reduction in the discharge flow rate. This slippage is due to the fact that the fluid follows the path of least resistance. When the resistance of the external system becomes infinitely large (for example. A closed valve blocks the outlet line) the pump will produce no flow and thus its volumetric efficiency becomes zero.

For example the dramatic drop in volumetric efficiency withy increase in load resistance occurs when using a centrifugal pump. The operation of the centrifugal pump is simple.

The fluid enters at the center of the impeller and is picked up by the rotation impeller. As the fluid rotates with the impeller, the centrifugal force causes the fluid to move radically outward. This causes the fluid to flow through the outlet discharge port of the housing. One of the interesting characteristics of a centrifugal pump is its behavior when there is no demand for fluid. In devices to prevent pump damage. The tips of the impeller blades merely slosh through the fluid, and the rotational speed maintains a fluid pressure corresponding to the centrifugal force established. The fact that there is no positive internal seal against leakage is the reason that the centrifugal pump is not forced to produce flow against no demand. When demand for the fluid occurs (for example, the opening of a valve), the pressure delivers the fluid to the source of the demand. This is why centrifugal pumps are so desirable for pumping stations used for delivering water to homes and factories. The demand for water may go to near zero during the evening and reach a peak sometimes during the daytime. The centrifugal pump can readily handle these large changes in fluid demand.

Although hydrodynamic pumps provide smooth continuous flow (when a demand exist) their output flow rate is reduced as resistance to flow is increased. This is shown in where pump pressure is potted versus pump flow. The maximum pressure is called the shutoff head because all external circuit valves are closed the there is no flow. As the external resistance decreases, the flow increases at the expense of reduced pressure. Because the output flow changes significantly with external circuit resistance, non positive displacement pumps are rarely used in hydraulic systems.

2. Hydrostatic or positive displacement pumps:

This type of pump ejects a fixed quantity of fluid per revolution of the pump shaft. As a result, pump output flow, neglecting the small internal leakage, is constant and not dependent on system pressure. This makes them particularly well suited for fluid power systems. However, positive displacement pumps must be protected against overpressure if the resistance to flow becomes very large or infinite. This can happen if a Valve is completely closed and there is no physical place for the fluid to go. The reason for this is that a positive displacement pump continues to eject fluid (even through it has no place to go), causing an extremely rapid buildup in pressure as the fluid is compressed. A pressure relief valve is used to protect the pump against stored for system use

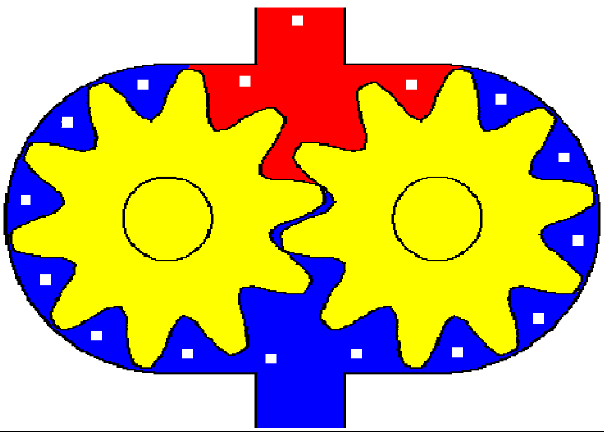
Positive displacement pumps can be classified by the type of motion of internal elements. The motion may be either rotary or reciprocating. Although these pumps come in a wide variety of different designs, there are essentially three basic types:

1. Gear pumps (fixed displacement only by geometrical necessity):
    a. External gear pumps
    b. Internal gear pumps
    c. Lobe pumps
    d. Screw pumps

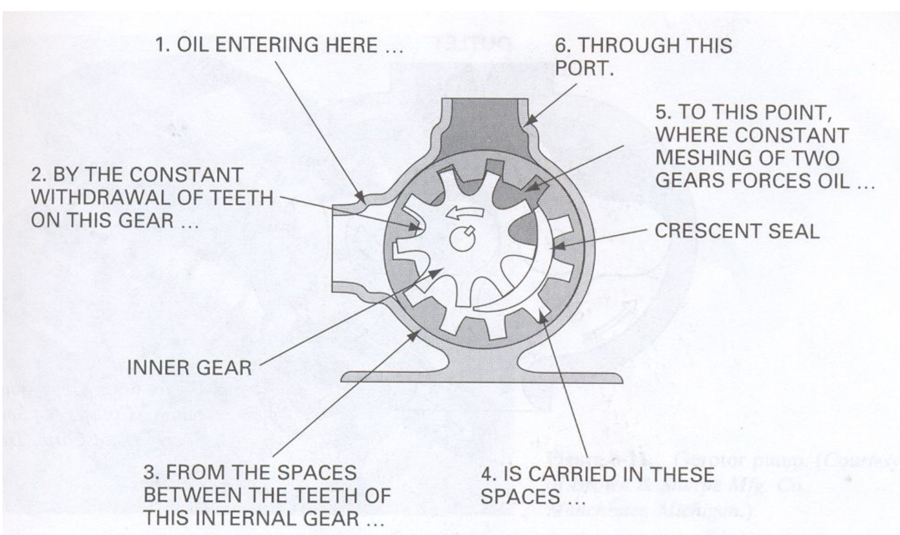
2. Vane pumps:
    a. Unbalanced vane pumps (fixed or variable displacement)
    b. Balanced vane pumps (fixed displacement)
3. Piston pumps (Fixed or variable displacement)
    a. Axial design
    b. Radial design

In addition, van pumps can be of the balanced or unbalanced design. The unbalanced design can have pressure compensation capability. Which automatically protects the pump against overpressure.

Gear pump



External gear pump



Internal gear pump

An external gear pump which develops flow by carrying fluid between the teeth of two meshing gears. One of the gears is connected to a drive shaft connected to the prime mover. The second gear is driven as it meshes with the driver gear. Oil chambers are formed between the gear teeth, the pump housing, and side wear plates. The suction side is where teeth come out of mesh, and it is here where the volume expands, bringing about a reduction in pressure to below atmospheric pressure. Fluid is pushed into this void by atmospheric pressure because the oil supply tank is vented to the atmosphere the discharge side is where teeth go into mesh, and it is here where the Volume decreases between mating teeth. Since the pump has a positive internal seal against leakage, the oil is positively ejected into the outlet port.

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 (inch/rev, m^3rev)
N = rpm of pump
Q_r = theoretical pump flow rate

From gear geometry, the volumetric displacement is found:

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

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

$$Q_r(in.3/\min) = V_D(in.3/rev) \times N(rpm)$$

Since 1 gal = 231 $in^{3,}$ we have

$$Qr(gpm) = \frac{V_D N}{231}$$

Using metric units, we have

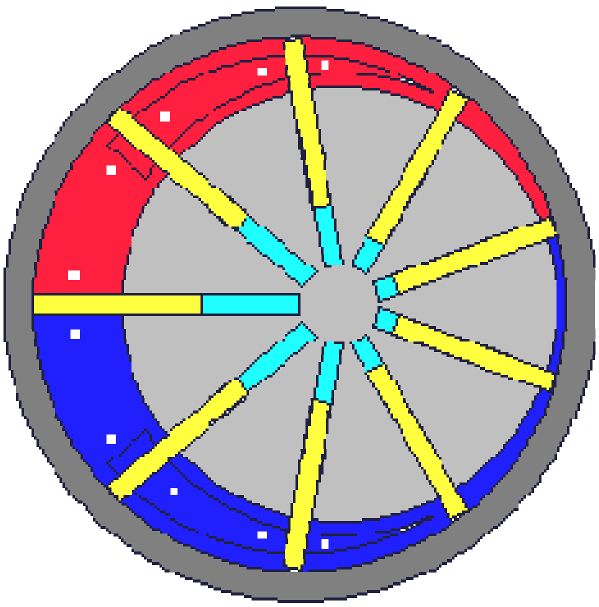
$$Qr\left(\frac{m^3}{\min}\right) = V_D\left(\frac{m^3}{rev}\right) \times N\left(\frac{rev}{\min}\right)$$

There must be a small clearance (less than 0.001 in.) between the teeth tip and pump housing. As a result some of the oil at the discharge port can leak directly back toward the suction. This means that the actual flow rate Q_A is less than the theoretical flow rate $Q_{r,}$ which is based on volumetric displacement and pump speed. This internal leakage, which is called pump slippage, is identified by the term volumetric efficiency, which is usually greater than 90% for positive displacement pumps, operating at design pressure:

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

The higher the discharge pressure, the lower the volumetric efficiency because internal leakage increases with pressure. This shown by the dashed line in Fig. pump manufacturers usually specify volumetric efficiency at the pump sure below which no mechanical damage due to overpressure will occur to the pump and the result will be a long reliable service life. Too high a pressure not casing and overloading the shaft bearings. This brings to mind once again the need for over pressure protection. Also keep in mind that high pressures occur when a large load or resistance to flow is encountered

Vane Pump



- Unbalanced vane pumps
- Balanced vane pumps

On many industrial installations with a maximum pressure of about 200 bar, vane pumps are applied.

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.

The following analysis and nomenclature is applicable to the vane pump:

D_c = Diameter of cam ring (in., .M)
$D_{i\,=}$ diameter of rotor (in., M)
L = width of rotor (in., M)
V_D= displacement volume of pump (in^3, m^3)
N = rotor rpm
e = eccentricity (in., m)
e_{max}= maximum possible eccentricity (in., m)
V_{Dmad}=maximum possible volumetric displacement (in^3. M)

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.

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

Rearranging, we have

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

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:

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

Some vane pumps have provisions for mechanically varying the eccentricity. Such a design is called a variable displacement pump. A hand wheel or a pressure compensator can be used to move the cam ring to change the eccentricity. The direction of flow through the pump can be reversed by movement of the cam ring on either side of center.

It is a pressure compensated one in which system pressure acts directly on the cam ring via a hydraulic piston on the right side. This forces the cam ring against the compensator spring-loaded piston on the left side of the cam ring. If the discharge pressure is large enough, it overcomes the compensator spring force and shift the cam ring to the left. This reduces the eccentricity, which is maximum when discharge pressure is zero. As the discharge pressure continues to increase, zero eccentricity is finally achieved, and the pump now becomes zero. Such a pump basically has its own protection against excessive pressure buildup, as shown in fig. when the pressure reaches a value called P_{cutoff} the compensator spring force equals the hydraulic piston force. As the pressure continues to increase, the compensator spring is compressed until zero eccentricity is achieved. The maximum pressure achieved is called $P_{deadhead}$ at which point the pump is protected because it attempts to produce no more flow. As a result there is no horse power wasted and fluid heating is reduced.

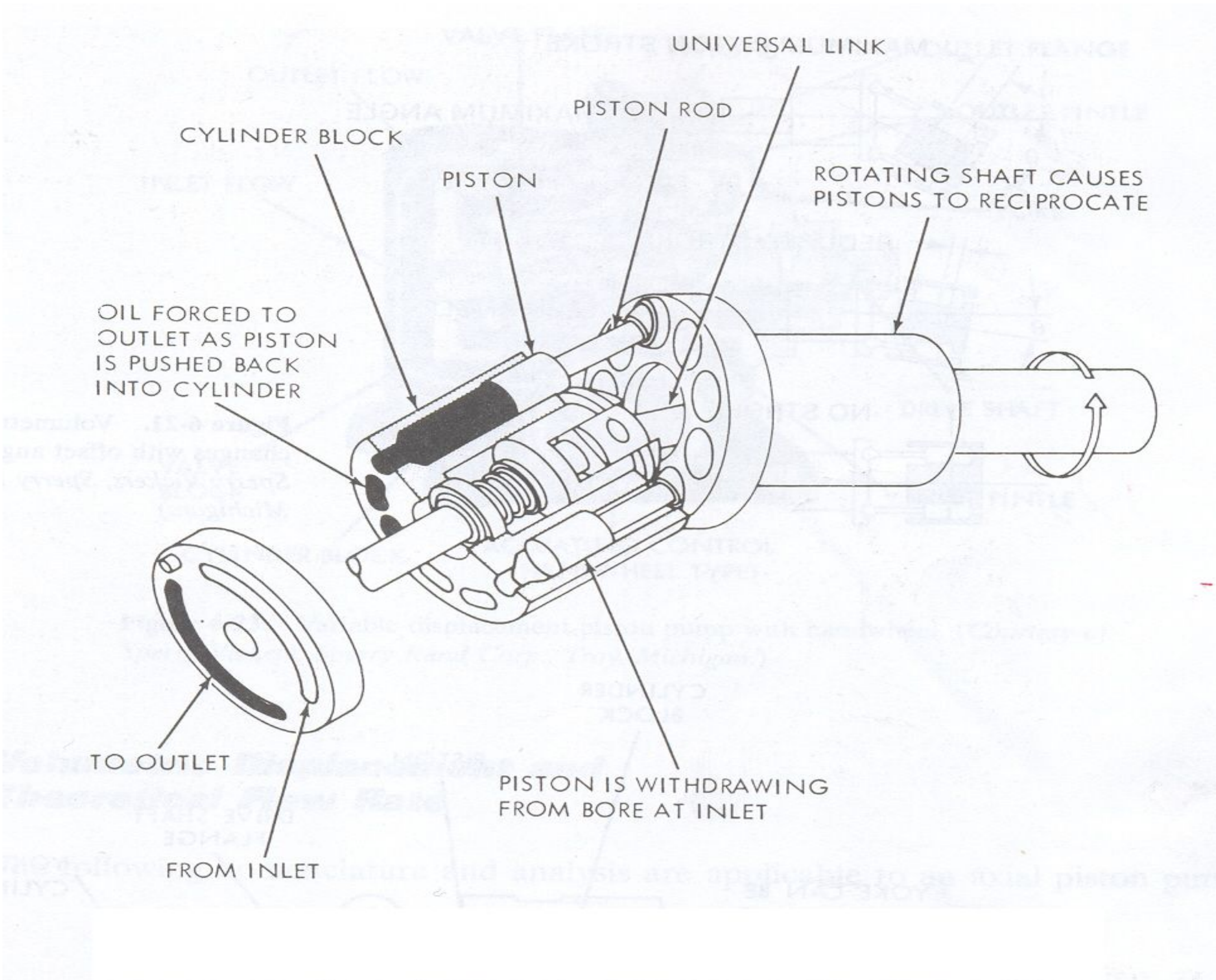
The internal configuration of an actual pressure compensated vane pump. This design contains a cam ring that rotates slightly during use. Thereby distributing wear over the entire inner circumference of the ring.

A side load is exerted on the bearings of the vane pump because of pressure unbalance. This same undesirable side load exists for the gear pump such pumps are hydraulically unbalanced.

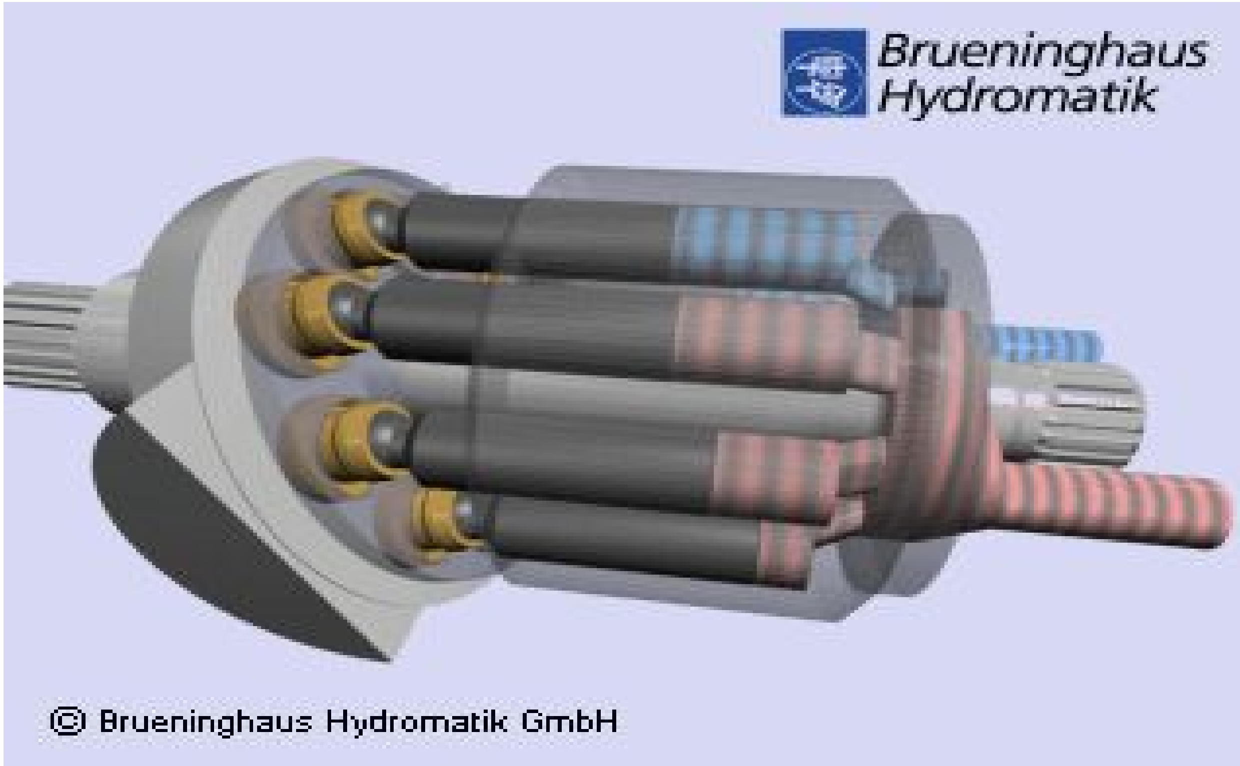
A balanced vane pump is one that has two intake and two outlet ports diametrically opposite each other. Thus pressure ports are opposite each other, and a complete hydraulic balance is achieved. One disadvantage of a balanced vane pump is that it cannot be designed as a variable displacement unit. Instead of having a circular cam ring, a balanced design vane pump has an elliptical housing, which forms two separate pumping chambers on opposite sides of the rotor.

Piston pumps

- Axial design
- Radial design



- Radial design



- Axial design

A piston pump works on the principle that a reciprocating piston can draw in fluid when it retracts in a cylinder bore and discharge it when it extends. The basic question is how to mechanize a series of reciprocating pistons. There are two basic types of piston pumps.

One is the axial design, having pistons that are parallel to the axis of the cylinder block. Axial piston pumps can be either of the bent axis configuration or of the swash plate design. The second type of piston pump is the radial design, which has pistons arranged radically in a cylinder block.

An axial piston pump (bent-axis type) that contains a cylinder block rotating with the drive shaft. However, the centerline of the cylinder block is set at an offset angle relative to the centerline of the drive shaft. The cylinder block contains a number of pistons arranged along a circle. The piston rods are connected to the drive shaft flange by ball and socket joints. The pistons are forced in and out of their bores as the distance between the drive shaft flange and cylinder block changes. A universal link connects the block to the drive shaft to provide alignment and positive drive.

The volumetric displacement of the pump varies with the offset angle θ no flow is produced when the cylinder block centerline is parallel to the drive shaft centerline. θ Can vary from 0° to a maximum of about 30°. Fixed displacement units are usually provided with 23° Or 30° offset angles.

Variable displacement units are available with a yoke and some external control to change the offset angle.

The following nomenclature and analysis are applicable to an axial piston pump:

θ = offset angle (°)
S = piston stroke (in., m)
D = piston circle diameter (in., m)
Y = number of pistons,
A = piston area (in^2. m^2)

From trigonometry we have

$$\text{Tan}\ (\theta) = \frac{s}{D}$$

Or

$$S = D \tan(\theta)$$

The total displacement volume equals the number of pistons multiplied by the displacement volume preposition:

$$V_D = YAS$$

Substituting, we have

$$V_D = YAD \tan(\theta)$$

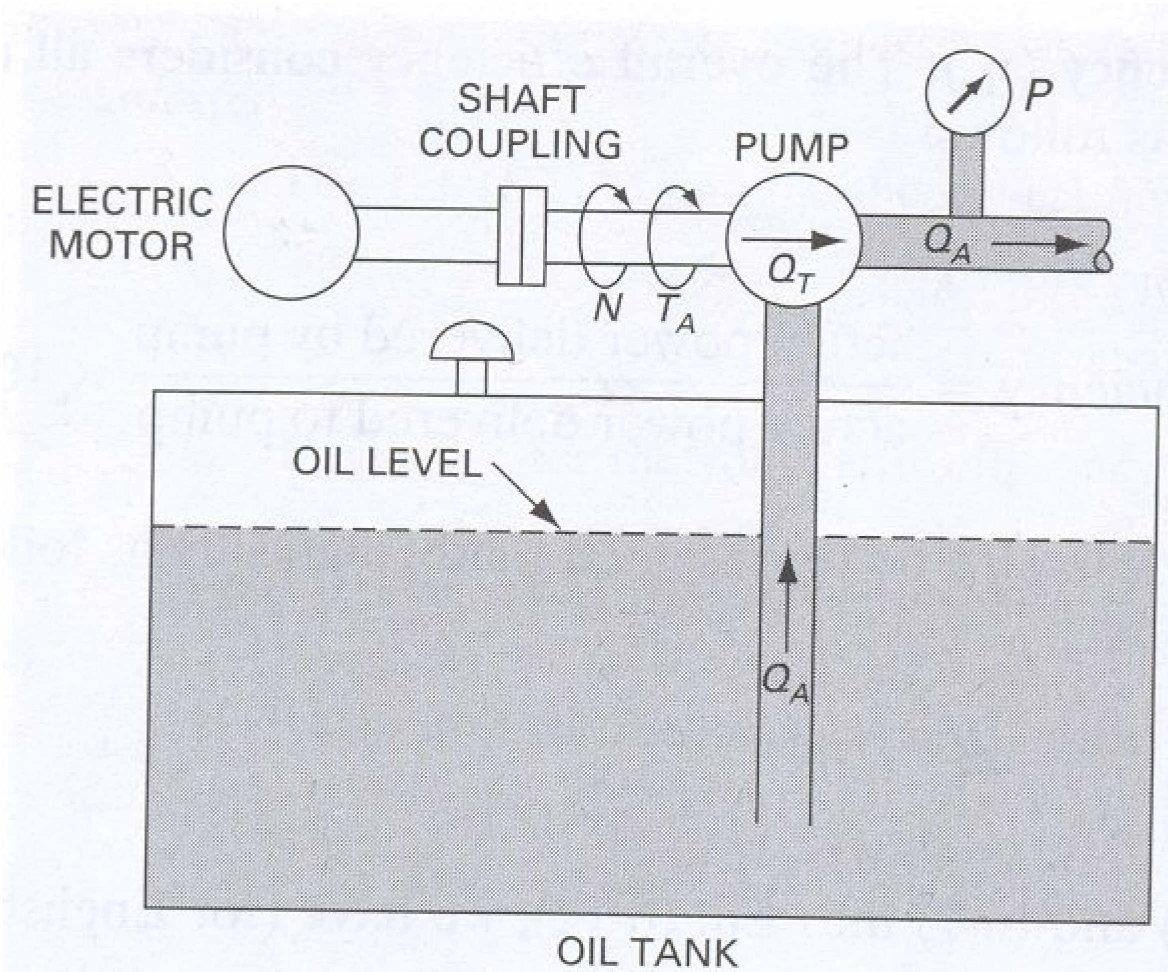
From Eq. we obtain upon, substitution and using English units.

$$Q = \frac{DANY \tan(\theta)}{231}$$

Similarly, for metric units, we have

$$Q = DANY \tan(\theta)$$

PUMP PERFORMANCE:



The performance delivered by a pump is primarily a function of the precision of its manufacture. Components must be made to close tolerances, which must be maintained while the pump is operating under design conditions. The maintenance of close tolerances is accomplished by designs that have mechanical integrity and balanced pressures.

Theoretically the ideal pump would be one having zero clearance between all mating parts. Although this is feasible, working clearances should be as small as possible while maintaining proper oil films for lubrication between rubbing parts.

Pump manufacturers run tests to determine performance data for their various types of pumps. The overall efficiency of a pump can be computed by comparing the power available at the output of the pump to the power supplied at the input. Overall efficiency can be broken into two distinct components called volumetric and mechanical efficiencies.

1. Volumetric efficiency (η_r): volumetric efficiency indicates the amount of leakage that takes place within the pump. This involves considerations such as manufacturing tolerances and flexing of the pump casing under design pressure operating conditions:

$$\eta_u = \frac{\text{actual flow rate produced by pump}}{\textit{theoretical}\text{ flow rate pump should produce}} \times 100$$

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

Volumetric efficiencies typically run from 80% to 90% for gear pumps, 82% to 92% for vane pumps, and 90% to 98% for piston pumps.

2. Mechanical efficiency (η_m): Mechanical efficiency indicates the amount of energy losses that occur due to reason other than leakage. This includes friction in bearings and between other mating parts. It also includes energy losses due to fluid turbulence. Mechanical efficiencies typically run from 90% to 95%.

$$\eta_m = \frac{\text{theoretical powe required to operate pump}}{\textit{actual}\text{ power delivered to pump}}$$

or

$$\eta_m = \frac{\text{pump output power assuming no leakage}}{\textit{input power delivered to pump}}$$

Using English units and horsepower for power yields.

$$\eta_m = \frac{PQ_T/1714}{TN/63{,}000} \times 100$$

In metric units, using watts for power,

$$\eta_m = \frac{PQ_r}{TN} \times 100$$

P = measured pump discharge pressure (psi, pa)
Qr = calculated theoretical pump flow rate (gpm, m^3/s)
T = measured input torque in prime mover shaft of pump (in. lb N-m)
N = measured pump speed (rpm, rad/s)
Mechanical efficiency can also be computed in terms of torques:

$$\eta_m = \frac{\text{theoretical powe required to operate pump}}{\textit{actual} \text{ power delivered to pump}} \times 100 = \frac{T_r}{T_A} \times 100$$

Equations for evaluating T_T and T_A are given as follows:

$$T_T(in.lb) = \frac{V_D(in.^3) \times P(psi)}{2\pi}$$

or

$$T_r(N.m) = \frac{V_D(m^3) \times P(pa)}{2\pi}$$

$$T_A = \frac{\textit{horsepower} \text{ supplied to pump} \times 63{,}000}{N(rpm)}$$

or

$$T_A = \frac{\textit{power} \text{ supplied to pump (W)}}{N\left(\frac{rad}{s}\right)}$$

where

$$\text{N}\left(\frac{\text{rad}}{\text{s}}\right) = \frac{2\pi}{60} N(rpm)$$

3. Overall efficiency (η_o)**:** The overall efficiency considers all energy losses and is defined mathematically as follows:

$$\textit{overall} \text{ efficiency} = \frac{\text{volumetric effeciency} \times \text{mechanical efficieancy}}{100}$$

$$\eta_o = \frac{\eta_o \eta_m}{100} = \frac{Q_A}{Q_1} \frac{100}{100} \frac{PQ_1 / 1714}{TN / 63{,}000} \times 100$$

Canceling like terms yields

$$\eta_o = \frac{PQ_A / 1714}{TN / 63{,}000} \times 100 = \frac{\textit{pump} \text{ output horse power}}{\textit{pump} \text{ input horse power}} \times 100$$

$$\eta_o = \frac{PQ_A}{TN} \times 100 = \frac{\textit{pump} \text{ output power}}{\textit{pump} \text{ input power}} \times 100$$

PUMP TYPE	PRESSURE RATING (PSI)	SPEED RATING (RPM)	OVERALL EFFICIENCY (PER CENT)	HP PER LB RATIO	FLOW CAPACITY (GPM)	COST (DOL LARS PER HP)
EXTERNAL GEAR	2000-3000	1200-2500	80-90	2	1-150	4-8
INTERNAL GEAR	500-2000	1200-2500	70-85	2	1-200	4-8
VANE	1000-2000	1200-1800	80-95	2	1-80	6-30
AXIAL PISTON	2000-12000	1200-3000	90-98	4	1-200	6-50
RADIAL PISTON	3000-12000	1200-1800	85-95	3	1-200	5-35

The volumetric efficiency is greatly affected by the following leakage losses which can rapidly accelerate due to wear.

1. Leakage around the outer periphery of the gears
2. Leakage across the faces of the gears
3. Leakage at the points where the gear teeth make contact.

Gear pumps are simple in design and compact in size. Therefore, they are the most common type of pump used in fluid power systems. The greatest number of application of gear pumps are in the mobile equipment and machine tool fields.

Vane pump efficiencies and costs fall between those of gear and piston pumps. Vane pumps have good efficiencies and last for a reasonably long period of time. However, continued satisfactory performance necessitates clean oil with good lubricity. Excessive shaft speeds can cause operating problems the bronze wear plates and the pressure ring.

Piston pumps are the most expensive and provide the highest level of overall performance. They can be driven at high speeds (up to 500 rpm) to provide a high horse power-to-weight ratio. They produce essentially a non pulsating flow and can operate at the highest pressure levels. Due to very close-fitting pistons, they have the highest efficiencies. Since no side loads occur to the pistons, the pump life expectancy is at least several years. However, because of their complex design piston pumps cannot normally be repaired in the field.

Pump selection

- Select the actuator (hydraulic cylinder or motor) that is appropriate based on the loads encountered.
- Determine the flow-rate requirements. This involves the calculation of the flow rate necessary to drive the actuator to move the load through a specified distance within a given time limit.
- Determine the pump speed and select the prime mover.
- pump type based on the application
- Select the system pressure. This ties in with the actuator size and the magnitude of the resistive force produced by the external load on the system.
- Select the reservoir and associated plumbing, including piping, valving, hydraulic cylinders, and motors and other miscellaneous components
- Calculate the overall cost of the system.

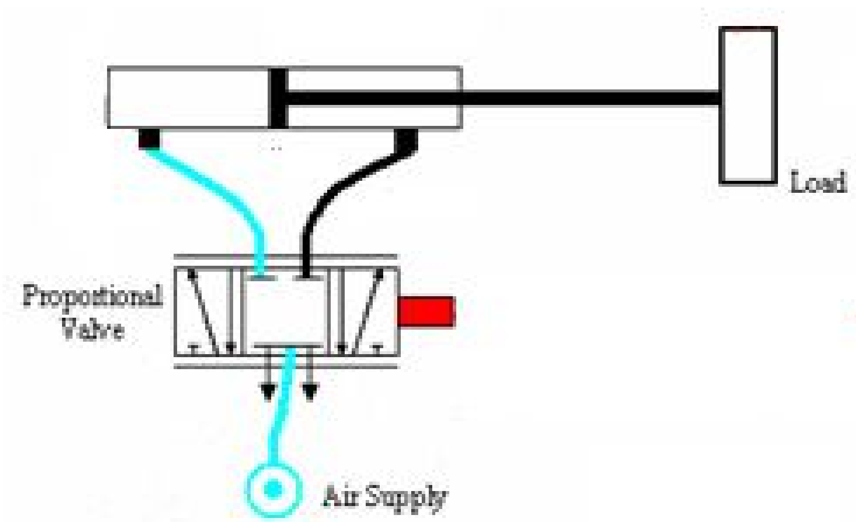
UNIT II: HYDRAULIC ACTUATORS AND CONTROL COMPONENTS

Fluid Power Actuators

A hydraulic actuator is used for converting hydraulic energy into mechanical energy.

Classification of hydraulic actuators

1. Linear actuators (also called ‘hydraulic cylinders’), and
2. Rotary actuators (also called ‘hydraulic motors’).



Hydraulic cylinder (Linear actuators)

The hydraulic cylinder is used to convert fluid power into linear mechanical force and motion.

Applications of hydraulic cylinders.

The hydraulic cylinders are basically used for performing work such as pushing, pulling, tilting, and pressing in a variety of engineering applications such as in material handling equipment, machine tools, construction equipment, and automobiles.

Different types of hydraulic cylinders are

1. single acting cylinders,
2. Double acting cylinder,
3. Telescoping cylinders,

4. Tandem cylinders, and
5. Through rod cylinder.

<u>Types of Hydraulic Cylinder</u>

Single Acting Cylinders

A single acting hydraulic cylinder is designed to apply force in only one direction.

It consists of a piston inside a cylindrical housing called a barrel. Attached to one end of the piston is a rod which extends outside. At the other end (bland end) is a port for the entrance and the exit of oil. A single acting cylinder can exert a force only in the extending direction, as fluid from the pump enters through the blank end of the cylinder. Single acting cylinders do not hydraulically retract. Retraction is accomplished by using gravity or by the inclusion of a compression spring at the rod end.

Double Acting Cylinders

A double acting cylinder is capable of delivering forces in both directions. The barrel is made of seamless steel tubing, honed to a fine finish on the inside surface. The piston which is made of ductile iron contains u cup packing's to seal the leakage between the piston and the barrel. The ports are located in the end caps which are secured to the barrel by tie rods. The load of the piston rod at the neck is taken by a rod bearing, which is generally made of brass or bronze. A rod wiper is provided at the end of the beck to prevent foreign particles and dust from entering into the cylinder along with the piston rod.

When the fluid from the pump enters the cylinder through port 1, the piston moves forward and the fluid returns to the reservoir from the cylinder through port 2. During the return stroke the fluid is allowed to enter the cylinder through port 2 and fluid from the other side of the piston goes back to the reservoir through port 1.

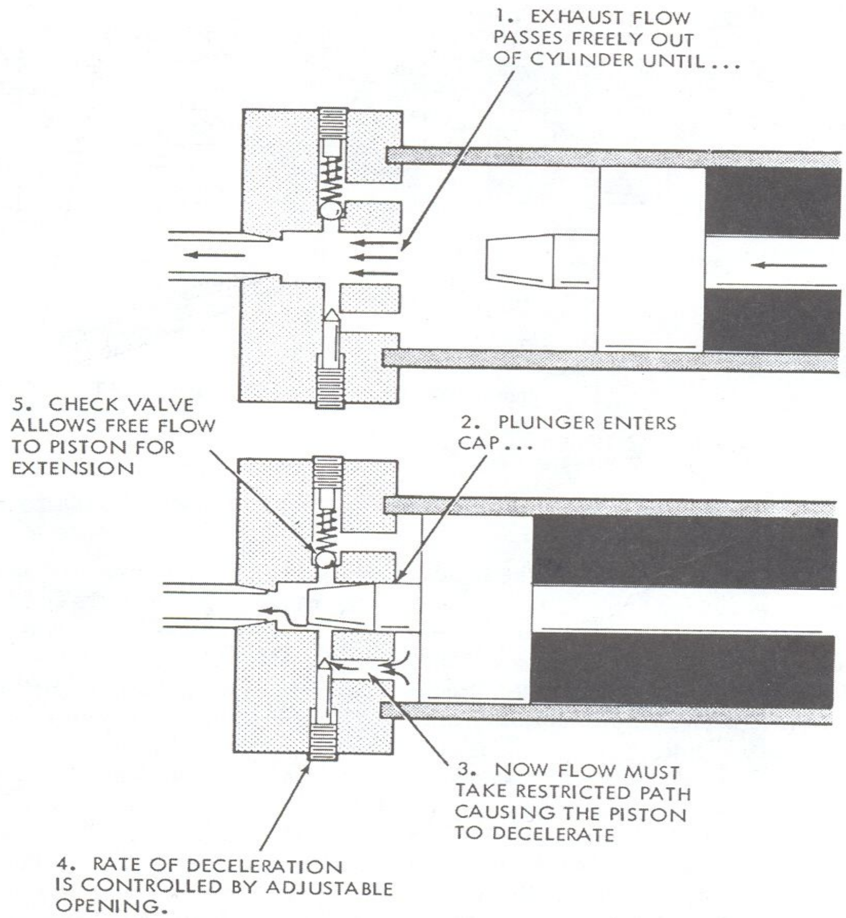
Telescoping Cylinders

Telescoping cylinders are used where long work-strokes are needed. A telescoping cylinder provides a relatively long working stroke for an overall reduced length by employing several pistons which telescope into each other.

Two stage double acting telescopic cylinder. Fluid for the retraction strokes is fed into port 'A' and passes through the hollow piston rod into the annulus behind the first stage piston. So the first stage piston is forced to the left until it uncovers the fluid ports connecting this with the second stage annulus, thereby moving the larger piston to the left until both the pistons are fully retracted into the body of the cylinder.

Fluid for the extension stroke is then fed through port 'B', forcing both pistons to the right until the cylinder is fully extended.

Cylinder cushioning



As long as the piston is moving in the middle range of the cylinder, nothing will hit the piston head. But due to the inertia forces of the moving parts at the end of the piston travel, the piston will hit the cylinder head at full speed.

To overcome this, the designers provide a 'cushioning' arrangement by which the hydraulic cylinder can be slowly retarded or cushioned, during the last portion of the stroke.

The piston at the start of the cushioning action. In this position, the fluid from the pump enters into the rod end of the cylinder moving the piston towards the left. The fluid from the head end of the cylinder flows freely to the reservoir through the fluid port.

As the stroke nears completion, the cushion nose starts entering in the space of the cylinder head. Due to the taper front of the cushion nose, the fluid port path (c) is gradually closed. So the fluid cannot flow through 'c' or through the passage (x) due to the presence of the check valve. Now the entrapped fluid can escape only through passage(y), the size of which can be controlled by a needle valve. Thus due to the restricted outflow during the last portion of the stroke, the piston decelerates slowly. By adjust6ing the needle valve, rate of deceleration is controlled.

For starting the forward stroke of the piston, the fluid is allowed to enter the fluid port. The fluid will now flow from all passages. Thus, the full piston area will be subjected to the system pressure.

Control components

Directional control valves

As the name implies, directional control valves are used to control the direction of flow in a hydraulic circuit. The simplest type is a check valve which is in reality a one-way directional control valve. It is a one –way valve because it permits free in one direction and prevents any flow in the opposite direction.

Check valves

The internal operation of a check valve. , a light spring holds the poppet in the closed position. In the free-flow direction, the fluid pressure overcomes the spring force at about 5 psi. If flow is attempted in the opposite direction, the fluid pressure pushes the poppet (along with the spring force) in the closed position. Therefore, no flow is permitted. The higher the pressure, the greater will be the force pushing the poppet against its seat. Thus, increased pressure will not result in any tendency to allow flow in the no-flow direction.

The free-flow direction implied when using the symbolic representation of a check valve. This symbol, which clearly shows the function of a check valve, will be used when drawing total hydraulic circuits. Note that a check valve, will be used when drawing total hydraulic circuits. Note that a check valve is analogous to a diode in electric circuits.

Pilot operated check valve

A second type of check valve is the pilot- operated check valve, with its symbol. This type of check valve always permits free flow in one direction but permits flow in the normally blocked opposite direction only of pilot pressure is applied at the pilot pressure port of the valve. In the design the check valve poppet has the pilot piston attached to the threaded poppet stem by a nut. The light spring holds the poppet seated in a no-flow condition by pushing against the pilot piston. The purpose of the separate drain port is to prevent oil from crating a pressure buildup on the bottom of the piston. The dashed line represents the pilot pressure line connected to the pilot pressure port of the valve. Pilot check valves are frequently used for locking hydraulic cylinders in position.

Two way and four way valves

Additional types of directional control valves are the two-way and four-way valves used to direct inlet flow to either of two outlet ports. Flow entering at the pump port P (this is the port that is connected to the pump discharge line) can be directed to either the outlet port A or B. Most direction control valves use a sliding spool to change the path of flow through the valve Pg a given position of the spool, a unique flow path configuration exists within the valve. Directional control valves are designed to operate with either two position of the spool or three positions of the spool. The flow path configuration for the unique spool position is shown symbolically by a rectangle, sometimes called envelop. Therefore, the valves are two-position valves (the graphical symbols show two side-by-side rectangles for each valve).

1. Two-way valve: Notice that the flow can go through the value in two unique ways depending on the spool position.

a. spool position I: Flow can go from P to B as shown by the straight through line and arrowhead. Ports A and T are blocked as shown.

b. Spool position 2: Flow can go from P to A. Notice that the ports are labeled for only one envelope so that the reader must mentally identify the ports.

Two – way valves can be used to direct pump flow to either of two different part of a circuit, Four-way valves are typically used to control double-acting hydraulic cylinders. The spool of a directional control valve can be positioned manually, mechanically, by using pilot pressure, or by using electrical solenoids.

A physical understanding of the flow path configuration of two-way and four-way valves is provided by Figs, respectively. Notice that a spool is a cylindrical member that has large-diameter lands machined to slide in a very close- fitting bore of the valve body. The radial clearance is usually less than 0.001 in. The grooves between the lands provide the flow passages between ports.

Four-way valve that is spring offset. In this case the lever shifts the spool, and the spring returns the spool to its original position when the lever is released. There are only two unique operation positions, as indicated by the graphical symbol. Notice that the ports are labeled at the envelope representing the neutral (spring offset or return) or unactuated position of the spool.

The directional control valves are manually actuated by the use of a lever. A two-position, four-way spring offset valve that is mechanically rather than manually actuate. This is depicted in the cut-away view, with the spool end containing a roller that is typically actuated by a cam-type mechanism. Notice that the basic graphical symbol is the same by that actuation is depicted as being mechanical rather than manual.

Directional control valves can also be shifted by applying air pressure against a piston at either end of the valve spool, springs (located at both ends of the spool) push against centering washers to center the spool when no air is applied. When air is introduced

Through air is introduced through the left end passage, its pressure pushes against the piston to shift the spool to the right. Removal of this left end air supply and introduction of air through the right end passage caused the spool to shift to the left. Therefore, this is a four-qay, three-position, spring-centered, air pilot-actuated directional control valve.

A very common way to actuate a spool valve is by using a solenoid, when the electric coil (solenoid) is energized, it creates a magnetic force that pulls the armature into the coil. This causes the armature to push on the push rod to move the spool of the valve.

This valve has a flow capacity of i2 gpm and a maximum operating pressure of 3500 psi. It has a wet armature solenoid. Which means that the plunger or armature of the solenoid moves in a tube that is open to the tank cavity of the valve. The fluid around the armature serves to cool it and cushion it's stoke without appreciable affecting response time. There are no seals around this armature to wear or restrict its movement. This allow all the power developed by the solenoid to be transmitted to the valve spool without having to overcome seal friction. Impact loads, which frequently cause premature solenoid failure, are eliminated with this construction. This valve has a solenoid at each of the Spool. Specifically, it is a solenoid-actuated, four-way, three-position, spring centered directional control valve

Solenoids are commonly used to actuate small spool valves. This three-way valve is specially designed to be used with small cylinders and other similar devices requiring low flow rates.

Most three-position valves have a variety of possible flow path configurations. Each four-way valve has identical flow path configuration in the actuated positions but different spring-centered flow paths.

Shuttle valve

A shuttle valve is another type of directional control valve. It permits a system to operate from either of two fluid power sources. One application is for safety in the event that the main pump can no longer provide hydraulic power to operate emergency devices. The shuttle valve will shift to allow fluid to flow from a secondary backup pump. A shuttle valve consists of a floating piston that can be shuttle to one side or the other of the valve depending on which side of the piston has the greater pressure. Shuttle valves may be spring loaded in one direction to favor one of the supply sources or unbiased so that the direction of flow through the valve is determined by circuit conditions. A shuttle valve is essentially a direct-acting double-check valve with a cross- bleed. As shown by the double arrows on the graphical symbol, reverse flow is permitted.

Pressure Control Valves

The most widely used type of pressure control valve is the pressure relief valve, since it is found in practically every hydraulic system. It is a normally closed valve whose function is to limit the pressure to a specified maximum value by diverting pump flow back to the tank.

A poppet is held seated inside the valve by a heavy spring. When the system pressure reaches high enough value, the poppet is forced off its seat. This permits flow through the outlet to the tank as long as this high pressure level is maintained. Notice the external adjusting screw, which varies the spring force and, thus, the pressure at which the valve begins to open (cracking pressure).

It should be noted that the puppet must open sufficiently to allow full pump flow. The pressure that exists at full pump flow pump flow can be substantially greater than the cracking pressure. Where system pressure is plotted versus flow through the relief valve.

Does not accept any flow, then all the pump flow must return back to the tank via the relief valve. The pressure relief valve provides protection against any over loads experienced by the actuators in the hydraulic system. Of course. A relief valve is not needed if a pressure-compensated vane pump is used. Obviously one important function of a pressure relief valve is to limit the force or torque produced by hydraulic cylinders and motors.

A compound pressure relief valve is one that operates in two stages. The pilot stage is located in the upper valve body and contains a pressure limiting poppet that is held against a seat by an adjustable spring. The lower body contains the port connection. Diversion of the full pump flow is accomplished by the balanced piston in the lower body.

The operation is as follows: In normal operation, the balanced piston is in hydraulic balance. Pressure at the inlet port acts under the piston and also on its top, because an orifice is drilled the large land. For Pressures less than the valve setting, the piston is held on its seat by a light spring. As soon as pressure reaches the setting of the adjustable spring, the poppet is force off its seat. This limits the pressure in the upper chamber. The restricted flow through the orifice and into the upper chamber results in an increase in pressure in the lower chamber. This causes an unbalance in hydraulic forces, which tends to raise the piston off its seat. When the pressure difference in hydraulic forces, which tends to raise the piston off its seat. When the pressure difference between the upper and lower chambers reaches approximately 20psi, the large piston lifts off its seat to permit flow directly to the tank. If the flow increases through the valve. The piston lifts farther off its seal. However, this compresses only the light spring, and hence very little override occurs. Compound relief valves may be remotely operated by using the outlet port from the chamber above the piston. For example, this chamber can be vented to tank via a solenoid directional control valve. When this valve vents the pressure relief to the 20-psi pressure in the bottom chamber overcomes the light spring and unloads the pump to the tank.

Pressure-reducing valve.

This type of valve (which is normally open) is used to maintain reduced pressures in specified locations of hydraulic systems. It is actuated by downstream pressure and tends to close as this pressure reaches the valve setting. The operation of a pressure-reducing valve that uses a spring-loaded spool to control the downstream pressure. If downstream pressure is below the valve setting, fluid will flow freely from the inlet to the outlet. Notice that there is an internal passageway from the outlet, which transmits outlet pressure to the spool end opposite the spring. When the outlet (downstream) pressure increases to the valve setting, the spool moves to the right to partially block the outlet port, as shown in view B. just enough flow is passed to the outlet to maintain its preset pressure level. If the valve closed completely. Leakage past the spool could cause downstream pressure to build up above the valve setting. This is prevented from occurring because a continuous bleed to the tank is permitted via a separated drain line to the tank. .

An additional pressure control device is the unloading valve. This valve is used to permit a pump to build up to an adjustable pressure setting and then allow I to discharge to the tank at essentially zero pressure as long as pilot pressure is maintained on the valve from a remote source. Hence, the pump has essentially no load and no load is therefore developing a minimum amount of horsepower. This is the case in spite of the fact that the pump is delivering a full pump flow because the pressure is practically zero. This is not the same with a pressure relief valve because the pump is delivering full pump flow at the pressure relief valve setting and thus is operating at maximum horsepower condition.

Sequence valve

It is designed to cause a hydraulic system to operate in a pressure sequence. After the components connected to port A have reached the adjusted pressure of the sequence valve, it passes fluid through port B to do additional work in a different portion of the system. The high-flow poppet of the sequence valve is controlled by the spring –loaded cone. Flow entering at port A is blocked by the poppet at low pressures. The pressure signal at A passes through orifices to the topside of the poppet and to the cone. There is no flow through these sections until the pressure rises at A to the maximum permitted by the adjustable set spring loaded cone. When the pressure at A reaches that Value, the main poppet lifts passing flow to port B. it maintains the adjusted pressure at port A until the pressure at B rises

To the pressure A, the control piston seats and prevents further pilot flow loss. The main poppet opens fully and allows the pressure at A and B to rise to higher values together. Flow may go either way t this time. The spring cavity of the control cone drains externally from port Y, generally to the tank. This sequence valve may be remotely controlled from vent port X.

Counterbalance valve.

The purpose of a counterbalance valve is to maintain control of a vertical cylinder to prevent it from descending due to gravity. The primary port of this valve is connected to the bottom of the cylinder, and the secondary port is connected to a directional control valve. (DCV). the pressure setting of the counterbalance valve is somewhat higher than is necessary to prevent the cylinder load from falling. As shown in Dig. (a), when pup flow directed (via the DCV) to the top of the cylinder, the cylinder piston is push downward. This causes pressure at the primary port to increase to raise the spool. This opens a flow path for discharge through the secondary port to the DCV back to the tank, when raising the cylinder an integral check valve opens to allow free flow for retracting the cylinder.

Flow Control Valves

Flow control valves are used to regulate the speed of hydraulic cylinders and motors controlling the flow rate to these actuators.

They may be a simple as a *fixed orifice or an adjustable needle valve.* Needle valves are designed to give fine control of flow in small – diameter piping. , their name is derived from their sharp, pointed conical disk and matching seat.

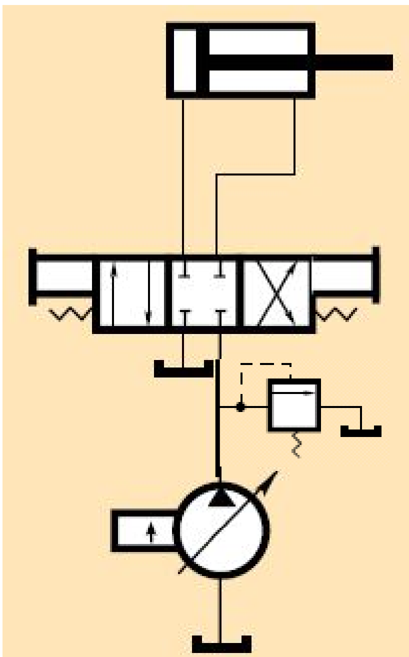
The stem has several color rings, which, in conjunction with a numbered knob, permits reading of a given valves opening as shown. Charts are available that allow quick determination of the controlled flow rate for given valve settings and pressure drops. A locknut prevents unwanted changes in flow

There are two basic types of flow control valves: non pressure-compensated and pressure-compensated. The non pressure –compensated type is used where system **pressures are relatively constant** and motoring speeds are not too critical. They work on the principle that the flow through an orifice will be constant if the pressure drop remains constant.

If the load on an actuator changes significantly, system pressure will change appreciable. Thus, the flow rate through a non pressure-compensated valve will change for the same flow rate setting. This design incorporates a hydrostat that maintains a constant 20-psi differential across the throttle, which is an orifice whose area can be adjusted by an external knob setting. The orifice area setting determines the flow rate to be controlled. The hydrostat is held normally open by a light spring. However, it states to close as inlet pressure increases and overcomes the light spring force. This closes the opening through the hydrostat and thereby block off all flow in excess of the throttle setting.

An actual pressure-compensated flow control valve, which has a pressure rating of 3000 psi. Pressure compensation will maintain preset flow within 1 to5%

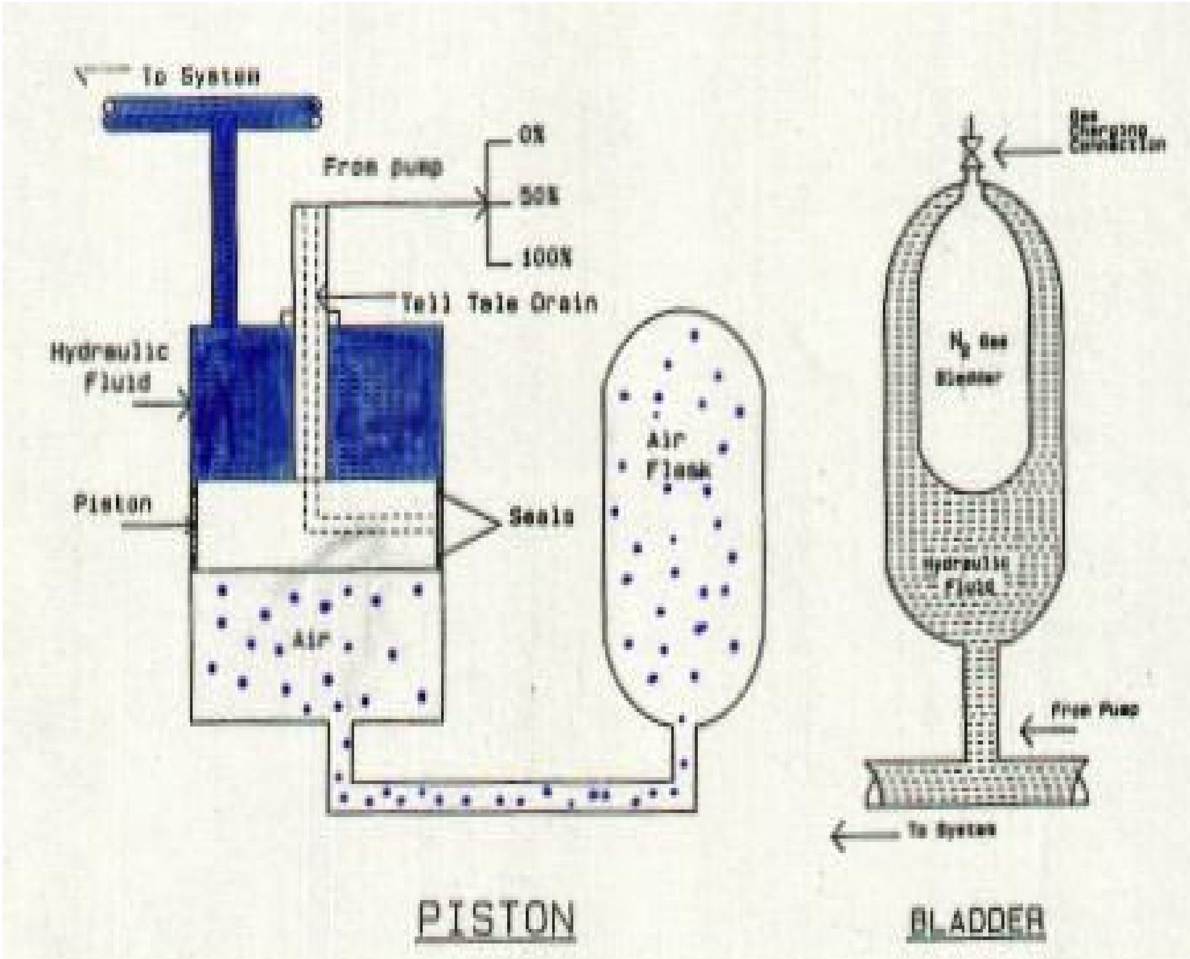
depending on the basic flow rate as long as there is 150-psi pressure differential between the inlet and outlet ports. The dial is calibrated for easy and repeatable flow setting. Adjustments over the complete valve capacity of 12 gpm are obtained within a 270^0 arc. A dial key lock prevents tampering with valve settings. A sharp-edged orifice design means that the valve is immune to temperature of fluid viscosity changes.



1. Weight – loaded, or gravity, type
2. Spring-loaded type
3 Gas –loaded type

The weight-loaded type is historically the oldest. This type consists of a vertical, heavy-wall steel cylinder, which i**ncorporates a piston with packing to prevent leakage.** A dead weight is attached to the top of the piston the force of gravity of the dead weight 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.

In the other types of accumulators, the fluid output pressure decreases as a function of the volume output of the accumulator. The main disadvantage of this type of accumulator is its extremely large size and heavy weight, which makes it unsuitable for mobile equipment.



<u>A spring-loaded accumulator is similar to the weight-loaded type except that the piston is preloaded with a spring,</u> 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 preloading of the spring. In addition, the pressure exerted on the fluid is not a constant. The spring-loaded accumulator typicality 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 application requiring high cycle rates because the spring will fatigue and lose it elasticity.* The result is an inoperative accumulator.

<u>Gas-loaded accumulators (frequently called hydro pneumatic accumulators) have been found to be more practical than the weight-and spring –loaded types.</u> The gas-loaded type operates in accordance with *Boyle's law of gases, which states that for a constant temperature process, the pressure of a gas varies in verily with its volume.* Thus, for example, the gas volume of the accumulator would be cut in half if the pressure were doubled. The compressibility of gases accounts for the storage of potential energy. This energy forces the oil out of the accumulator when

the gas expands due to the reduction of system pressure when, for example, an actuator rapidly moves a load.

Gas-loaded accumulators fall into two main categories:

1.Nonsparator type
2.Separator type

The nonseparator type consists of a fully enclosed shell containing an oil port on the bottom and a gas charging valve on the top the gas is confined in the top and the oil at 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 is its ability to handle large volumes of oil. The main disadvantage is absorption of the gas in the oil due to the lack of a separator. This type must be installed vertically to keep the gas confined at the top of the shell. This type is not recommended for use with high-speed pumps because the entrapped gas in the oil could cause cavitations and damage to the pump. Absorption of gas in the oil also makes the oil compressible, resulting in spongy operation of the hydraulic actuators.

The commonly accepted design of gas-loaded accumulator is the separator type. In this type there is a physical barrier between the gas and the oil. This barrier effectively utilizes the compressibility of the gas.

The three major classifications of the separator accumulator are

1. Piston type
2. Diaphragm type
3. Bladder type

Piston Type

The piston type consists of a cylinder containing a freely floating piston with proper seals, the piston serves as the barrier between the gas and oil. A threaded lock ring provided a safety feature, which prevents the operator from disassembling the unit while it is precharged. The main disadvantages of the piston type are that they are expensive to manufacture and have practical size limitation. Piston and seal friction may also be a problem in low-pressure systems. Also, appreciable leakage tends to occur over a long period of time, requiring frequent precharging. Piston accumulators should not be used as pressure pulsation dampeners or shock absorbers because of the inertia of the piston and the friction of the seals. The principal advantage of the piston accumulator is its ability to handle very high or low temperature system fluids through the utilization of compatible O-ring seals.

A piston –type accumulator that has a safety seal feature. This unique design concept permits the end cap O-rings to lose their pressure seal through a limited degree of housing deformation should pressures exceed safe operating limits and before fracture can occur. A specially designed end cap with a split-ring locking arrangement prevents the pressure within the accumulator from dislodging the end caps.

Diaphragm-type accumulator

The diaphragm-type accumulator consists of a diaphragm, secured in the shell, which serves as an elastic barrier between the oil and gas A shutoff button, which is secured at the base of the diaphragm, covers the inlet of the line 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 charging of the accumulator by means of a charging and testing device. The hydraulic pump delivers oil into the accumulator and deforms the diaphragm. As the pressure increases, the volume of gas decreases, thus storing hydraulic energy. In the reverse case, where additional oil is required in the circuit, it comes from the accumulator as the pressure drops in the system by a corresponding amount. The primary advantage of this type of accumulator is its small weight to volume ratio, which makes it suitable almost exclusively for airborne applications.

A bladder-type accumulator contains an elastic barrier (bladder) between the oil and gas, as illustrated in Fig. The bladder is fitted in the accumulator by means of a vulcanized gas-valve element and can be installed or removed through the shell opening at the poppet valve. The poppet valve closes the inlet when the accumulator 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 quick opening. The greatest advantage of this types of accumulator is the positive sealing between the gas and oil chambers. The light weight bladder provides quick pressure response for pressure regulating, pump pulsation, and shock-dampening applications.

The hydraulic pump delivers oil into the accumulator and deforms the bladder. As the pressure increases, the volume of gas decreases, thus storing hydraulic energy. In the reverse case, where additional oil is required in the circuit, it comes from the accumulator as pressure drops in the system by a corresponding amount.

An actual bladder-type accumulator, which contains the following features:

1. The gas valve is integrally molded in the separator bag.
2. The spring-loaded poppet valve maintains the bag inside the shell. This increases volumetric efficiency.
3. There is a drain plug for bleeding air from the system.

One of the most common applications of accumulators is an auxiliary power source. The purposed of the accumulator in this application is to store oil delivered by the pump during a portion of the work cycle. The accumulator then releases this stored oil upon demand to complete the cycle, thereby serving as a secondary power source to assist the pump. In such a system where intermittent operations are performed, the use of an accumulator results in being able to use a smaller-sized pump.

A second application for accumulators is as a *compensator for internal or external leakage* during an extended period of time during which the system is pressurized but not in operation. 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 of time. Finally, when system pressure drops to the minimum pressure setting of the pressure switch, it closed the electrical circuit of the pump motor until the system has been recharge. The use o an accumulator as a leakage compensator saves electrical power and reduces heat in the system.

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 failure. Such an application requires the use of an accumulator as an emergency power source, a solenoid actuated three way valve is utilized in conjunction with the accumulator. When the three-way valve is energized, oil flows to the bland end of the cylinder and also through the check valve into the accumulator and rod end of the cylinder. The accumulator charges as the cylinder extends. If the pump fails due to an electrical failure, the solenoid will de-energize, shifting the valve to its spring offset mode. Then the oil stored under pressure is forced from the accumulator to the rod end of the cylinder. This retracts the cylinder to its starting position.

One of the most important industrial applications of accumulators is the elimination or reduction of high-pressure pulsations or hydraulic shock. Hydraulic shock (or water hammer, as it is frequently called) is caused by the sudden stoppage or deceleration of a hydraulic fluid flowing at relatively high velocity in a pipeline. This hydraulic shock creates a compression wave at the source, where the rapidly closing valve is located. This compression wave travels at the speed of sound upstream to the end of the pipe and back again, causing an increase in the line pressure. This wave travels back and forth along the entire pipe length until its energy is finally *dissipated by friction.* The resulting rapid pressure pulsation or high-pressure surges may cause damage to the hydraulic system components.

The pressure pulsation or high-pressure surges can be suppressed. In this application the accumulator serves as a shock-suppressing device.

Application of accumulation

An automotive power-steering example of a mechanical-hydraulic servo system (closed-loop system). Operation is as follows:

1. The input or command signal is the tuning of the steering wheel.
2. This move the valve sleeve, which ports oil to the actuator (steering cylinder)
3. The piston rod moves the wheels via the steering linkage.
4. The valve spool is attached to the linkage and thus move with it.

Intensifier circuit:

An intensifier is a device which converts low pressure fluid power into high pressure fluid power intensifiers are used to multiply forces when a great force is needed for a relatively short distance. Hydraulic presses, riveting machines and spot-welders are typical application.

An intensifier consist of two cylinders of different sizes having a common piston. Oil is admitted under pressure to the bigger cylinder and exerts a force on the larger end of the piston. The smaller end of the piston exerts the same force on the hydraulic fluid in the smaller cylinder in the intensifier chamber. Since the area of the high pressure end of the piston in the intensifier is smaller than that of the low pressure end of the piston, the pressure exerted by the smaller piston is increased or intensified.

P_0 = Pressure exerted on large or operating end of the piston
P_1= Pressure exerted by the small end of the piston
A_0 = Area of the large end of the piston
A_1 = Area of the small end of the piston
$P_0.A_0 = P_i.A_i$
$P_i = (P_0.A_0)/A_i$
Intensifier ration = $P_i/P_0 = A_0/A_i$

<u>Intensifier Press Circuit</u>

This circuit is used for the punch-press application. When the direction control valve (DCV) is shifted to the left position, the oil flows to the rod end of the cylinder. So one the pressure builds-up, the pilot signal opens the check valve and retraction of the cylinder occurs.

When the DCV is shifted to the right mode, the oil flow to the blank of the cylinder, through the check valve. When the pressure in the cylinder reaches the sequence valve pressure setting, the intensifier stats to operate. The pressure is intensified and the high pressure output of the intensifier closes the check valve and pressurizes the blank end of the cylinder to perform the punching operation.

The intensifier should be installed near the cylinder to keep the high pressure lines as short as possible.

Regenerative Circuit

A regenerative circuit is used to speed up the extending speed of a double acting hydraulic cylinder. Both ends off the hydraulic cylinder are connected in parallel so that one port of the four way valve is blocked.

When the DCV is shifted to its left mode, the fluid by passes the DCV and enters into the rod end of the cylinder. Fluid in the blank end drains back to the tank through the DCV as the cylinder retracts.

When the DCV is shifted into its left mode, the cylinder extends. The speed of extension is grater for a regular double acting cylinder.

Extending speed The equation for the extending speed can be obtained as follows. The total flow rate (Q_r) entering the blank end of the cylinder equals the pump flow rate (Q_p) plus the regenerative flow rate (Q_r) coming from the rod end of the cylinder.

$$Q_r = Q_p + Q_R$$

solving for the pump flow.

$$Q_r = Q_r - Q_R$$

$$But\ Q_r = A_p \times V_{EXT}$$

$$Q_R = (A_p - A_R) \times V_{EXT}$$

where A_R = Rod Area, A_p = Piston area, V_{EXT} = Extending speed

$$Q_p = (A_p \times V_{EXT}) - \left[(A_p \times A_R) \times V_{EXT} \right]$$

$$= A_R \times V_{EXT}$$

$$V_{EXT} = Q_p / A_R$$

So the extending speed is equal to the pump flow rate divided by the area of the rod. Thus a small rod area provides a large extending speed.

Speed Ratio

Retracting speed $V_{RET} = \dfrac{Q_p}{(A_p - A_R)}$

$$\frac{V_{EXT}}{V_{RET}} = \frac{Q_p / A_R}{Q_p (A_p - A_R)} = \frac{A_p - A_R}{A_R}$$

Upon futher simplification

$$\frac{V_{EXT}}{V_{RET}} = \frac{A_p}{A_R} \text{-1}$$

In general, the grater the ration of piston area to rod area, the grater is the ratio of extending speed to retracting speed. When the piston area equals two times the rod area, the extension and retraction speeds are equal.

Load carrying capacity In accordance with Pascal's law, the same system pressure is acting on both sides of the piston during the extension stroke.

$$\begin{aligned} F_{load} &= (A_p \times P) - \left[(A_p - A_R) \times P\right] \\ &= A_R \times P \end{aligned}$$

So the load carrying capacity of a regenerative cylinder during extension is less than that obtained from a regular double acting cylinder. The carrying capacity for a regenerative cylinder equals the product of the pressure and the piston rod area rather than the pressure and the piston area. Thus due to the regenerative cylinder the extension speed is increased at the expense of the lo0ad carrying capacity.

Synchronizing Circuits

Many times in hydraulic machines, some object or platform is to be lifted with the help of two or more hydraulic cylinders simultaneously. In such cases it becomes absolutely necessary that both the cylinders move in unison.

There are many ways of synchronizing the mechanical motions of the actuators.

Tie cylinders: Cylinders tied together for mechanical synchronization are perhaps the most advantageous in action. This arrangement works well on heavy equipment when the mechanical linkage is rigid. Rack and pinion connections are good if the mesh is proper and backlash is not present. This method id limited to cylinders which move in the same direction.

Fluid from the pump is delivered to the blank end of cylinder 1 and fluid from the rod end of the cylinder 1 is delivered to the blank end of the cylinder2. Fluid returns to the tank from the rod end of cylinder 2 via the DCV. Thus the cylinders are hooked in series.

For the two cylinders to be synchronized the piston area of cylinder 2 must be equal to the difference between areas of piston and rod for cylinder 1.

i.e., $A_{p_2} = A_{p_i} = A_{p_i} - A_{R_1}$

The force euqtion are

$$P_1 A_{p_1} - P_2 (A_{p_i} - A_{R_1}) = F_1$$

$$P_2 A_{p_2} - P_3 (A_{p_2} - A_{R_2}) = F_2$$

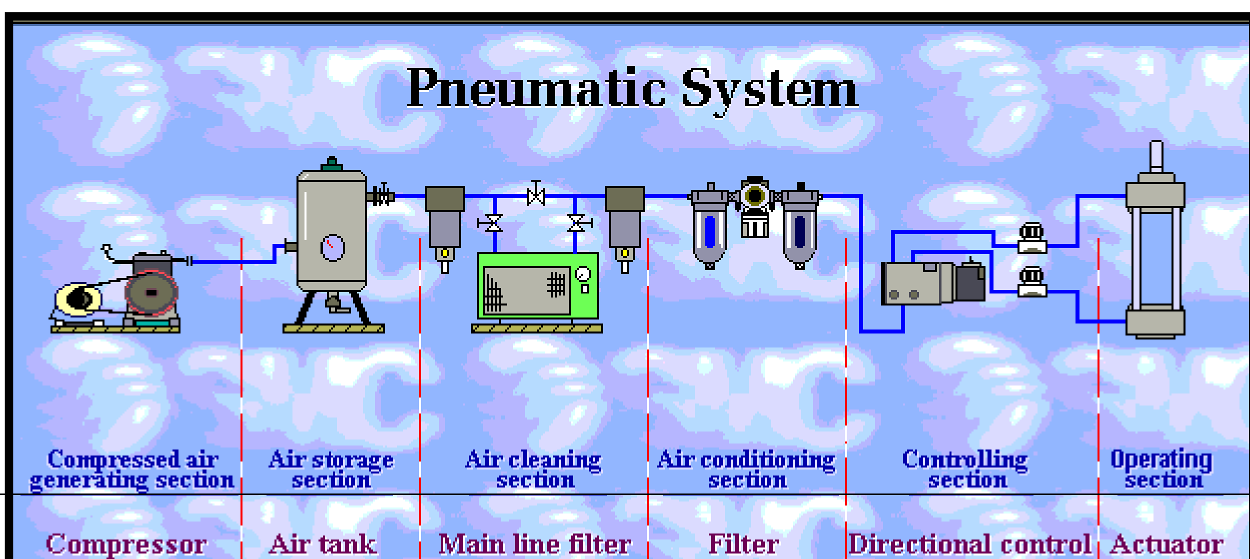
Adding both equation, we note that $A_{p_2} = A_{p_i} - A_{R_1}$ and that $P_3 = 0$ (due to the drain line to the tank)

$$P_1 A_{p_1} = F_1 + F_2$$

So, the pump must be capable of delivering a pressure equal to that required for the piston of cylinder 1 to overcome the loads acting on both the cylinders.

UNIT III

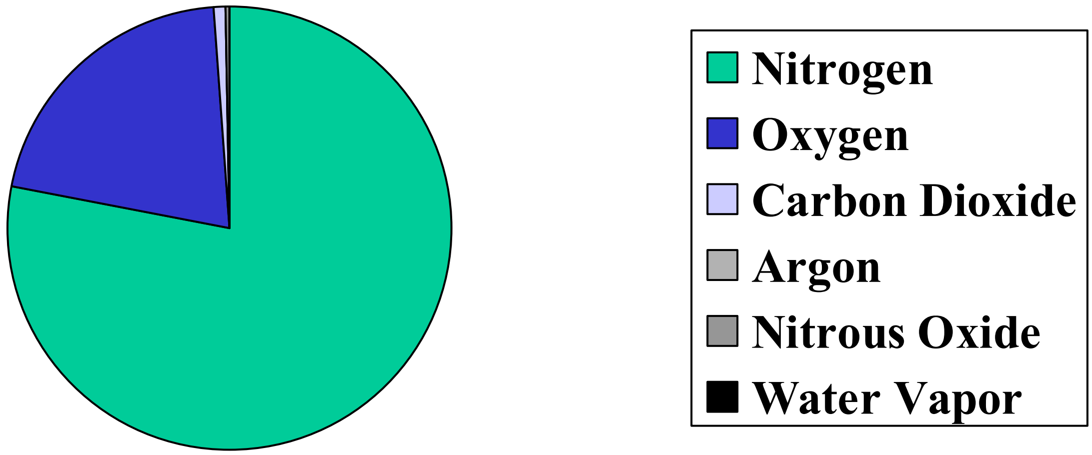
PNEUMATIC SYSTEMS COMPONENTS



Applications of the Pneumatics system

- Operation of system valves for air, water or chemicals
- Operation of heavy or hot doors
- Unloading of hoppers in building, steel making, mining and chemical industries
- Ramming and tamping in concrete and asphalt laying
- Lifting and moving in slab molding machines
- Crop spraying and operation of other tractor equipment
- Spray painting
- Holding and moving in wood working and furniture making
- Holding in jigs and fixtures in assembly machinery and machine tools
- Holding for gluing, heat sealing or welding plastics
- Holding for brazing or welding
- Forming operations of bending, drawing and flattening
- Spot welding machines
- Riveting
- Operation of guillotine blades
- Bottling and filling machines
- Wood working machinery drives and feeds
- Test rigs
- Machine tool, work or tool feeding
- Component and material conveyor transfer
- Pneumatic robots
- Auto gauging
- Air separation and vacuum lifting of thin sheets
- Dental drills

Components of air



Properties of air

Air is actually a mixture of gases containing about 21% of oxygen, 78% nitrogen, and 1% other gases such as argon and carbon dioxide. The preceding percentage values are based on volume. Air also contains up to 4% water vapor depending on the humidity. The percent of water vapor in atmospheric air can vary constantly from hour to hour even at the same location.

The earth is surrounded by a blanket of air called the atmosphere. Because air has weight, the atmosphere exerts a pressure at any point due to the column of air above that point. The reference point is sea level, where the atmosphere exerts a pressure of 14.7 psi (101 kPa) the atmospheric pressure decreases with altitude. For the region up to an altitude of 20,000 ft (6.1 Km), the relationship is nearly linear, with a drop in pressure of about 0.5 psi per 1000-ft change in altitude (11 kPa per km)

When making pneumatic circuit calculations, atmospheric pressure of 14.7 psiis used as a standard. The corresponding standard weight density value of air is 0.0752 lb/ft^3 at 14.7 psi and 68^{o}F (11.8N/m^3 at 101 kPa abs and 20^{0}C). Perfect gas laws, the density of a gas depends not only on its pressure but also on its temperature.

Air is not only readily compressible, but its volume will vary to fill the vessel containing it because the air molecules have substantial internal energy and are at a considerable distance from each other. This accounts for the sensitivity of density changes with respect to changes in pressure and temperature.

Free air is considered to be air at normal atmospheric conditions. Since atmospheric pressure and temperature vary from day to day, the characteristics of free air vary accordingly. Thus, when making pneumatic circuit calculations, the term standard air is used.

Standard air is sea-level air having a temperature of 68°F, a pressure of 14.7 psia (20°C and 101 kPa) abs), and a relative humidity of 36%.

Circuit calculations dealing with volume and pressure changes of air must be performed using absolute pressure and absolute temperature values.

absolute pressure (psia) = gage pressure (psig) + 14.7

absolute pressure (Pa abs)=gage pressure (Pa gage)+101.000

absolute temperature (R^0) = temperature (^0F) + 460

absolute temperature (^0K) = temperature (^0C) + 273

The units of absolute temperature in the English system are degrees Rankine, abbreviated °R. A temperature of 0°R (-460°F) is the temperature at which all molecular motion ceases to exist and the volume and pressure of a gas

theoretically become zero. The units of absolute temperature in the metric system are kelvins, abbreviated K. we note that a temperature of 0K (absolute zero) equals – 273°C.

Perfect gas laws

During the sixteenth century, scientists discovered the laws that determine the interactions of pressure, volume and temperature of a gas. These laws are called the perfect gas laws because they were derived on the basis of a perfect gas. Even though perfect gases do not exist, air behaves very closely to that predicted by Boyle's law, Charles' law, Gay-Lussac's law, and the general gas law for the pressure and temperature ranges experienced by pneumatic systems. Each of these laws (for which absolute pressure and temperature values must be used) is defined and applied to a particular problem as follows.

Boyle's law states that if the temperature of a given amount of gas is held constant, the volume of the gas will change inversely with the absolute pressure of the gas:

$$\frac{V_1}{V_2} = \frac{P_2}{P_1} \qquad (10\text{-}3)$$

Boyle's law is demonstrated by the cylinder piston system , the air in the cylinder is compressed at constant temperature from volume V_1 to V_2 by increasing the force applied to the piston from F_1 to F_2. Since the volume decreases, the pressure increases, as depicted by the pressure gage.

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

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

Charles' law is demonstrated by the cylinder-piston system, the air in the cylinder is heated while the piston rod is supporting at W. Since the weight maintains a constant force on the piston, the pressure shown constant and the volume increases.

Compressors

A compressor is a machine that compresses air or another type of gas from a low inlet pressure (usually atmospheric) to a higher desired pressure level. This is accomplished by reducing the volume of the gas.

Air compressors are generally positive displacement units and are either of the reciprocating piston type or the rotary screw or rotary vane types. Such a design contains pistons sealed with piston rings operating in precision-bored close-fitting cylinders. Notice that the cylinders have air fins to help dissipate heat. Cooling is necessary with compressors to dissipate the heat generated during compression.

When air is compressed it picks up heat as the molecules of air come closer together and bounce off each other at faster and faster rates. Excessive temperature can damage the metal components as well as increase input power requirements. Portable and small industrial compressors are normally air-cooled, whereas larger units must be water-cooled.

NUMBER OF STAGES	PRESSURECAPACITY (PSI)
1	150
2	500
3	2500
4	5000

Pneumatic systems typically involve a source of compressed air being controlled by valves and causing output devices such as cylinders to operate in a controlled way.

The compressed air is typically obtained from a COMPRESSOR, which is usually driven by an electric motor or an internal combustion engine..

Air is routed through pipes to VALVES which control the routing of the compressed air. Valves may be operated by a range of ACTUATORS including levers, rollers and solenoids.

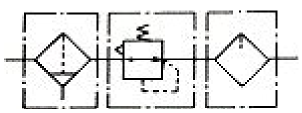
The air is then passed on to cylinders which convert the energy in the compressed air into linear motion and do useful work.

Finally, the used compressed air is released into the atmosphere as EXHAUST.During the course of the above, the compressed air may pass through filters and lubricators to clean the air and add lubricant to ensure that equipment has a long and reliable working life. It may also pass through regulators to control the amount of pressure available in the system.

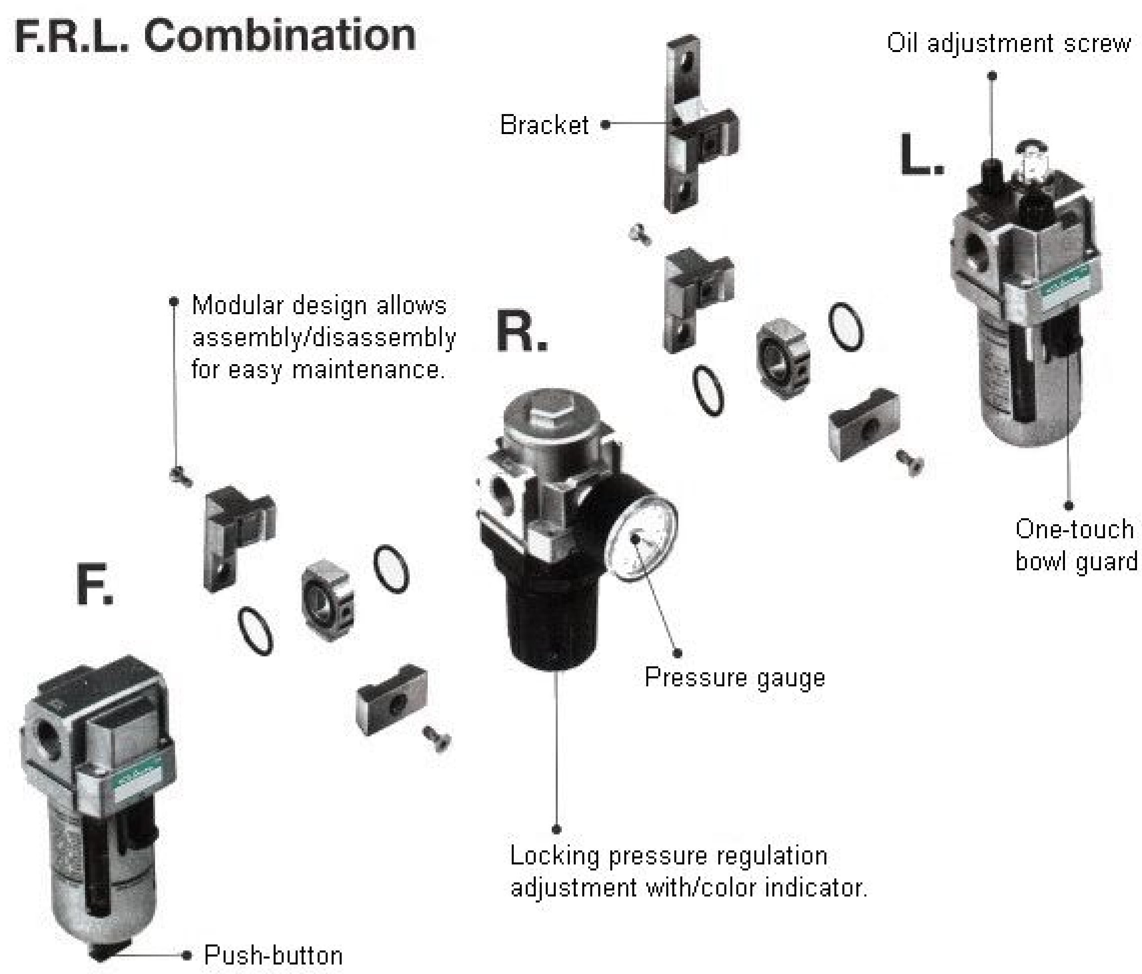
Filters(F) Regulators(R), Lubricators(L), Mufflers & Air dryers

F.R.L. **FR + L** **F** **R**

Symbol



Filter Regulator Lubricator



The purpose of fluid conditioners is to make air a more acceptable fluid medium for the pneumatic system as well as operating personnel. Fluid conditioners include filters, regulators, lubricators, mufflers and air dryers.

The function of a filter is to remove contaminants from the air before it reaches pneumatic components such as valves and actuators. Generally speaking in-line filters contain filter elements that remove contaminants in the 5-μm cellulose felt, reusable, surface-type elements. These elements have gaskets molded permanently to each to prevent air bypass and make element servicing foolproof. These elements have a large ratio of air to filter media and thus can hold an astonishing amount of contamination on the surface without suffering significant pressure loss. The baffling system used in these filters mechanically separates most of the contaminants collected in the bowl from reentering the air stream.

The compressor control system maintains system air pressure within a given range. For example, the compressor may automatically start when the pressure drops to 100psi and automatically stop when the pressure in the receiver reaches

125 psi. This is generally accomplished with pressure switches, and a relief valve is used to protect the system if the compressor fails to shut down when required.

So that a constant pressure is available for a given pneumatic system pressure regulator is used.A pressure regulator that use spring-loaded diaphragm and features balanced valves for superior regulation characteristics. Large main valve seats and precisely positioned aspirator tube provide for excellent flow characteristics and minimal pressure drop. The relationship between the diaphragm, valve size, and valve travel assure the controlling and maintaining of secondary pressures whether for circuit requirements, safety, or energy-saving needs. Units are provided with gage ports on both front and back, and either port can be used as an additional regulated outlet. Maintenance is easily performed when required without removing regulators from the air line. The regulator contains an adjustable upper spring, which allows the valve to hold a given pressure on the downstream side. The force of the spring is set for the required downstream pressure. This force holds the valve open until downstream pressure, acting on the diaphragm, starts to exceed the spring force. As a result, the push rod is allowed to move up and the spring-loaded valve at the bottom begins to close to throttle the air supply to the controlled pressure side.

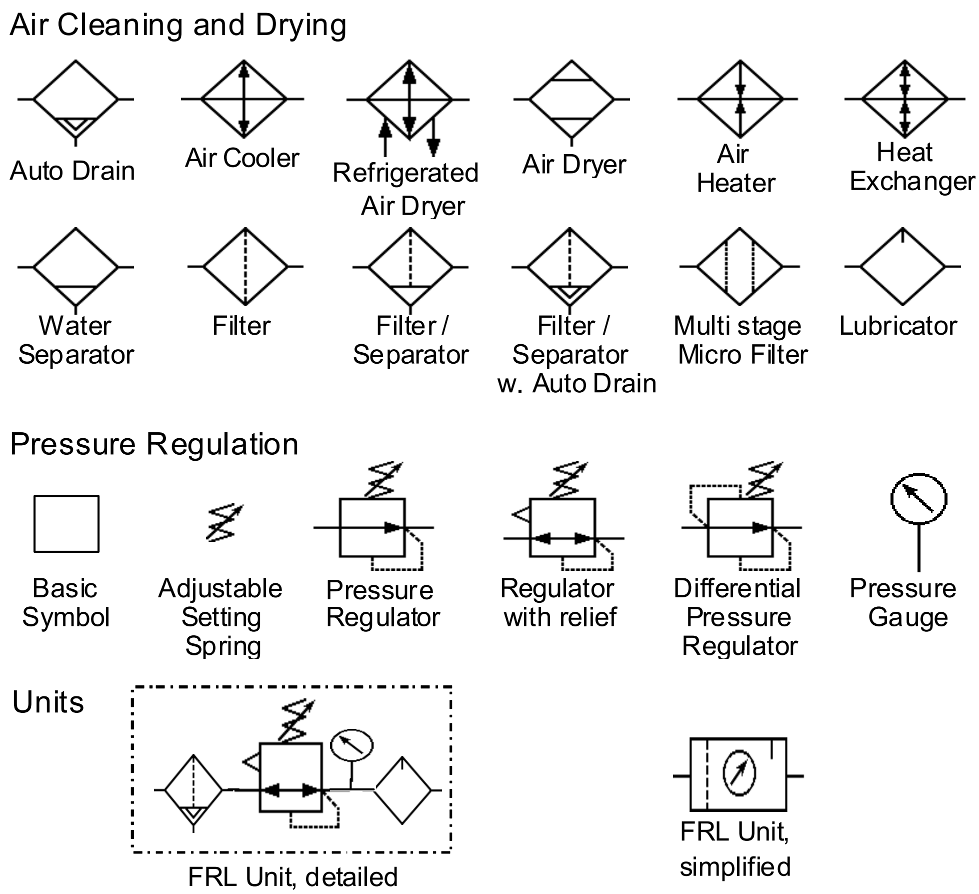
A lubricator ensures proper lubrication of internal moving parts of pneumatic components. The operation of a lubricator, which inserts every drop of oil leaving the drip tube, as seen through the sight dome, directly into the airstream. These drops of oil are transformed into an oil mist prior to their being transported downstream. This oil mist consists of both coarse and fine particles. The coarse particles may travel distances 0f 20ft or more, while the fine particles often reach distances as great as 300ft from the lubricator source.

a) A pneumatic indicator that provides a two-color, two-position visual indication of air pressure. The rounded lens configuration provides 180^{o} view of the indicator status, which is a fluorescent signal visible from the front and side. This indicator is easily panel-mounted using the same holes as standard electrical pilot lights. However, they are completely pneumatic, requiring no electrical power.

These pneumatic indicators are field adjustable for either one input with spring return or two inputs with memory. This memory does not require continuous pressure to maintain its last signal input. Field conversion may be made to select either single-input, spring return, or two-input maintained modes of operation. By using the same adjustment, either of the two display colors and its individual input may be selected for single-input operation. In the center position, this adjustment allows the indicator to accept two inputs for a maintained (memory) mode of operation. If both inputs are on simultaneously, the indicator will assume in intermediate position and show parts of both colors.

A pneumatic exhaust silencer (muffler) is used to control the noise caused by a rapidly exhausting airstream flowing into the atmosphere. The increased use of compressed air in industry has created a noise problem. Compressed air exhausts generate high-intensity sound energy, much of it in the same frequency ranges as normal conversation. Excessive exposure to these noises can cause loss of hearing without noticeable pain or discomfort. Noise exposure also causes fatigue and lowers production. It blocks out warning signals, thus causing accidents. This noise problem can be solved by installing a pneumatic silencer at each pneumatic exhaust port.

ISO SYMBOLS for AIR TREATMENT EQUIPMENT



Air from the atmosphere contains varying amounts of moisture in the form of water vapor. Compressors do not remove this moisture. Cooling of compressed air in piping causes condensation of moisture, much of which is eventually carried along into air-operated tools and machines. Water washes away lubrication, causing excessive wear and decreased efficiency. In addition, the temperature of the compressed air in piping causes condensation of moisture, much of which is eventually carried along into air-operated tools and machines. Water washes away lubrication, causing excessive wear and decreased efficiency. In addition, the temperature of the compressed air discharge from virtually all air compressors should be reduced to approximately 100ºF before entering the piping system. If an aftercooler is placed immediately downstream of a compressor, it will remove most of the moisture. An aftercooler is essential to reduce the air temperature to convenient levels and to act as a first stage in the removal of moisture prior to entering an air dryer. An aftercooler that is installed in the air line between the compressor and the air receiver. Water flow is opposite to air flow with internal baffles to provide proper water velocity and turbulence for high heat transfer rates. After passing through the tubes, the cooled air enters the moisture separating chamber.

Air Control Valves

Air control valves are used to control the pressure, flow rate, and direction of air in pneumatic circuits. Pneumatic pressure control valves are air line regulators that are installed at the inlet of each separate pneumatic circuit.

As such, they establish the working pressure of the particular circuit. Sometimes air line regulators are installed within a circuit to provide two or more different pressure levels for separate portions of the circuit. The desired pressure level is established by the T-handle, which exerts a compressive force on the spring. The spring transmits a force to the diaphragm, which regulates the opening and closing of the control valve. This regulates the air flow rate to establish the desired downstream pressure.

A photograph of a pneumatic shuttle valve that automatically selects the higher of two input pressures and connects that pressure to the one output port and employs a free-floating spool with an open-center action. At one end of the spool's travel, it connects one input with the output port. At the other end of its travel, it connects the second input with the output port.

When a pressure is applied to an input port, the air shifts the spool and then moves through the sleeve ports and out the output port. When the pressure is removed from the input port, the air in the output port exhausts back through the shuttle valve and out one of the input ports. It normally exhausts out the input port through which it entered, but there is no guarantee and it may excess of the other. If a single is applied to the second input port, a similar action takes place.

Quick Exhaust Value

When the air is feed to the piston side of the cylinder, the air in the rod-end side of the cylinder can be exhausted to the atmosphere quickly by using a special valve. This valve is called a quick-exhaust valve. Here, the air flowing to the cylinder from the direction control valve will pass to P port of the quick exhaust valve and from the P port, it will pass to the A port of the quick exhaust through A and R to the atmosphere without traveling through A and R to the atmosphere without traveling through the P port and thus avoids the direction control valve as it normally happens. Thus the resistance to piston movement is eliminated to some extend and the speed of the cylinder is accelerated proportionately by that amount of less resistance.

The Time delay valve consists of an inbuilt air reservoir, an in-built non-return flow control valve and a pilot controlled spring return 3 way 2 position direction control valve. This valve is used in the pneumatic system to initiate a delayed signal.

When the compressed air is supplied to the port P of the valve, it is prevented from flowing to port A from P as this is blocked by the spring actuated spool. Air is accumulated in an in-built reservoir of the valve from the pilot control port Z, the control passage of the same being controlled by the needle of the in-built throttle valve. Pressure starts building up here. When the pressure needed to push the spool is built-up in the reservoir, the pilot spool of the 3/2 direction control valve shifts, thus opening port P of the main valve to A and closing R. The time required to built-up the pressure in the reservoir, is the amount of delay time offered by the time delay valve. With further increases of pressure, the in-built check valve opens, the air from the reservoir gets exhausted and the valve spool returns to its original position.

Shuttle valve

A shuttle valve consists of a valve body and a synthetic ball or a cuboids valving element moving inside the bore in the valve housing. There are three opening P1, P2 and A. If an air signal is fed to port P1, the ball moves, closing port P2 and air passes to A. If the air is fed to port P2 port P1 closed and air moves to A. If air is fed simultaneously to port P1 and P2 then air moves to A either from P1 or P2 form both. This element is also called an OR GATE.

Service unit (Air preparation unit):

In pneumatic systems a moisture separator, a pressure regulator a pressure indicator, a lubricator and a fitter are all frequently required. This need is so common that combined devices called service unit are available.

Pneumatic Actuators

Pneumatic systems make use of actuators in a fashion similar to that of hydraulic systems. However, because air is the fluid medium rather than hydraulic oil, pressures are lower, and hence pneumatic actuators are of lighter construction. For example, air cylinders make extensive use of aluminum and other nonferrous alloys to reduce weight, improve heat transfer characteristics and minimize corrosive action of air.

Internal construction features of a typical double acting pneumatic cylinder. The piston uses wear-compensating, pressure-energized U-cup seals to provide low-friction sealing and smooth chatter-free movement of this 200-psi pressure-rated cylinder. The end plates use ribbed aluminum alloy to provide a positive leakproof cushion with check valve action, which reverts to free flow upon cylinder reversal. The cushion adjustment, which uses a tapered self-locking needle at each end, provides positive control over the stroke, which can be as large as 20 in.

A rotary index table driven by a double-acting pneumatic cylinder. The inlet pressure can be adjusted to provide exact force for moving the load and to prevent damage in case of accidental obstructions. A rack and gear drive transmits the straight-line motion of the air cylinder to the rotary motion with full power throughout its cycle. Through the use of different cams, the table can be indexed in 90^o, 60^o, 45^o, 30^o or 15^o increments.

Pneumatic rotary actuator, which is available in five basic models to provide a range of torque outputs from 100 to 10,000 in. Ib using 100-psi air. Standard rotations are 94^o, 184^o and 364^o. The cylinder heads at each end serve as positive internal stops for the enclosed floating pistons. The linear motion of the piston is modified into rotary motion by a rack and pinion made of hardened steel for durability.

Rotary air motors can be utilized to provide a smooth source of power. They are not susceptible to overload damage and can be stalled for long periods of time without any heat problems. They can be started and stopped very quickly and with pressure regulations and metering of flow can provide infinitely variable torque and speed.

The equations for determining the output torque and power for air motors are identical to those used for hydraulic motors. However, because air is compressible, the accuracy of these equations is not as good for air motors as for hydraulic motors. For example, the speed of an air motor decreases significantly as the lad torque increases. In addition, the air-consumption rate (scfm) increases at the same air motor speed with increased pressure.

PNEUMATIC CIRCUIT DESIGN CONSIDERATIONS

When analyzing or designing a pneumatic circuit, the following four important considerations must be taken into account:

1. Safety of operation
2. Performance of desired function
3. Efficiency of operation
4. Costs

Safety of operation means that an operator must be protected by the use of build-in emergency stop features as well as safety interlock provisions that prevent unsafe, improper operation. Although compressed air is often quiet, it can cause sudden movements of machine components. These movements could injure a technician who, while troubleshooting a circuit, inadvertently opens a flow control valve that controls the movement of actuator.

Performance of the desired function must be accomplished on a repeatable basis. Thus, the system must be relatively insensitive to adverse conditions such as high ambient temperatures, humidity, and dust. Shutting down a pneumatic system due to failure or misoperation can result in the stoppage of a production line. Stoppage can result in very large costs, especially if the downtime is long due to difficulty in repairing the pneumatic system involved.

Efficiency of operation and costs are related design parameters. A low-efficiency compressor requires more electrical power to operate, which increases the system operating costs. Although atmospheric air is 'free," compressed air is not. Yet if a pneumatic system leaks air into the atmosphere without making significant noise, it is often ignored, because the air is clean. On the other hand, a hydraulic leak would be fixed immediately, because it is messy and represents a safety hazard to personnel walking in the vicinity of the leak.

Pneumatic circuit air losses through various leakage areas with a combined area of a 0.25-in-diameter hole would equal about 70 scfm for an operating pressure of 100 psig. Examples of such leakage areas include the imperfect sealing surfaces of improperly installed pipe fittings. A typical cost of compressing air to 100 psig is about \$0.35 per 1000 ft^3 of standard air. Therefore, it costs about \$0.35 to compress 1000 ft^3 of standard air. Therefore, it costs about \$0.35 to compress 1000 ft^3 of air from 14.7 psig to 100 psig. Thus, the yearly cost of such a leaking pneumatic system operating without any downtime is

$$\text{Yearly cost } = \frac{\$0.35}{1000\,ft^3} \times 70\,\frac{ft^3}{\min} \times \frac{60\min}{1hr} \times \frac{24hr}{1day} \times \frac{365days}{1yr}$$

= 4 12,900/yr

Another cause of increased operating costs is significantly undersized components such as pipes and valves. Such components cause excessive pressure losses due to friction. As a result the compressor must operate at much higher output pressure, which requires greater input power. Of course, greatly oversized components result in excessive initial installation costs along with improved operating efficiencies. Thus, a compromise must be made between higher initial costs with lower operating energy costs and lower initial costs with higher operating energy costs based on the expected life of the pneumatic system.

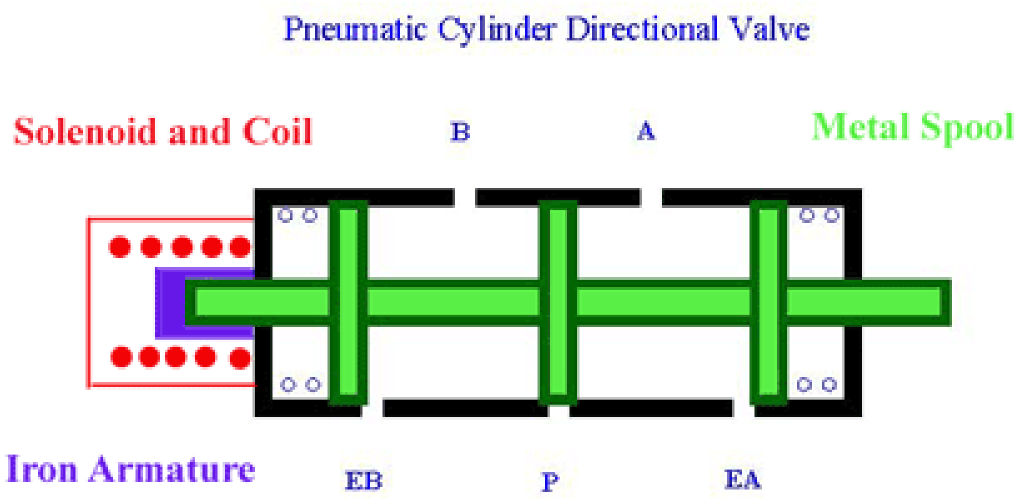
BASIC PNEUMATIC CIRCUITS

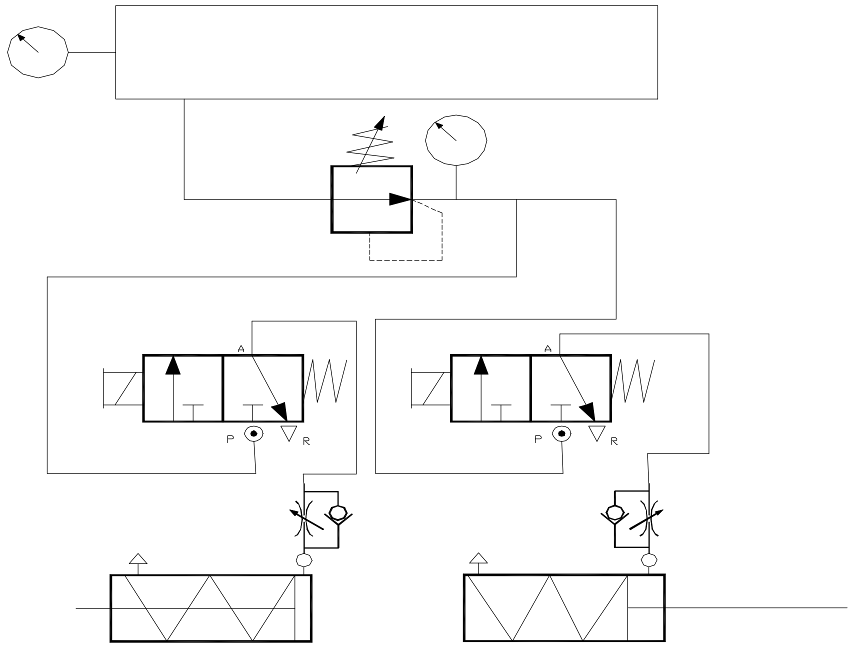
In this section we present a number of basic pneumatic circuits utilizing pneumatic components that have been previously discussed. Pneumatic circuits are similar to their hydraulic counterparts. One difference is that no return lines are used in pneumatic circuits because the exhausted air is released directly into the atmosphere. This is depicted by a short dashed line leading from the exhaust port of each valve. Also, no input device (such as a pump in a hydraulic circuit) is shown, because most pneumatic circuits use a centralized compressor as their source of energy. The input to the circuit is located at some conveniently located manifold, which leads directly into the filter-regulator-lubricator (FRl) unit.

A simple pneumatic circuit, which consists of a three-way valve controlling a single-acting cylinder. The return stroke is accomplished by a compression spring located at the rod end of the cylinder. When the push-button valve is actuated, the cylinder extends. It retracts when the valve is deactivated. Needle valves V_1 and V_2 permit speed control of the cylinder extension and retraction stroked, respectively.

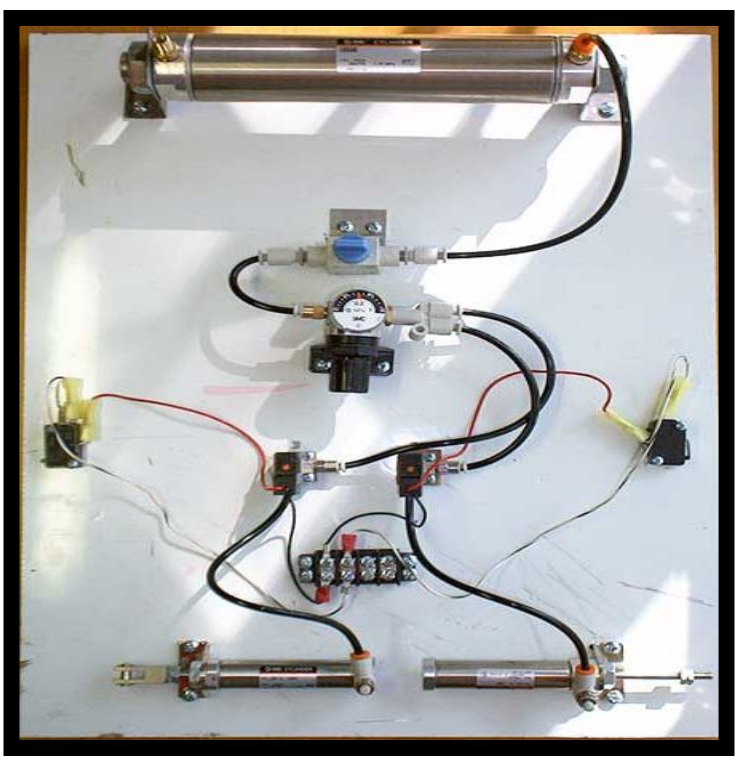
Notice that control of a double-acting cylinder requires a DCV with four different functioning ports (each of the two exhaust ports perform the same function). Thus a four-way valve has four different functioning ports. In contrast, the control of a single-acting, spring-return cylinder requires a DCV with only three ports. Hence a three-way valve has only three ports.

Actuation of the push-button valve extends the cylinder. The spring offset mode causes the cylinder to retract under air power.





Mini Pneumatic Circuits



Pneumatic Vacuum Systems.

When we think of the force caused by a fluid pressure acting on the surface area of an object, we typically envision the pressure to be greater than atmospheric pressure. However, there are a number of applications where a vacuum air pressure is used to perform a useful function. Industrial applications where a vacuum form pressure is used include materials handling, clamping, sealing, and vacuum forming.

In terms of materials-handling applications, a pneumatic vacuum can be used to lift smoothly objects that have a flat surface and are not more than several hundred pounds in weight. Examples of such objects include glass plates, sheet metal, sheets of paper, and floor-covering materials, such as ceramic tile and sheets of linoleum. The weight limitation is due to the fact that the maximum suction pressure equals 1 atm of pressure in magnitude.

Materials-handling application where a vacuum cup (sometimes called a suction cup) is used to establish the force capability to lift a flat sheet. The cup is typically made of a flexible material such as rubber so that a seal can be made where its lip contacts the surface of the flat sheet.

A vacuum pump (not shown) is turned on to a remove air from the cavity between the inside of the cup and top surface of the flat sheet. As the pressure in the cavity falls below atmospheric pressure, the atmospheric pressure acting on the bottom of the flat sheet pushed the flat sheet up against the lip of the cup. This action results in vacuum pressure in the activity between the cup and the flat sheet that causes an upward force to be exerted on the flat sheet. The magnitude of this force can be determined by algebraically summing the pressure forces on the top and bottom surfaces of the flat sheet.

$$F = P_{atm} A_o = P_{suction} A_i \qquad (11\text{-}4)$$

where F = the upward force the suction cup exerts on the flat sheet (Ib, N),

P_{atm} = *the atmospheric* pressure in absolute units (psia, Pa, abs)

A_o = the area of the outer circle of the suction cup lip

$$= \frac{\pi}{4} D_o^2 \left(in.^2, m^2 \right)$$

D_o = the diameter of the suction cup lip outer circle (in.. m)

$P_{suction}$ = the suction pressure inside the cup cavity in absolute units (psia, Pa, abs)

A_i = the area of the inner circle of the suction cup lip

= $\frac{\pi}{4}D_o^2\left(in.^2, m^2\right)$

D_i = the diameter of the suction cup inner lip circle (in., m)

Notice the atmospheric pressure on the top and bottom surfaces of the flat sheet cancel out away from the outer area of the cup lip.

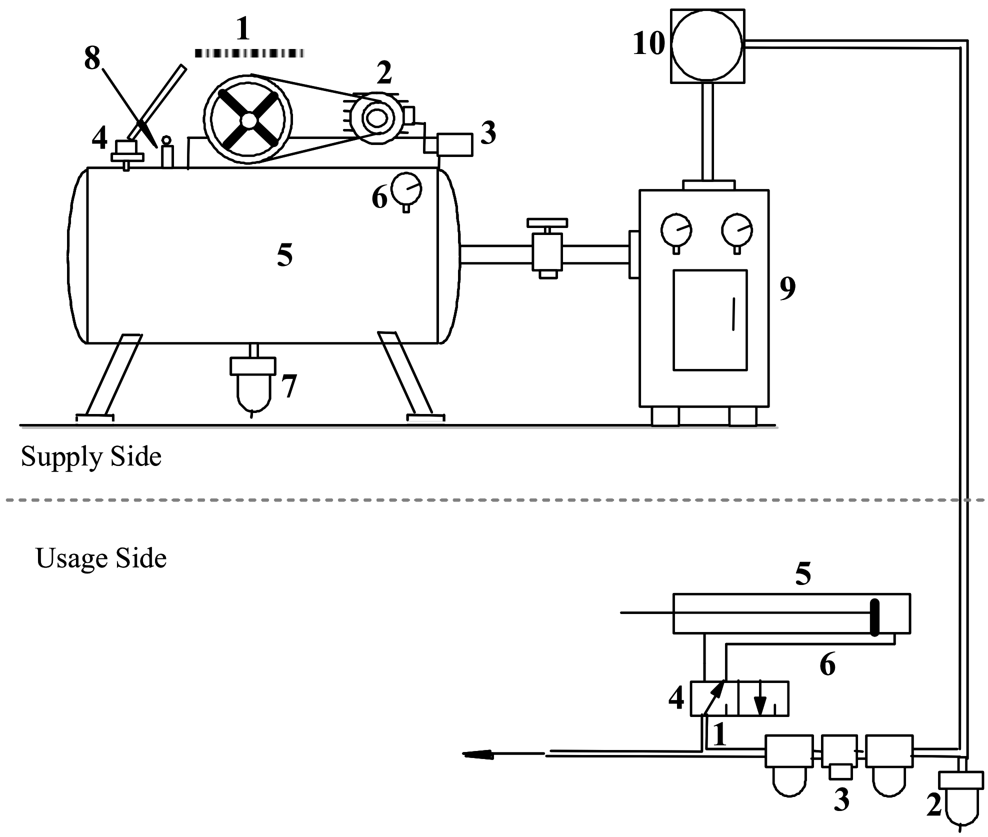
Because P_{atm} / P_{vacuum} is a ratio, it is dimensionless. Thus, any desired units can be used fpr P_{atm} and P_{vacuum} as long as the units are the same and are absolute. For example, inches of mercury absolute could also be used for both pressures instead of using psia or pascals absolute. Thus, for example, if P_{atm} is five times as large as P_{vacuum}, the pressure ratio will equal 5 no matter what units are used, as long as they are the same units and are absolute.

Discrete Control Logic

1. Pneumatic circuits

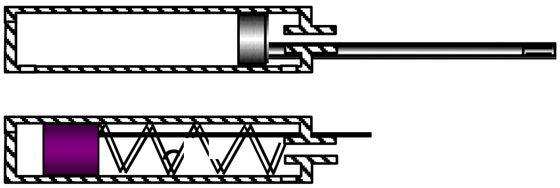
Low forces

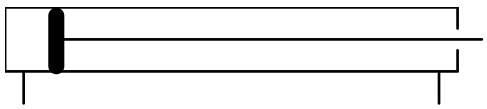
- Discrete, fixed travel distances
- Rotational or reciprocating motion



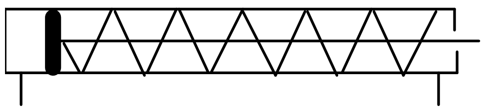
Main components: *compressor, valves, cylinders*

Pneumatic components: cylinders

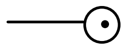




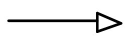
double -acting



spring-return

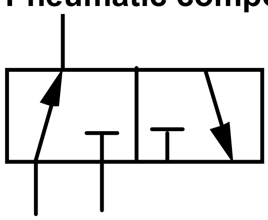


air supply

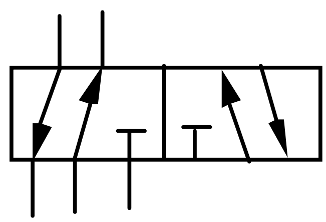


vent to atmosphere (air discharge)

Pneumatic components: valves

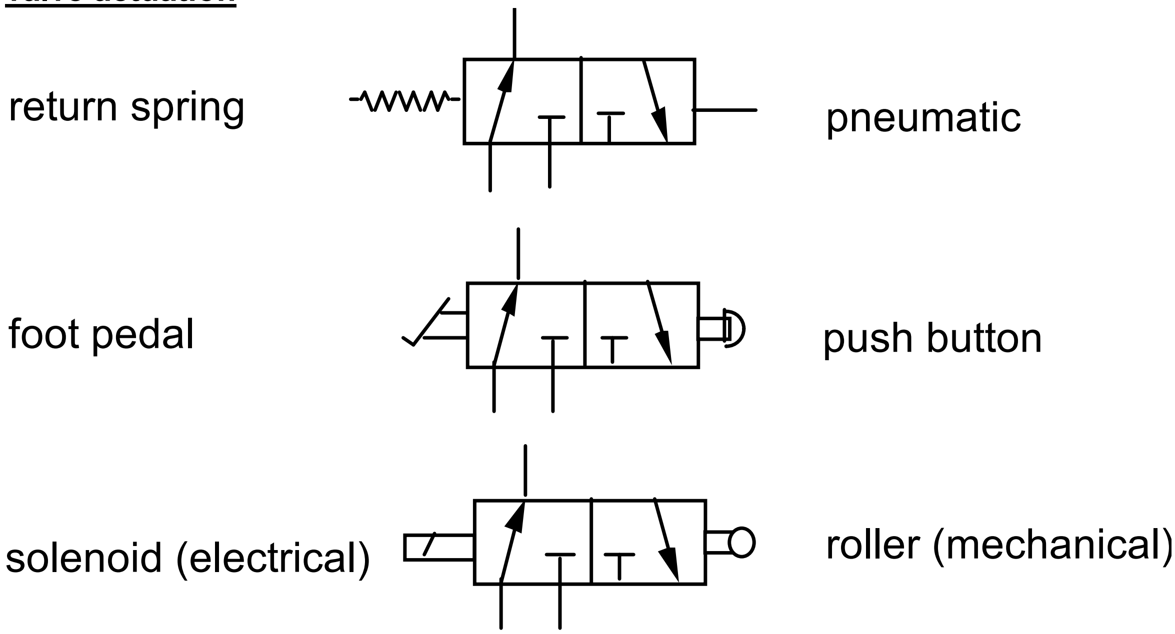


a 3/2 valve

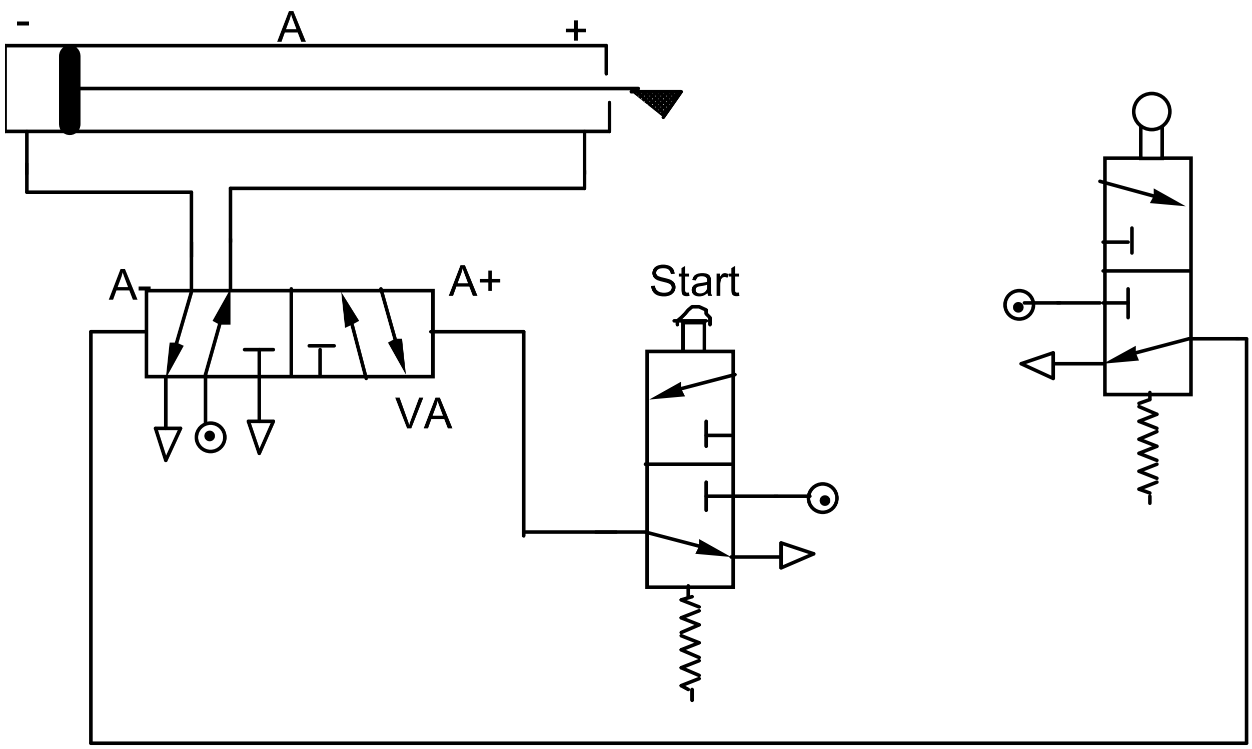


a 5/2 valve

valve actuation



Simple Pneumatic control



START, A+, A-

UNIT IV FLUIDICS & PNEUMATICS CIRCUIT DESIGN

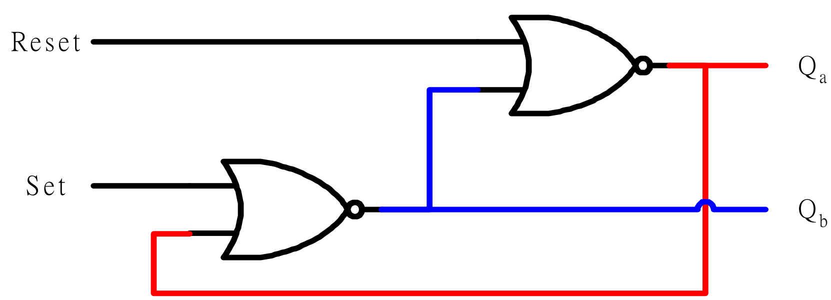
Fluidics :

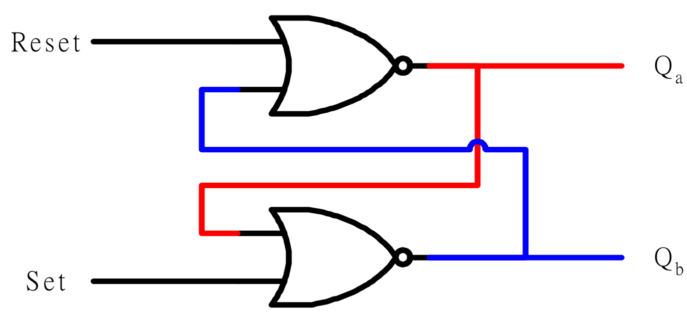
Fluidics or **Fluidic logic** is the use of a fluid to perform analog or digital operations similar to those performed with electronics.

The physical basis of fluidics is pneumatics and hydraulics, based on the theoretical foundation of fluid dynamics. The term *Fluidics* is normally used when devices have no moving parts, so ordinary hydraulic components such as hydraulic cylinders and spool valves are not considered or referred to as fluidic devices. The 1960s saw the application of fluidics to sophisticated control systems, with the introduction of the fluidic amplifier.

Basic Fluidic Devices.

These are basic fluidic devices. BASIC FLIP-FLOP, FLIP-FLOP WITH START UP REFERENCE, SRT FLIP-FLOP, OR/NOR, EXCLUSIVE-OR, and AND/NAND.

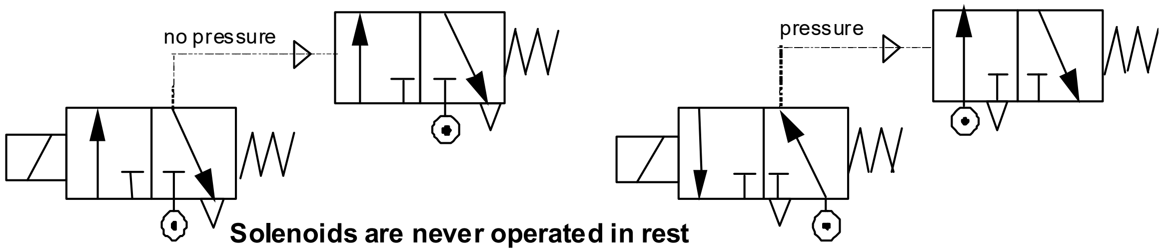




- Both circuit are the same
- The only feedback path is the red line

Electrically and pneumatically operated Valves

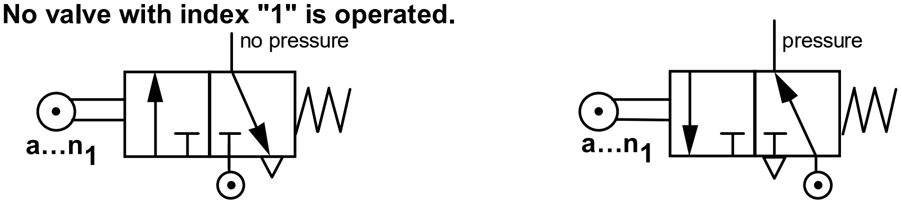
Air operated valves may be operated in rest



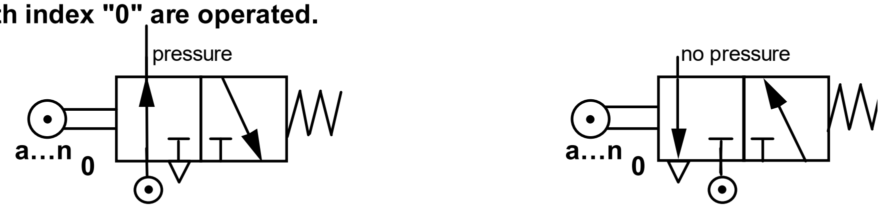
Solenoids are never operated in rest

Mechanically operated Valves

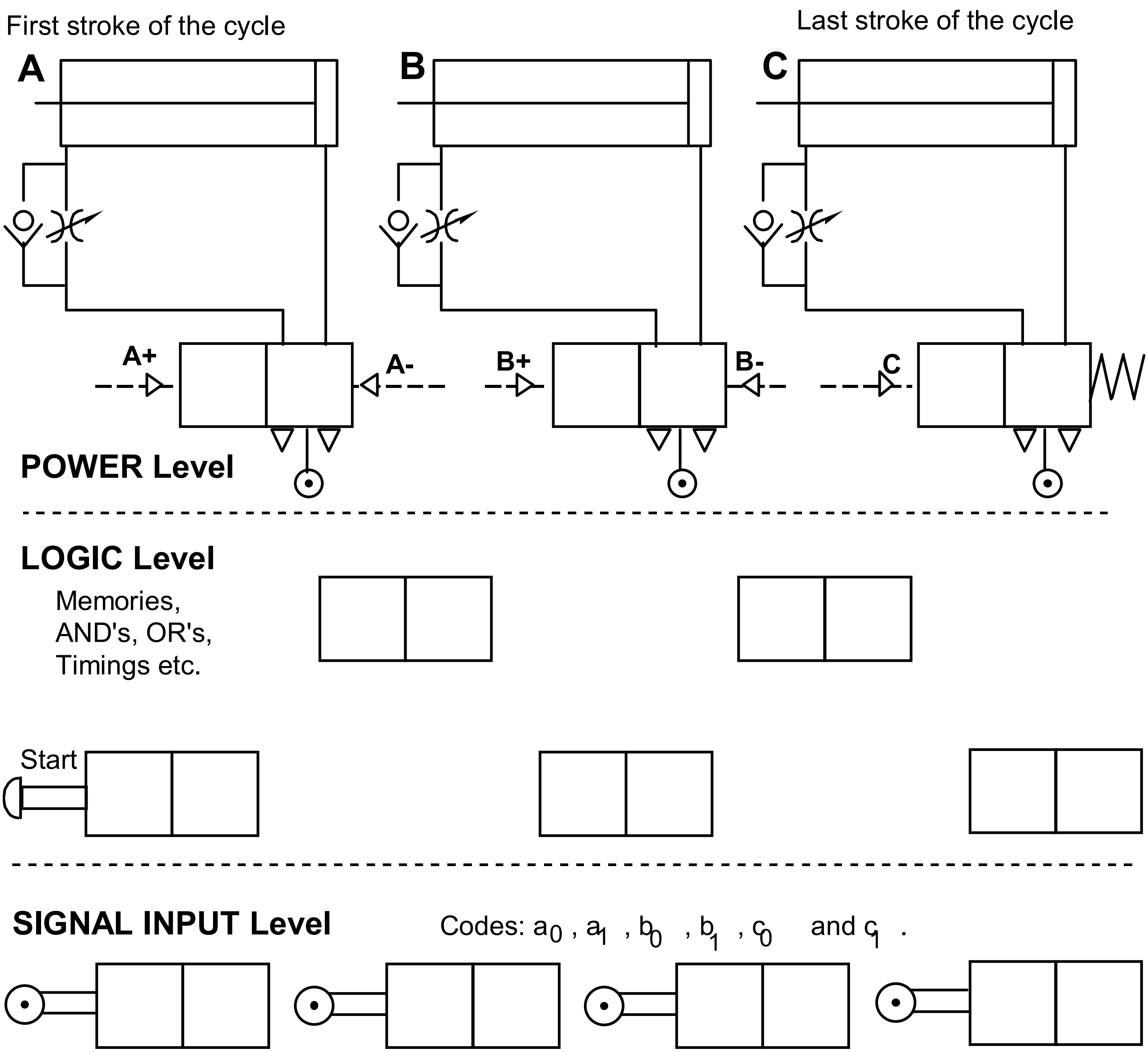
No valve with index "1" is operated.



All valves with index "0" are operated.



PLC applications in fluid power control:



Programmable Logic Controllers

PLC Basics:

computer + relays

STEP 1:

Write this logic into a PROGRAM

STEP 2:

Load program into PLC

STEP 3:

Connect the sensor output to *External Input terminal*.

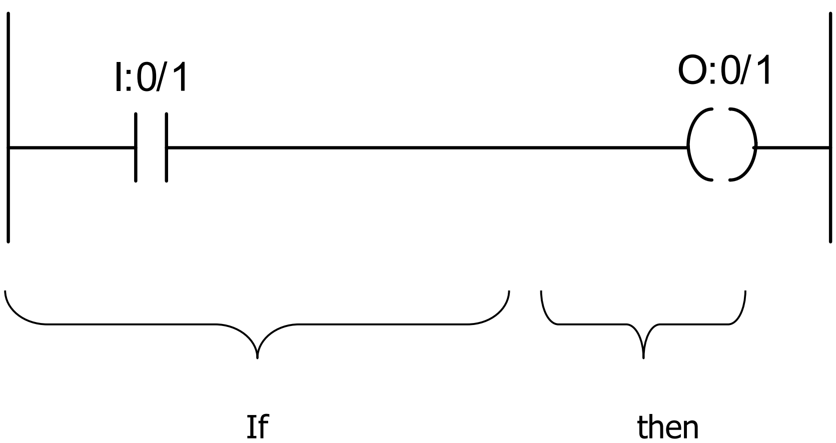
STEP 4:

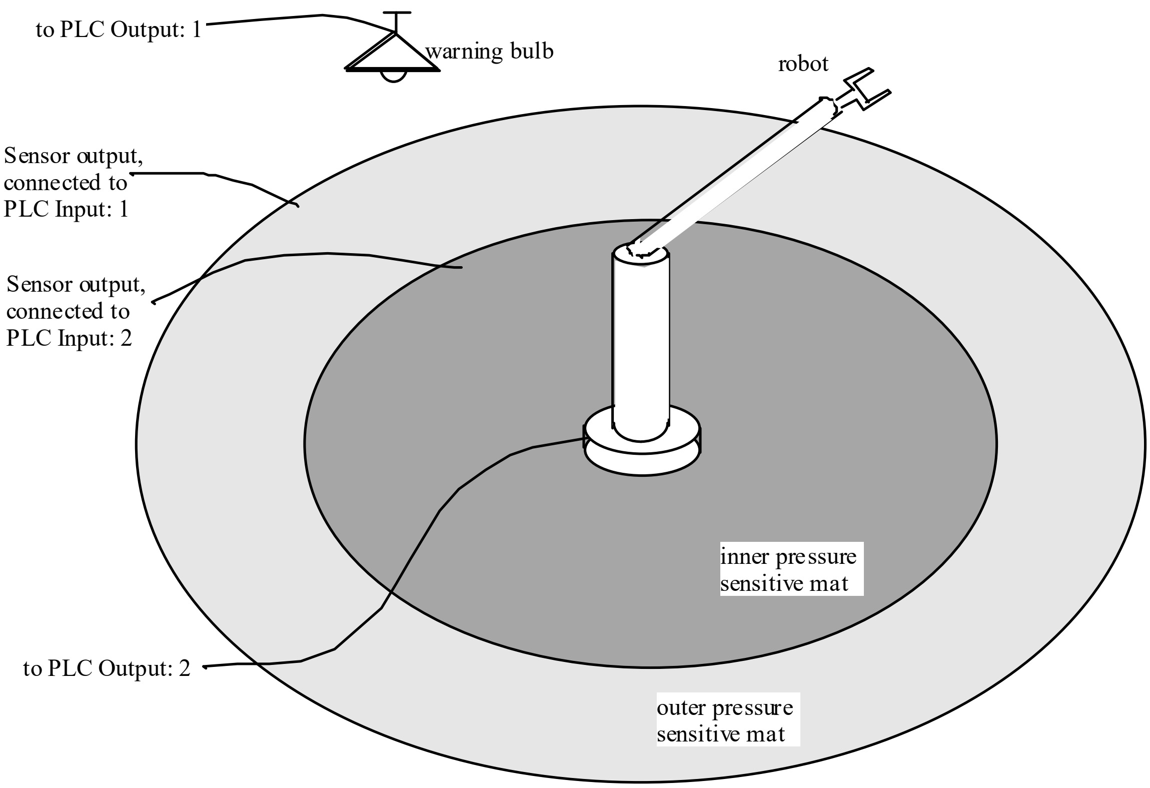
Connect the PLC *External Output Terminal* to Warning Light

STEP 5:

EXECUTE the logic program on the PLC.

Programming language: LADDER LOGIC





Outer mat ON → warning light ON

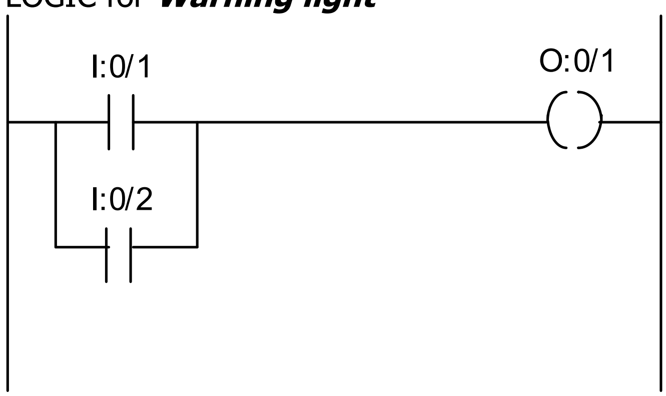
Inner mat ON → warning light ON AND Robot OFF

Stepping away from inner mat → Manually switch robot ON

PLC: example 2

Two actuators: Warning light, Robot master switch

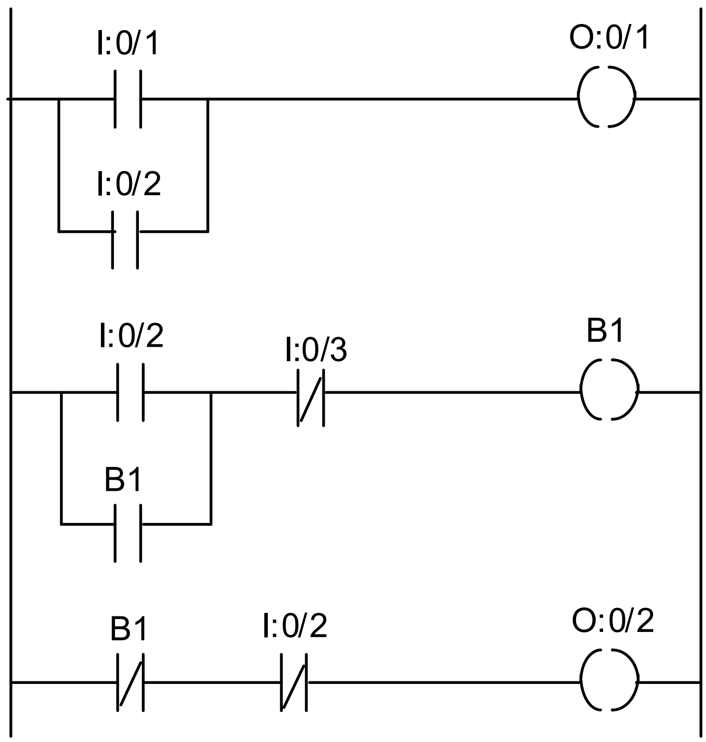
LOGIC for ***Warning light***



PLC: example 2

LOGIC for ***Robot***

Robot must ***STAY OFF*** until manual reset to ON



Legend:

I:0/1 connected to Outer Mat Switch

I:0/2 connected to Inner Mat Switch

I:0/3 connected to Push Button for robot reset

O:0/1 connected to warning light

O:0/2 connected to robot

ladder diagrams

Ladder Logic Programs

Switch (Relay) naming conventions

Lecture notes (Rockwell™ Automation PLC):

External inputs: I:0/1, I:0/2, …, I:1/1, I:1/2, … I:n/m

External outputs: O:0/1, O:0/2, …, O:1/1, O:1/2, … O:n/m

Internal Relays: B0, B1, …

etc.

Lab (SMC™ PLC):

External inputs: X0, X1, …

External outputs: Y0, Y1, …,

Internal Relays: R0, R1, …

etc.

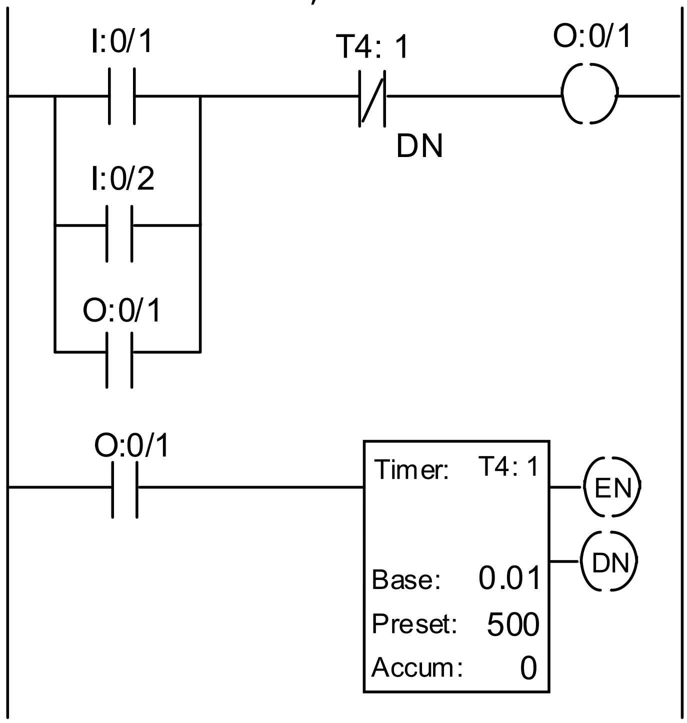
Ladder Logic: Timers

Solenoid actuated door-lock

Solenoid ON ➔ Door unlocked

Solenoid actuated when:

(i) ON signal from number-pad outside door
(ii) ON signal from door-open switch inside door
Solenoid ON for 5 sec, then OFF



Legend:

I:0/1 Number Pad Signal to open door

I:0/2 Push Button signal to open door

O:0/1 Solenoid to unlock door

Ladder Logic: Timers -- reset

Solenoid actuated when:

(i) ON signal from number pad outside door

(ii) ON signal from door-open switch inside door

Solenoid ON for 5 sec, then OFF

During ON, if button is pressed,

Timer resets to PRESET

During ON, light indicator is ON

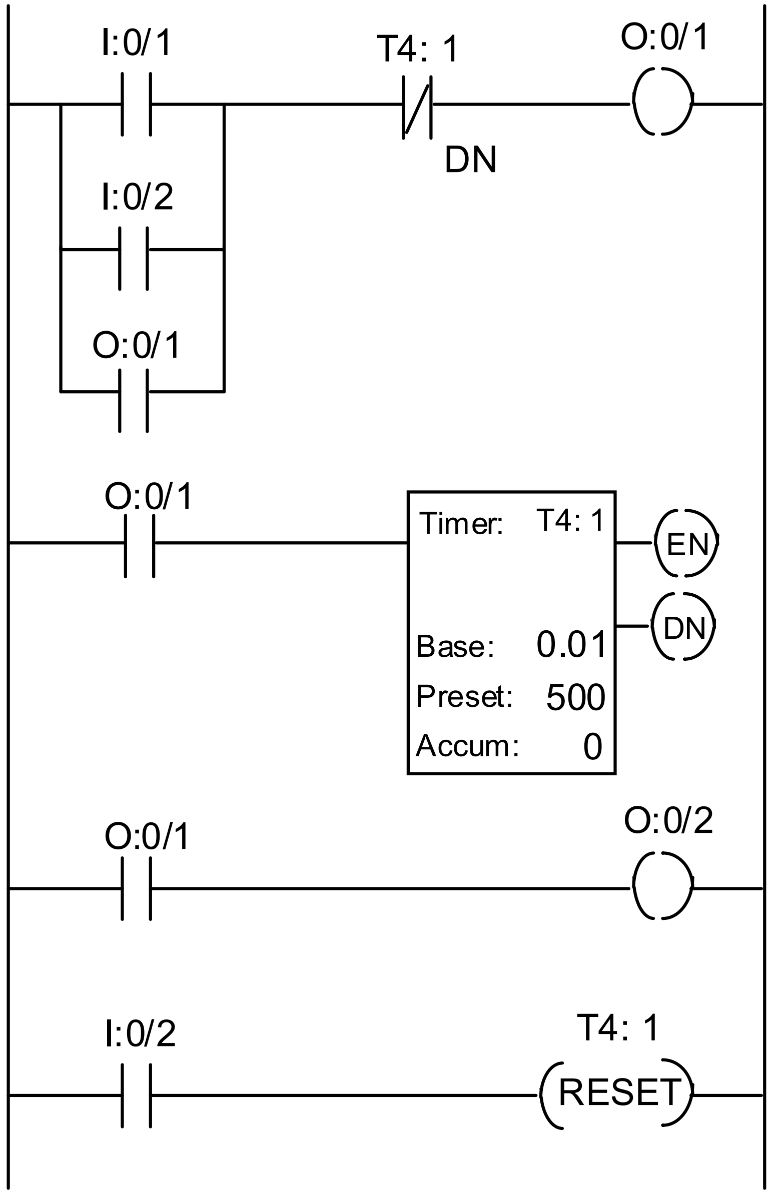
LEGEND:

I:0/1 → door-open

I:O/2 → card-reader

O:0/1 → solenoid

O:0/2 → light indicator



Programming a PLC

(1) Hand held console (direct feed of program into PLC

2) Computer-interface:

(i) Complete the program on a computer

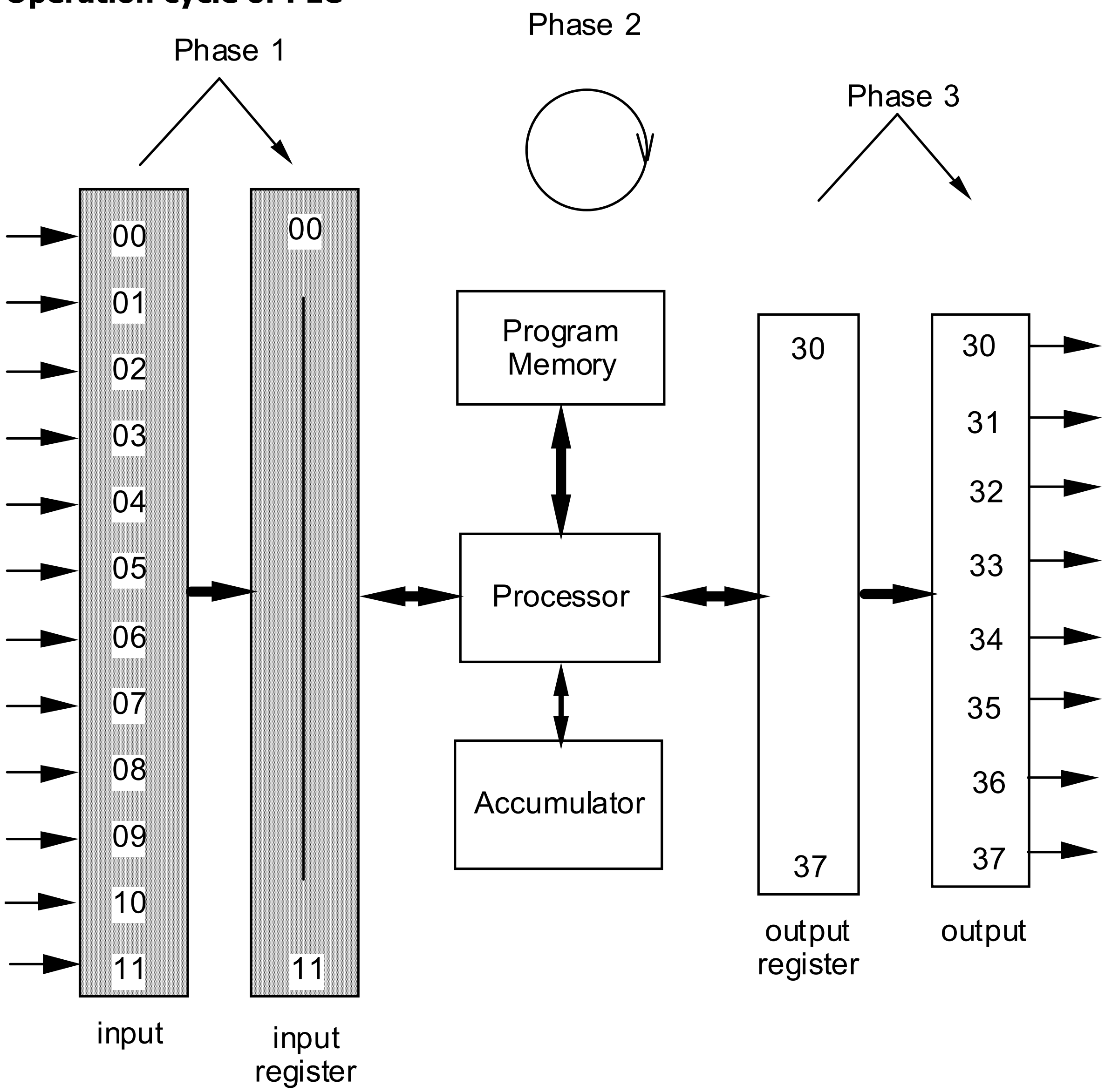
(ii) Test the program on PC

(iii) Upload the program to the PLC processor memory (persistent)

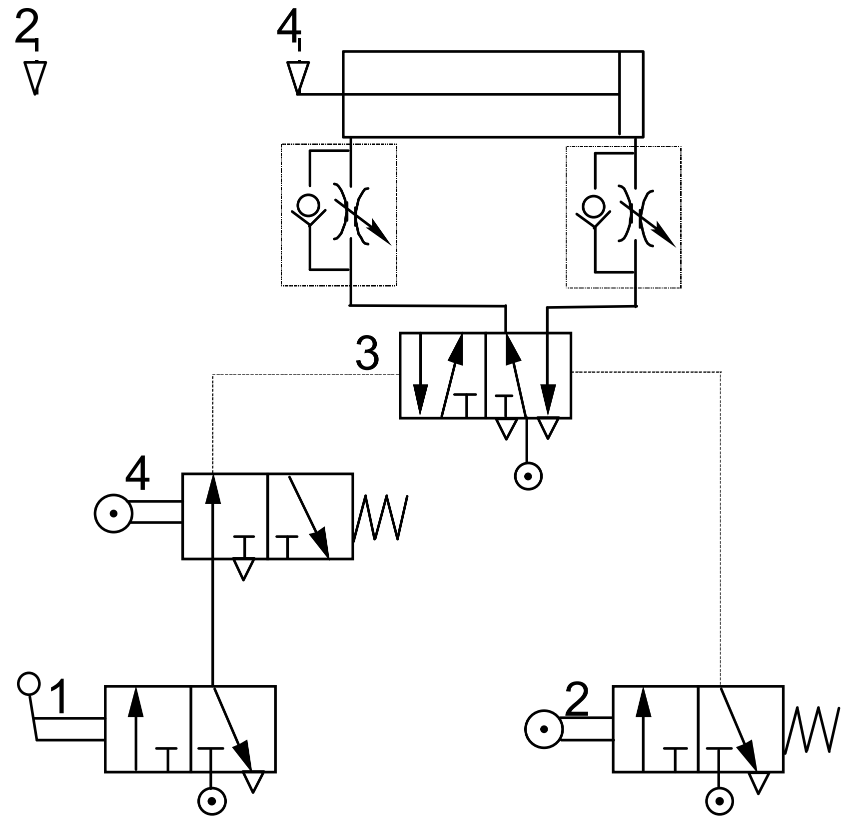
(iv) Connect external Inputs and Outputs

(v) Run the program on PLC

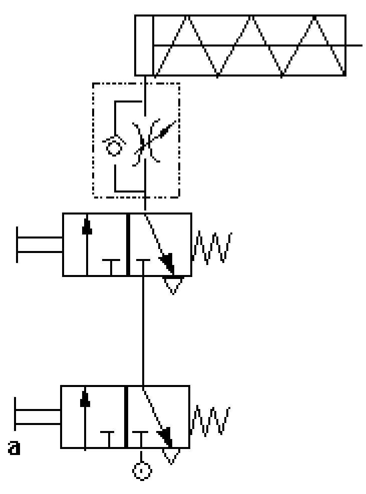
Operation cycle of PLC



Fluid Power Circuit Design: Sequential circuit design for simple applications using classic, cascade, step counter, logic with Karnaugh- Veitch Mapping and combinational circuit design methods.

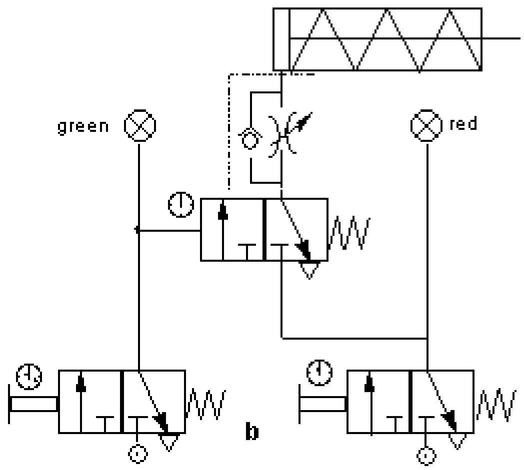


Sequence Control circuit

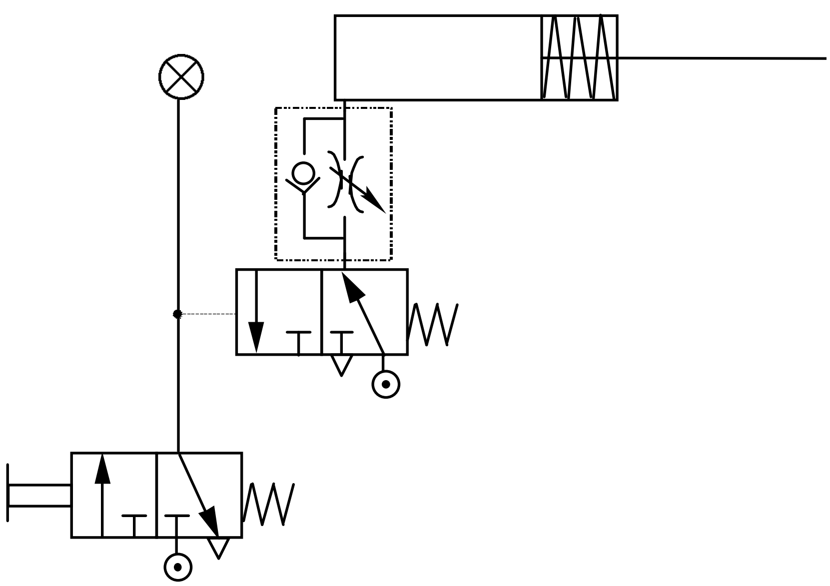


Safety interlock: AND Function

Safety interlock: AND Function



Inverse Operation: NOT Function



PRINCIPLES OF FLUIDIC LOGIC CONTROL.

The wall attachment device was one of the earliest fluidic elements to be developed. It has since become the most important digital fluidic device. Its operation is based on the wall attachment or Coanda effect.

Coanda effect phenomenon, a jet of air (from the supply port) is entitled into a confined region at a velocity high enough to produce turbulent flow. This turbulent jet functions very much like a jet pump and entrains air from its surroundings. As a result, a flow is established along the walls of the confined region. This air flow rushes into a replace the air being pumped out by the power jet.

Since a turbulent jet is dynamically unstable. It will very rapidly back and forth. When the jet veers close to one wall, it interrupts the flow path along the wall on that side, as shown in drawing B. The result is that no more air is flowing on that side to replace the air being pumped out by the power jet. This constricted flow causes a lowering of pressure on that side of the power nozzle. This generates a low-pressure bubble next to the jet. The low-pressure bubble (separation bubble) causes the stream to become stable and remain attached to that wall.

To have a practical control device out of this Coanda effect, a method must be established to reliably control this wall attachment phenomenon. This is accomplished by cutting control ports into the confined region

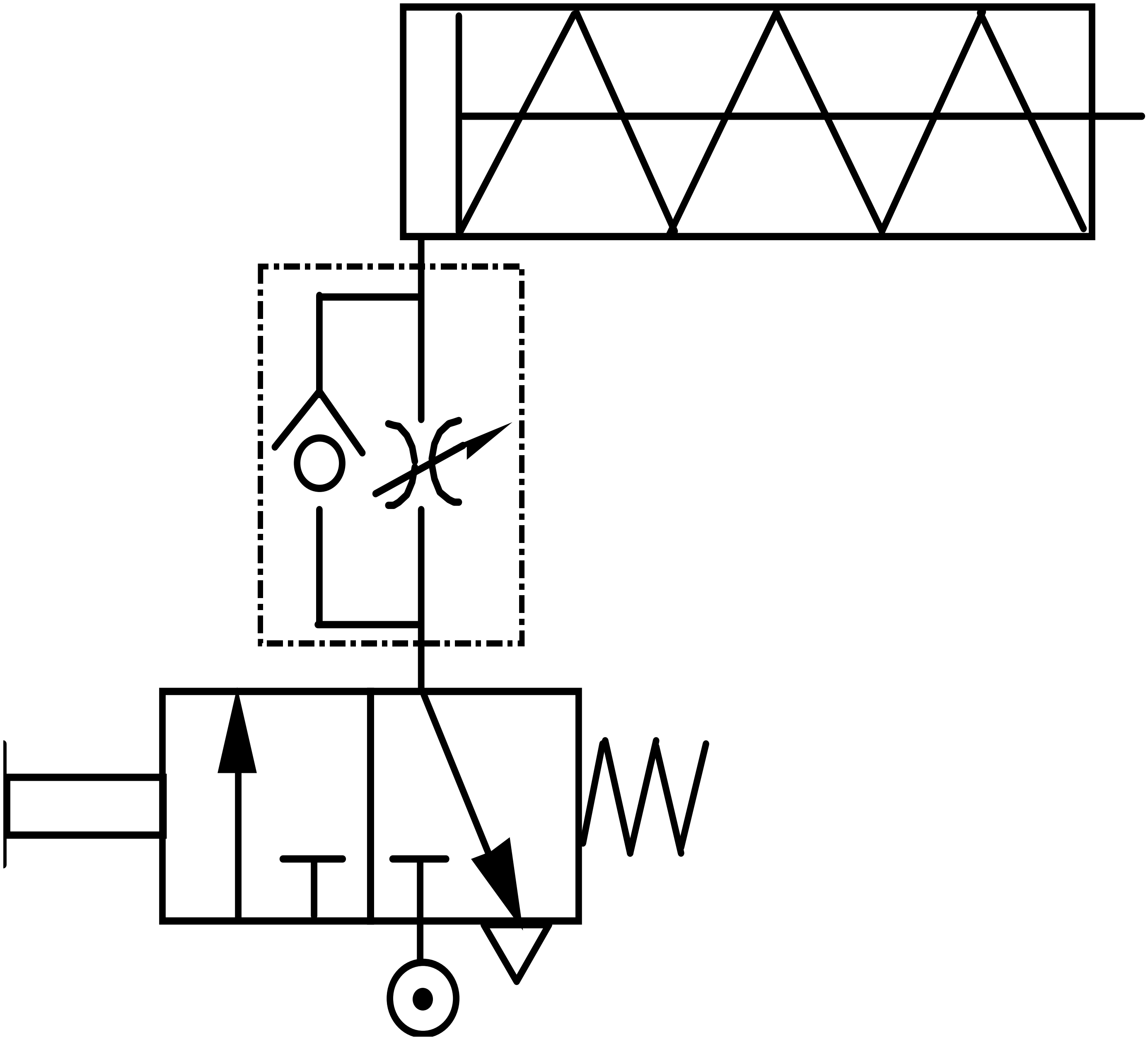
These control ports permit the selection of which wall the stream will attach. When a puff of air is admitted to the separation bubble through the control port, the low-pressure bubble is destroyed. This causes the power jet to flip over and attach itself to the opposite wall. This jet will stay there until an air signal is admitted to the new low-pressure bubble to destroy it. When this is done, the devices switches back. Such a component is called a digital device because a particular output is either fully on or fully off.

There are no intermediate output levels. Thus, digital systems have devices that have only two output states ON and OFF and that are switched rapidly from one sate to the other by control signals applied to their inputs. The control signal is considered ON when it is at a level that is high enough to guarantees switching a digital device to which it is applied. Conversely, the signal is considered OFF when it is at a second level that is low enough to allow the devices to switch back to its original state. Signals between these two levels are indeterminate and are avoided. Transmission from one level to the other are made as quickly as possible.

In contrast, analog systems are those in which the signals may assume a continuous range of meaningful values. Hence, the output of an analog device may take on any value within its output capability range. Most fluidic logic control devices are of the digital type and operate on the wall attachment or Coanda effect principle. The Coanda effect can be visually demonstrated by turning on a water faucet and holding a finger near the stream of water move your finger toward the stream of water. When your finger makes contact with the stream, the water attaches itself to the wall, which in this caste is your finger . A low-pressure bubble (between the stream and your finger) keeps the stream attached until you move your finger away from the stream to overcome the low-pressure bubble. This low pressure region is created due to particles of fluid (around the jet) becoming entrained in the jet. The location of the finger prevents additional fluid from entering the low-pressure bubble once the stream becomes attached.

UNIT V
DESIGN OF PNEUMATIC CIRCUITS

Speed Control circuits



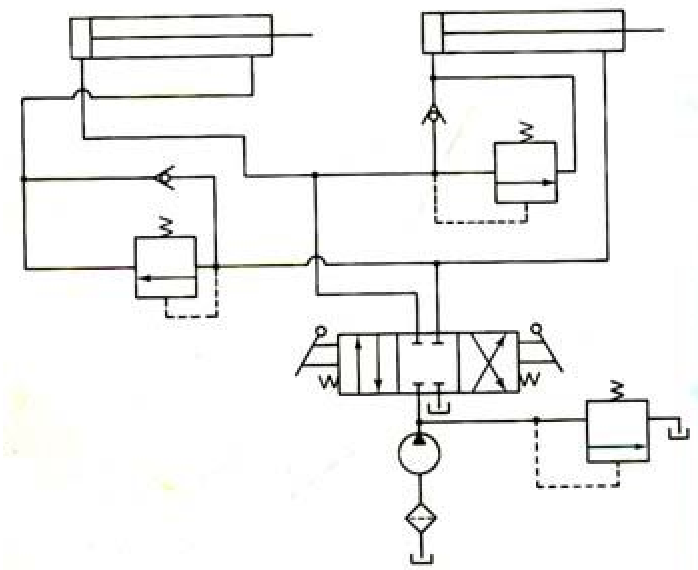
The maximum natural speed of a cylinder is determined by:

- the cylinder size,
- the ports size,
- inlet and exhaust valve flow,
- the air pressure,
- the bore and length of the hoses,

the load against which the cylinder is working

Synchronizing circuit

A synchronizing circuit for synchronizing an asynchronous serial two level input signal to a first clock signal employs a majority decoder which receives the asynchronous input signal at one of its inputs. A first latch is enabled by a second phase shifted clock signal to latch the asynchronous input signal to provide a second input to the decoder. A second latch is enabled by the first clock signal to latch the majority decoder output as the synchronized output signal. An inverted version of the output signal is fed back to the third input of the majority decoder after being delayed by an interval of less than the period of said clock signals.

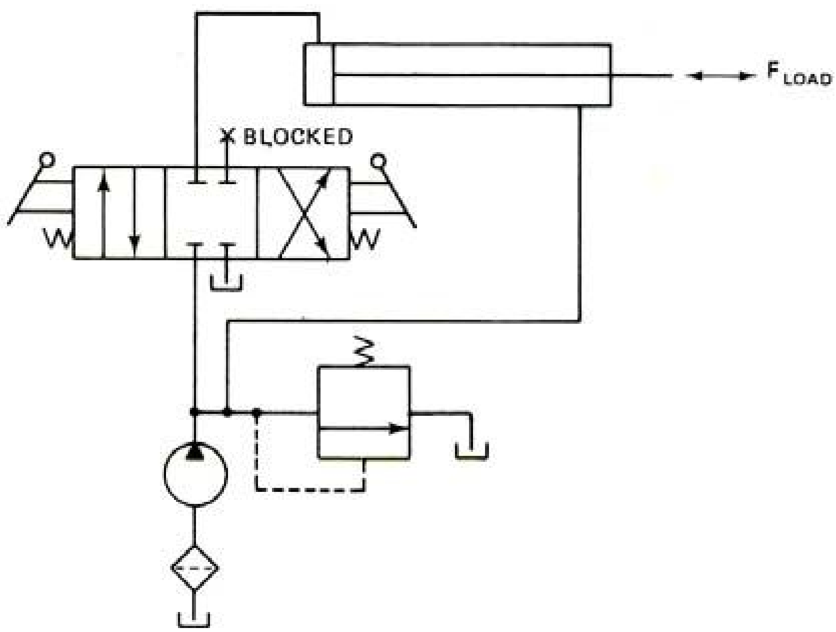


Hydraulic Cylinder Sequence Circuit

- Left Env: Left Cyl extends completely and then Right Cyl extend.
- Right Env: Right Cyl retracts fully and then Left Cyl retracts.

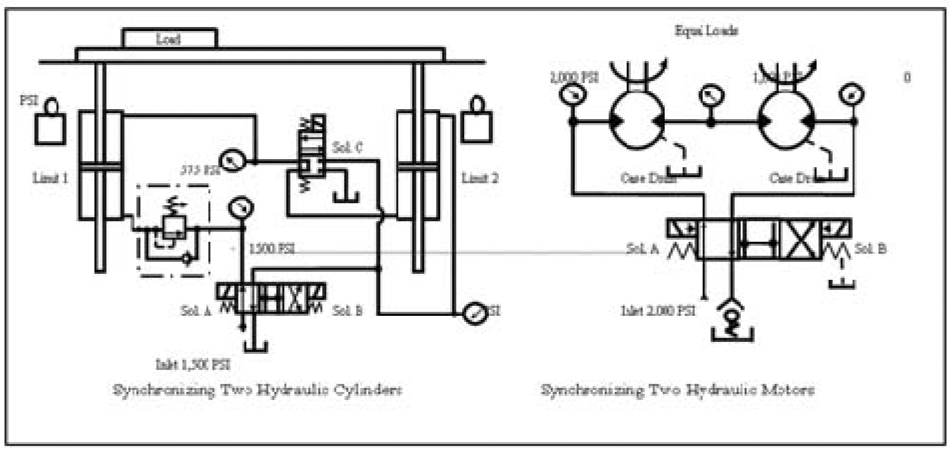
Regenerative Circuit

- Pressurized fluid discharge returned to system
- Speed up extending speed
- Retraction bypass DCV



The synchronizing circuits are the most common use for actuators in series. The schematic drawing at left shows how to control two or more cylinders so they move simultaneously at the same rate. Oil is fed to the cylinder on the left and it starts to extend. Oil trapped in its opposite end transfers to the right cylinder, causing it to extend at the same time and rate. Oil from the right cylinder goes to tank. The platen moves and stays level regardless of load placement. Notice that this circuit uses double-rod end cylinders so the volumes in both ends are the same. (Other variations of this circuit are shown in the chapter on cylinders, which also explains synchronizing circuits in detail.)

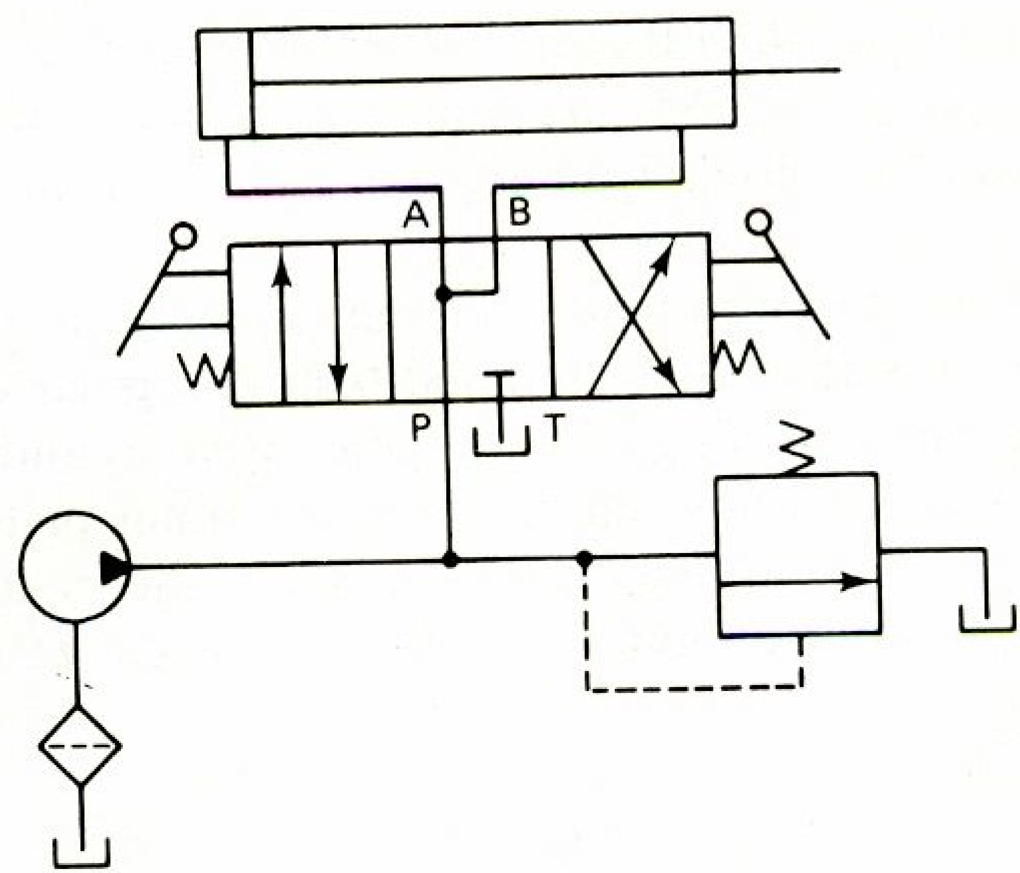
Schematic drawings of two synchronizing hydraulic circuits.



Drilling Machine Application

Spring centered position – Rapid spindle advance

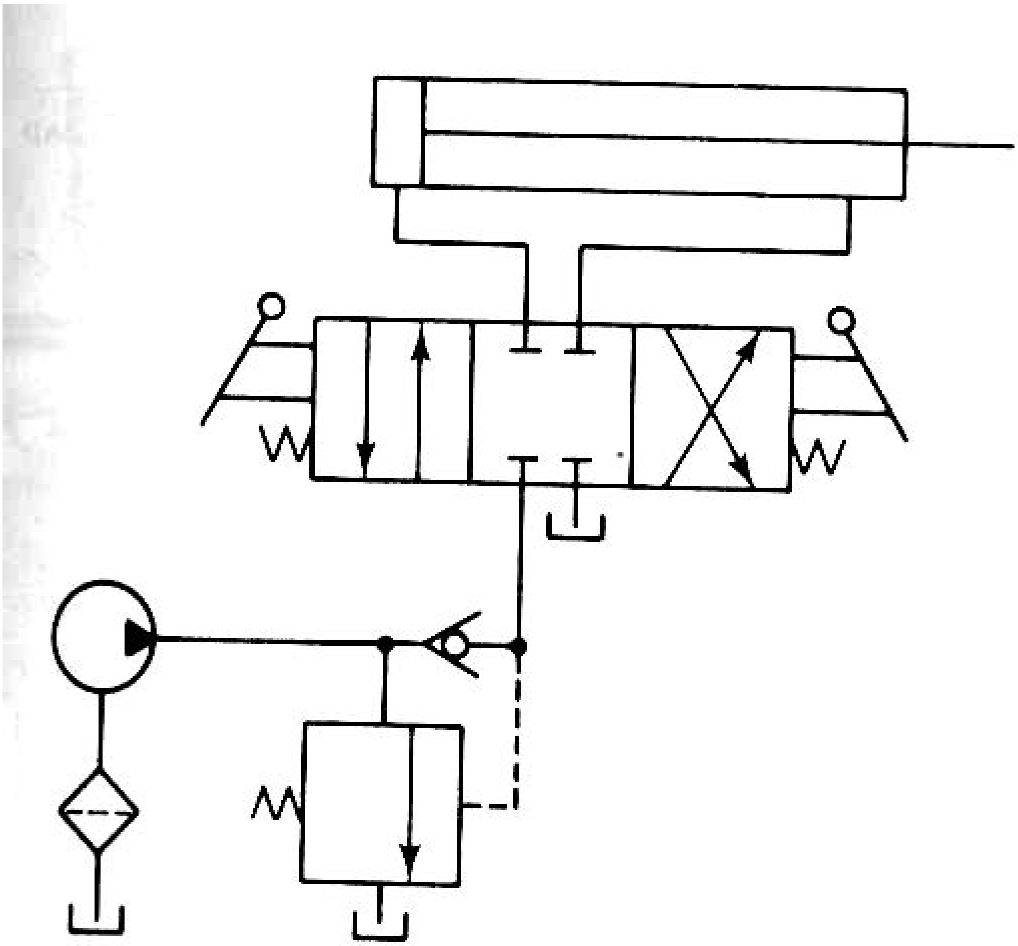
- Left envelope – Slow feed
- Right envelope – Retracts piston



PUMP Unloading circuit

Unloading valve unloads the pump at the ends of extending and retracting strokes

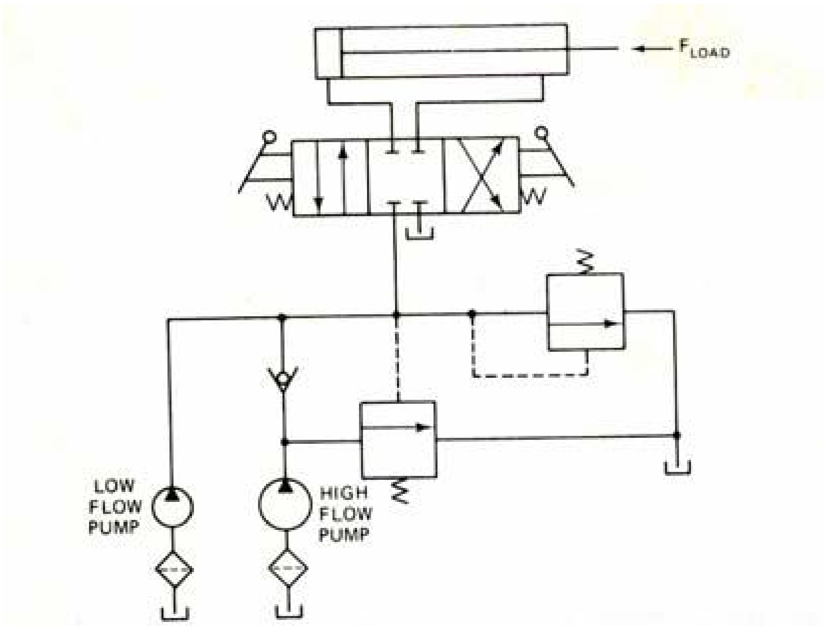
- As well as in spring centered



Double Pump Hydraulic System

Punch Press

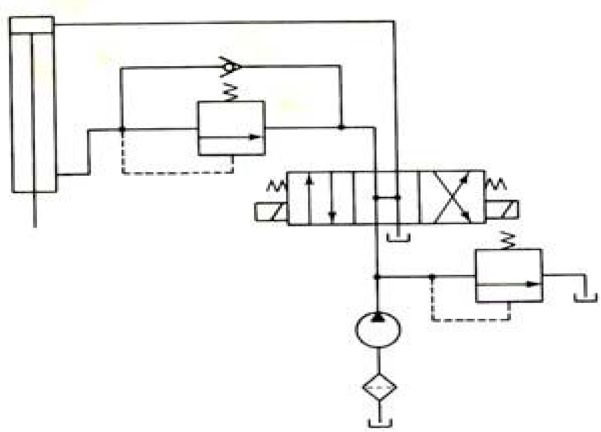
- Initial Low Pressure high flow rate req.
- When punching operation begins, increased pressure opens unloading valve to unload low pressure pump.



Counterbalance Valve

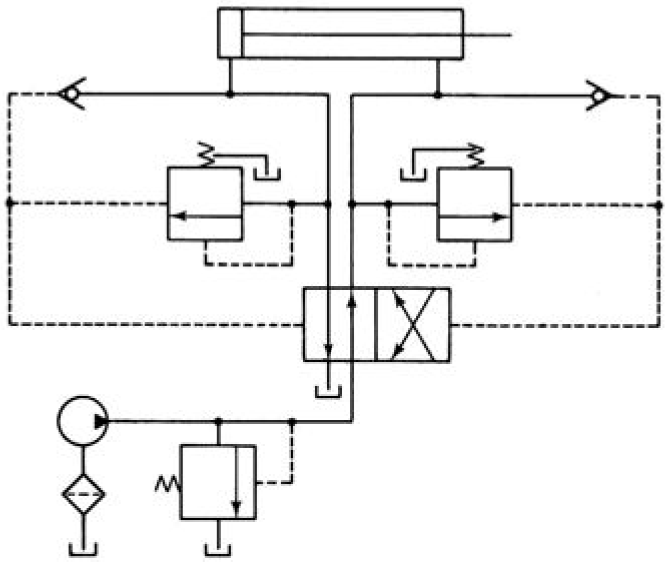
To keep vertically mounted cylinder in upward position while pump is idling.

- Counterbalance valve is set to open at slightly above the pressure required to hold the piston up.



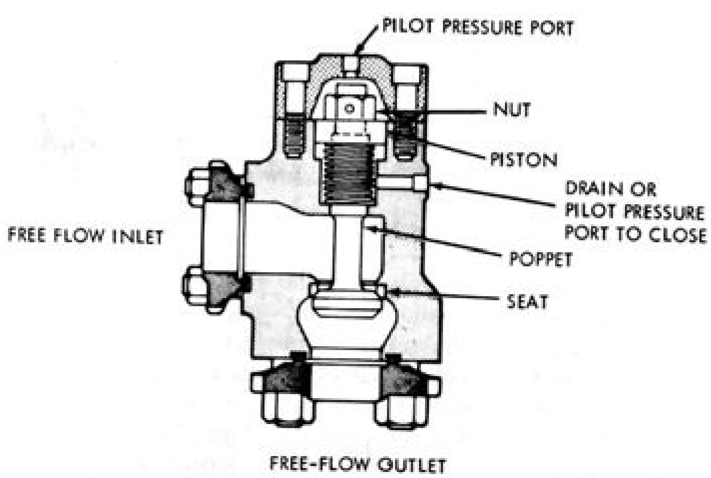
Automatic Cylinder Reciprocating System

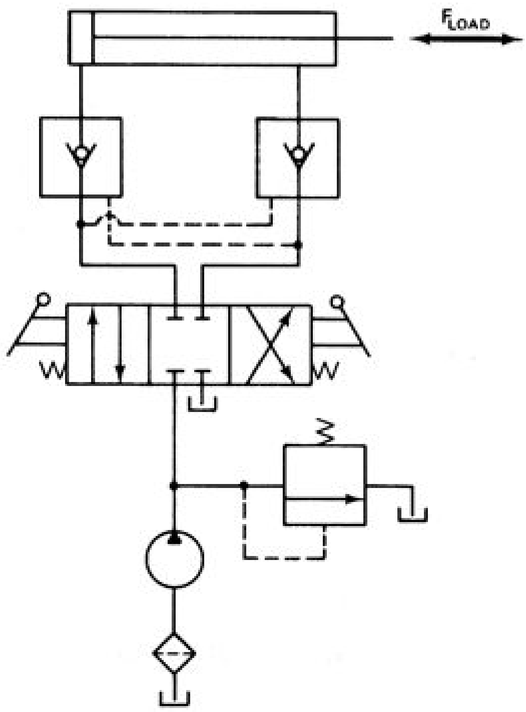
Two sequence valve sensing strokes completion by corresponding pressure build up.



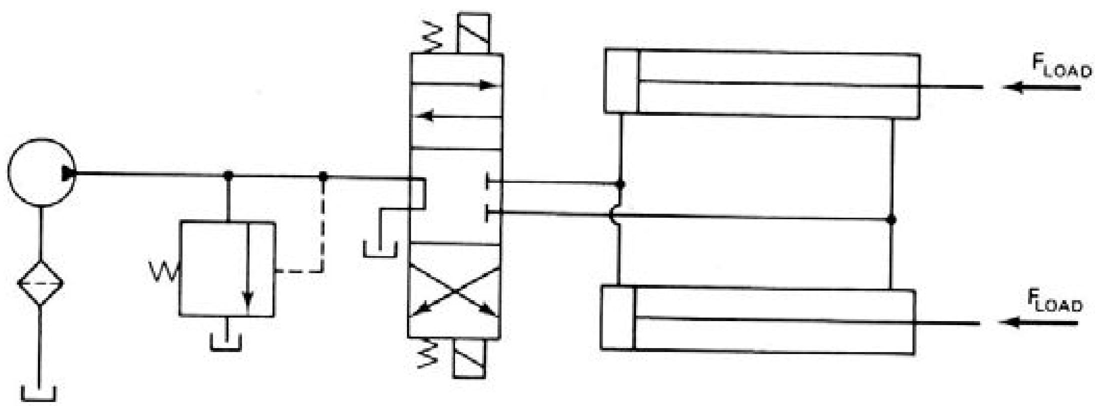
Locked Cylinder using Pilot Check Valves

- Lock Cylinder so that piston can not move by external load.



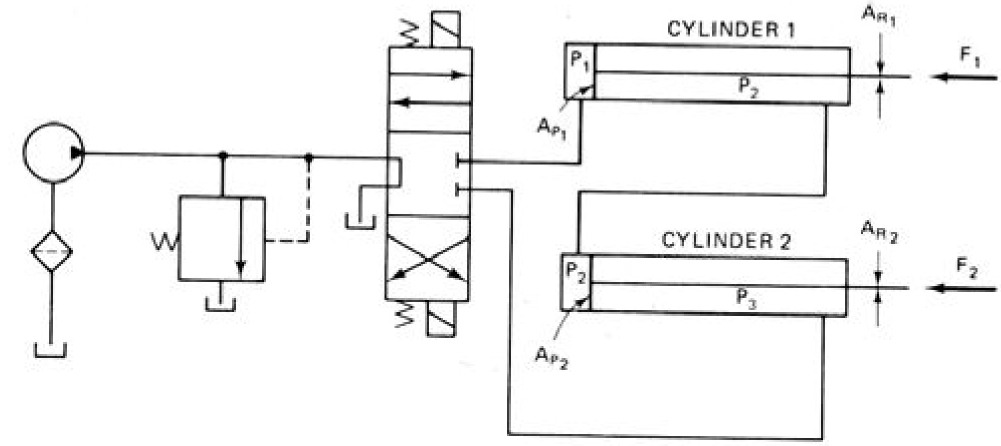


Cylinder Synchronizing Circuit



Cylinders connected in parallel

- Loads identical – Moves in exact synchronization
- Loads Not exactly Identical (practical situation)
- Cylinders also not exactly identical (packing Friction)



Cylinders connected in Series

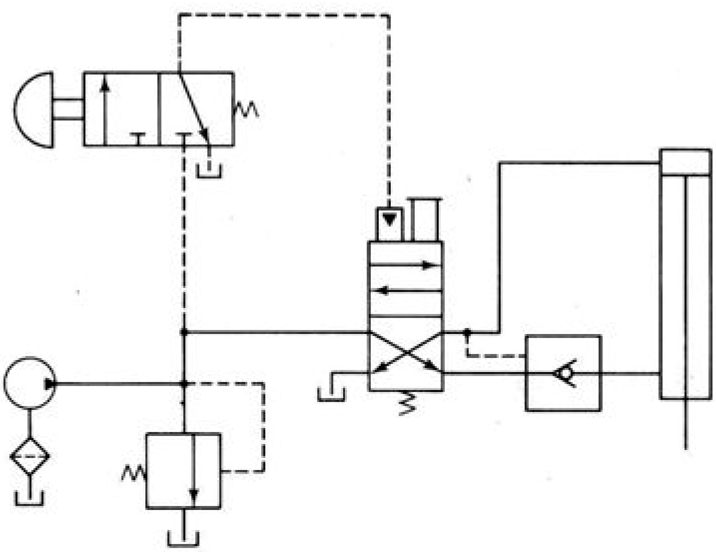
- For two cylinder to be synchronized
- Piston Area of Cyl 2 = Piston Area of Cyl 1-Rod area

Fail Safe Circuit

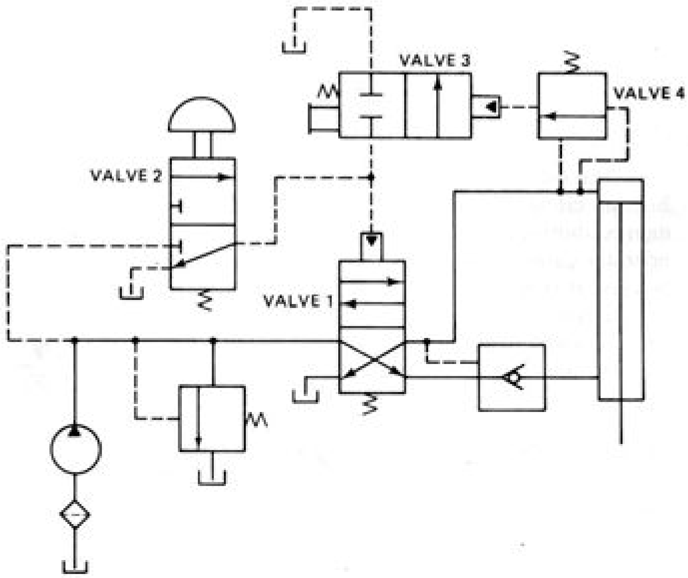
Designed to prevent injury to operator or damage to equipment.

Prevent Cylinder from accidentally falling on an
Operator in the event of:

- Hydraulic line ruptures
- Person inadvertently operates manual override on Pilot actuated DCV when pump not operating



Fail Safe Circuit with Overload Protection



- DCV-1 controlled by Push button valve-2.
- When Overload Valve -3 is in spring offset mode, it drains the pilot line of valve 1.
- If Cyl experience excessive resistance, Valve-4 actuates overload valve -3. This drains pilot line of Valve1, causing it to return to spring offset mode.
- Nothing happen if push button 2 pressed unless overload valve shifted manually into blocked configuration.

Hydrostatic Transmission

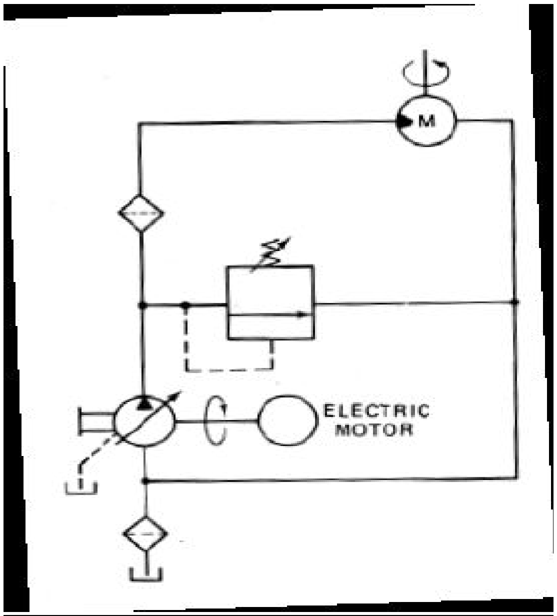
Open Circuit Drives

- Pump draws fluid from reservoir
- Pump output directed to Hydraulic Motor
- Discharge from Motor into reservoir
- Closed Circuit Drive
- Exhaust oil from the motor returned directly to pump inlet.

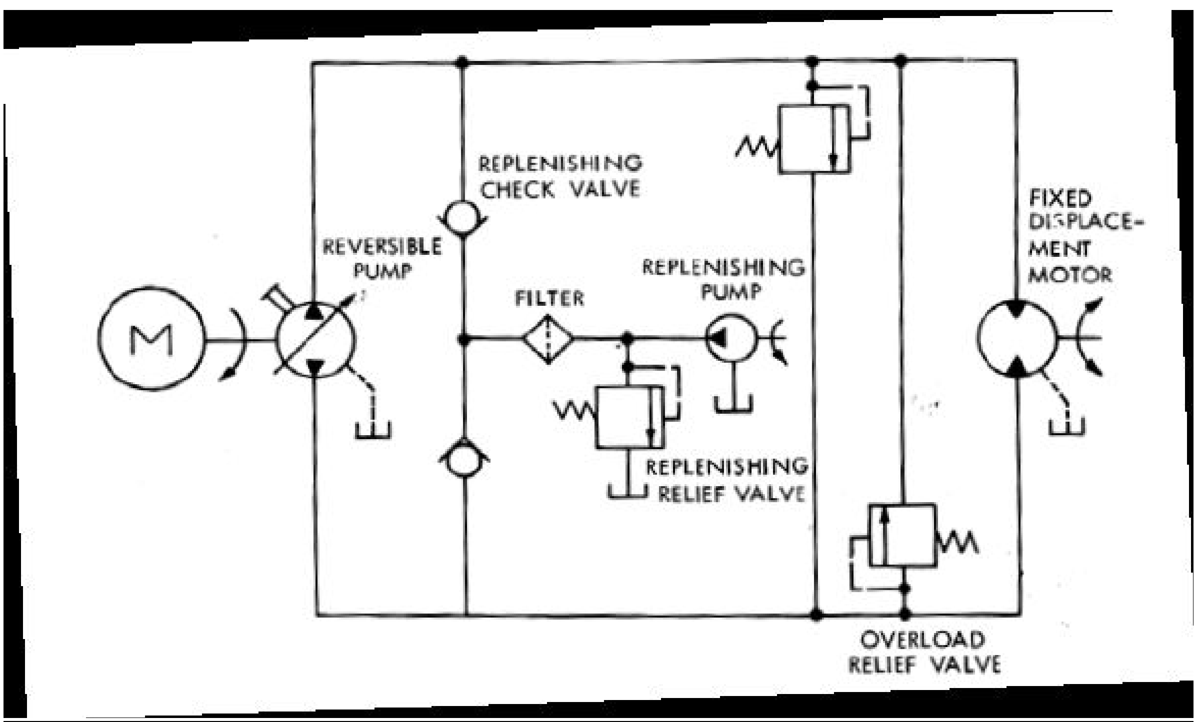
Closed Circuit One-Direction Hydrostatic Transmission

Closed Circuit that allows only one direction of motor rotation.

- Motor speed varied by changing pump displacement.
- Torque capacity of motor adjusted by pressure setting of the relief valve.



Closed Circuit Reversible Direction Hydrostatic Transmission



Mechanical Hydraulic Servo valve.

In this a small input force shifts the spool of the servo valve to the right by the specified amount. The oil flows through the port P, retracting the hydraulic cylinder to the right. The feedback link is connected to the rod of the piston. So the action of the feedback link shifts the sliding sleeve to the right until it blocks the hydraulic cylinder. Thus a given input motion produces a specific and a controlled amount of output motion.This type of valve is used in hydraulic power steering system of automobiles and other transportation type vehicles.

Electro Hydraulic Servo Valves.

The electro hydraulic servo valve operates due to an electrical signal to its torque motor which positions the spool of the directional control valve. A torque motor is a low displacement electric motor. Movement of the armature is proportional to the direct current applied to the windings of the motor. The signal to the torque motor comes from an electrical device such as a potentiometer. The signal from the potentiometer is electrically amplified to drive the torque motor.

The torque motor actuates the servo valve. The hydraulic flow output of the servo valve powers an actuator. The actuator in turn drives the load.

The velocity or position of the load is fed back in electrical form to input of the servo valve by a feedback device. The feedback signal is compared to the command input signal and the difference between the two signals is sent to the torque motor as an error signal. This produces the correction in the velocity or position of the torque motor until it matches with the desired value. At this point, the error signal to the torque motor becomes zero.

Electro hydraulic systems use low power electrical signals (1 W) for controlling the movements of large power hydraulic pistons (7640 W or more). The typical applications are aircraft controls and numerical control machines.

Single stage Servo Valves.

In a single stage servo valve, the armature of the motor is connected directly to one end of the valve spool. With equal currents flowing through the two coils, the armature remains centered. Increasing the current in one coil and reducing it in another causes the armature to more proportional to the change in current. Thus, the spool also shifts by a distance proportional to change in current.

The most commonly used servo valves are the two stage units. It can handle large flow at high pressure with a high sensitivity to control changes. This valve has sliding spools in both pilot and main stages.

A command signal from the servo amplifier is directed to the two coils of the permanent magnet torque motor. A differential current is established in the coil which deflects the armature by an amount proportional to the command. The deflection of the armature is mechanically transmitted to the pilot spool by means of a stiff connecting wire. Thus
Mechanical displacement of the pilot spool is directly proportional to the command received by the torque motor. The direction of movement is determined by the torque motor coil having the larger current.

When the pilot spool moves to the left, a flow of oil is metered to the end N of the main spool. The control pressure acting continuously on area (M) is acting now at both the ends. Since the effective area of the left hand end of the spool is twice that of the right hand end (due to the presence of a rod on the right hand end of the spool), the main spool shifts towards the right. The supply pressure is to be directed to port (A) to actuate the hydraulic cylinder in a direction, proportional to the electrical signal.

The spool in the proportional valve is acted upon by a spring at one end and a proportional solenoid at the other end. Thus, it is possible to control the force on the spool electrically and the orifice size can be varied in accordance to the control current. The flow from the valve is proportional to the current flowing through the solenoid.

Using notched spool or overlap spool in the proportional valve gives better control of the flow rate as the orifice is progressively opened. Due to difficulties in manufacturing zero ,lap spool, i.e., one in which the land on the spool is exactly the same length as the port in the valve body, overlapped spools are used in proportional spool valves. This means that the spool has to move a distance equal to the overlap before any flow occurs through the valve. This gives rise to a 'dead zone' in the valve characteristic..

Spool Position Control.

In order to increase the accuracy of proportional control valves, a linear transducer is fitted to measure the spool position. The output from the transducer is a voltage which is proportional to the spool displacement, continuously varying through the total spool movement. The actual position of the spool is fed back via the transducer to the electrical control system and compared with the required position, the control current being adjusted accordingly.

Proportional Pressure Relief Valves.

In conventional pressure relief valves, a compression spring is used to control the pressure at which the valve operates. This spring is replaced by a DC solenoid in the case of a proportional valve.

In this, the proportional solenoid exerts a force on the poppet keeping the valve closed until the hydraulic pressure at port P overcomes this force and opens the valve.

The force exerted by the proportional solenoid has an upper limit owing to the physical size limitations. So to increase the operating pressure of the valve, the size of the orifice in the valve is decreased and vice versa. The operating pressures of the valve will depend and vice versa. The operating pressures of the valve will depend on the current in the solenoid and the quantity of fluid flowing though the valve.

Proportional Pressure Reducing Valve.

This operates in a manner similar to a conventional pressure regulating valve, the control spring being replaced by a proportional solenoid. However, when the solenoid is not energized , the proportional valve is closed unlike the conventional pressure reducing valve which is normally open.

A signal from the servo amplifier, resulting in a pilot spool movement to the right, will permit the control pressure acting on area(M) to move only the main spool to the left because area N is now connected to the drain. The main supply pressure will be directed into port (B) and will not move the hydraulic cylinder in the opposite direction. Again the amount of movement is proportional to the electrical command.

The valve feed back linkage mechanically links the main spool and the pilot spool sleeve. So any movement of the main spool is fed back through the linkage to act on the pilot spool sleeve. The sleeve follows the pilot spool to the new position until the control pressure is closed off. Thus, the servo valve provides an extremely accurate flow modulation for fast and precise control of position, velocity and acceleration of an actuator.

Flapper Type Servo Valve.

In this type of valve, the sliding spool is actuated by a pressure difference at the two ends. Normally, control pressure is equal at both ends of the spool. A controlled amount of fluid continuously flows through the orifices passages of the nozzles against a ‘flapper’.

The spool moves in proportion to the movement of the flapper valve, which in turn is proportional to the input current. Therefore, the volume of fluid passing through the valve is also proportional to the input current.

Electro hydraulic servos of this type require fluids which are continuously filtered to a high standard of cleanliness, usually 10 microns absolute.

Proportional valves.

Conventional solenoid operated direction control valve has digital control systems i.e., either fully open or, when the solenoid is energized, fully closed. This

;bang-bang' operation gives rise to flow and pressure surges in the hydraulic circuit with all the resultant problems.

If the valve can be gradually closed or opened as a manually operated gate valve, it results in a gradual transmission between fully opened and fully closed conditions. For this, proportional valves are used.

The proportional valve has a DC solenoid. The force exerted by the armature of the solenoid is proportional to the current flowing through it and independent of the armature movement over the working range of the solenoid.

Control of Proportional valves

Force control: The electrical control of the proportional valve normally uses a variable current rather than a variable voltage. If a voltage control system is adopted, any variation in coil resistance caused by a temperature change will result in a change of current, although the voltage remains fixed. This causes a change in force. This problem is eliminated by using a current control system.

Principle of proportional pressure reducing valve:

When the solenoid is energized, it will move the spool to the right. The control office A will open and allow fluid to flow to the output port X. As the aperture of orifice A increases, the aperture of orifice B will decrease. The pressure at the control output X is dependent upon the openings of control orifices A and B.

Let the supply pressure be P_1. The pressure drops across the control orifices A and B are P_A and P_B respectively and the output pressure is P_x.

For equilibrium P X a = F. The output pressure is proportional to the current flowing in the proportional solenoid. There will always be a flow to the tank from this type of valve if the output pressure P_x is less than the supply pressure P_1. It is essential that there is no back pressure in the tank line if the valve is to function correctly.

Proportional Direction Control Valve.

The pressure output from proportional pressure reducing valves is directed to move the spool of the main valve against the control spring. Energizing solenoid 1 causes pressure to be applied to pilot port X, moving the spool to the right against a control spring. The movement of the spool will be proportional to the pressure applied to the pilot port X and hence to the current in solenoid 1.

As the main spool lands are notched, a movement to the right will progressively opens the flow paths from P to B and A to T. De-energizing solenoid 1 will depressurize spring chamber C and the control spring will centralize the spool.

Similarly solenoid 2 controls the flow paths P to A and B to T.

Moving – Part logic (MPL) control systems

Moving part logic (MPL) control systems use miniature valve – type devices, each small enough to fit in a person's hand. Thus an entire MPL control system can be placed in a relatively small space due to miniaturization of the logic components. Figure shows a miniature three – way limit valve along with its outline dimensions of 1 1/16 in long by ¾ in by ½ in. This valve, which is designed to give dependable performance in a small, rugged package, has a stainless steel stem extending 1/8 in. from the top. The valve design is a poppet type with fast opening and high flow 7.0 CFM at 100 psiair (working range is 0 to 150 psi). Mounted on a machine or fixture, the valve is actuated by any moving part that contacts and depresses the stem.

MPL pneumatic control package with a push button for ON/OFF operation. The subplate and the four valves mounted on it form a single push button input providing a binary four – way valve output that is pressure and speed regulated by restrictions on the exhaust ports. It is an ideal control for air collect vises, air clamps assembly devices, indexing positioners, and other air powered tools and devices.

MPL circuit manifold, which is a self-contained modular sub plate with all interconnections needed to a provide a "two-hand notice down" pneumatic circuit. The manifold is designed to be used with three modular plug-in control valves and to eliminate the piping time and materials normally associated with circuitry. The main function of this control system is to require a machine operator to use both hands to actuate the machinery, thus ensuring that the operator's hands are not in a position to be injured by the machine as it is actuated. When used with two guarded palm-button valves, which have been properly positioned and mounted, the control system provides an output to actuate machinery when inputs indicate the operator's hands are safe.

Moving-part logic circuits utilize four major logic control functions 'AND, OR, NOT, and MEMORY.

AND function, which are requires that two or more control signals must exist in order to obtain an output. The circuit consists of three two-way, two position, pilot – actuated, spring office valves connected in series. If control signals exist at all three valves (A,B, and C then output D will exist. If any one of the pilot signals is removed, output D & L disappear.

A second method of implementing an AND function, uses a single directional control valve and two shuttle valves. A,B and C must be vented to shut off the output from S to P.

An OR circuit is one in which a control signal at any one valve will be an output. Thus, all control signals must be off in order for the output

This is accomplished in which the three valves are parallel. If any one of the valves picks up an air pilot signal, it will produce an output at D. how an OR function can be implemented using one directional valve and two shuttle valves. In this case, a signal applied at A,B, or C will produce an output from S to P.

In a NOT function, the output is ON only when the single input control signal A is OFF and vice versa. The output will not exist if the control signal A is momentarily applied, output C will come on. Conversely, if control signal B is momentarily applied, the output will exist at D. Thus, an output at C means the signal was applied at A, and output at D means the signal was applied at B. The MEMORY circuit does not function if control signals A and B are applied simultaneously because both ends of the output pilot valve would be piloted at the same time.

A second way to implement a MEMORY function is to use two three-way, double-piloted valves.

MPL control of Fluid Power Circuits.

In this section we show the use of MPL control in fluid power circuits. we have an MPL circuit , which controls the extension and retraction stroke of two double-acting cylinders. The operation is as follows, assuming that both cylinders are initially fully retracted: When the START valve V1 is momentarily depressed, pilot valve ½ shifts to extend cylinder 1. At full extension, limit valve V4 is actuated. This shifts valve ½ to retract cylinder 1.Upon full retraction, limit valve 1/3 is actuated. This shifts valve 1/5 to fully retract cylinder 2. Thus, the cylinder sequence is as follows: Cylinder 1 extends, cylinder 2 extends, cylinder 1 retracts, and finally cylinder 2 retracts. The cycle can be repeated by subsequent momentary actuation of the START push-button valve. The sequence can be made continuous by removing the START valve and adding a limit switch to be actuated at the retraction end of cylinder 2. Upon actuation, this limit switch would pilot-actuate valve ½ to initiate the next cycle.

we have a MPL circuit that controls the extension double-acting cylinder by having the following features:

1. The system provides interlocks and alternative control position.
2. In order to extend the cylinder, either one of the two manual valves (A or B) must be actuated or valve C (controlled by a protective device such as guard on a press) must also be actuated.
3. The output signal is memorized while the cylinder is extending.
4. At the end of the stroke, the signal in the MEMORY is canceled.

Reset

The circuit operation is described as follows:

1.The input signals A and B are fed into an OR gate so that either A or B used to extend the cylinder. The OR gate consists of one shuttle three way, button-actuated direction control valves

2. The output from the OR gate (C or D) is fed into an AND gate along with the mechanical control signal F (guard of press actuates valve). A single three way directional control valve represents at the AND gate in this system.

3. The output from the AND gate is fed into the MEMORY device, which remembers to keep pressure on the blank end of the cylinder during extension.

4. At the end of the stroke, the inhibit (cancel) limit valve is actuated to cancel the signal in the memory. This stops the extension motion and retracts the cylinder.

It is interesting to note that the signal directional control valve (four-way, double-piloted) can function as a MEMORY device. Also note that for the limit valve to provide the inhibit (cancel) function, the operator must release the manual input A or B.