TVET CERTIFICATE IV in HYDROPOWER ENERGY

**Module Title:** PNEUMATIC AND HYDRAULIC SYSTEMS OPERATION

HDPPH401

# Operate pneumatic and hydraulic systems

Competence

**Learning hours**

**50**

**Credits: 5**

**Sector: Energy**

**Sub-sector:** Hydropower

**Module Note Issue date:** November, 2020

## Purpose statement

This module describes the skills, knowledge and attitude required to operate pneumatic and hydraulic systems, interpret pneumatic / hydraulic drawings and symbols. At the end of this module the learner will be able to identify different components used in pneumatic/hydraulic systems, identify measuring instruments, materials and tools to be used and personal protective equipment. He/she will be also able to identify status indicators and alarming signals for pneumatic/hydraulic systems, Table of Contents



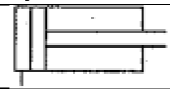
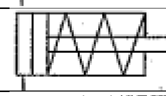
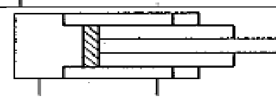
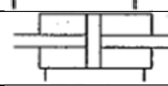
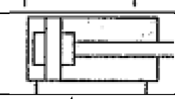
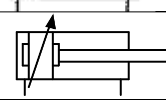
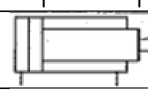
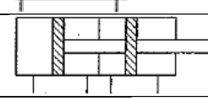
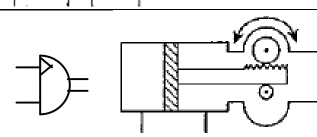
Total Number of Pages: 247

# LEARNING UNIT 1: PREPARE PRELIMINARY ACTIVITIES

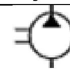
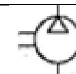
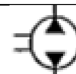
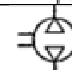
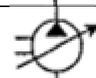
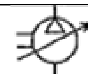
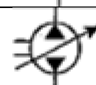
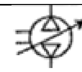
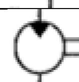
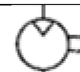
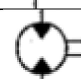
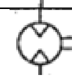
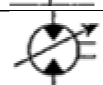
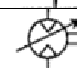
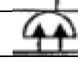
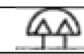
## LEARNING OUTCOMES 1.1: INTERPRET PNEUMATIC /HYDRAULIC DRAWINGS AND SYMBOLS

- **Topic 1: Symbols of pneumatic/hydraulic systems**

**1. Cylinders**

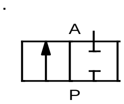
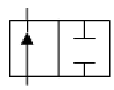
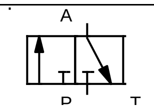
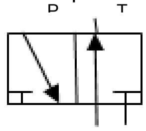
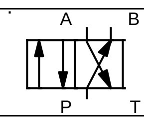
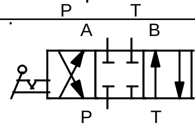
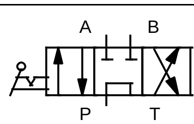
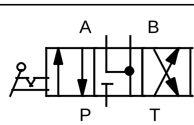
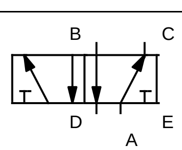
| NO | Name | Symbol |
|---|---|---|
| 1 | Single acting cylinder returned by external force |  |
| 2 | Single acting cylinder with spring return |  |
| 3 | Double acting Telescopic cylinder |  |
| 4 | Double acting cylinder with single piston rod |  |
| 5 | Double acting cylinder with through piston rod |  |
| 6 | Double acting cylinder with single end position cushioning |  |
| 7 | Double acting cylinder with end position cushioning at both ends |  |
| 8 | Double acting cylinder with adjustable end position Cushioning at both ends |  |
| 9 | Differential cylinder |  |
| 10 | Tandem cylinder |  |
| 11 | Rotary cylinder<br>Swivel or lack and pinion arrangement | <br>45,90,180 degrees |

## 2. Pumps and Motors

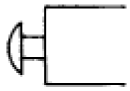
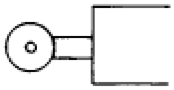
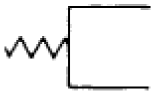
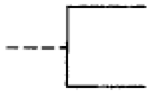
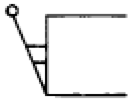
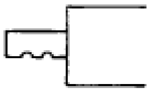
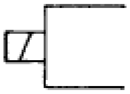
| NO | Name | Symbol | |
|---|---|---|---|
| | | **Hydraulic** | **Pneumatic** |
| **1** | Fixed displacement ,unidirectional pump |  |  |
| **2** | Fixed displacement, bidirectional pump |  |  |
| **3** | Variable displacement ,unidirectional pump |  |  |
| **4** | Variable displacement ,bidirectional pump |  |  |
| **5** | Fixed displacement ,unidirectional motor |  |  |
| **6** | Fixed displacement ,bidirectional motor |  |  |
| **7** | Variable displacement ,bidirectional motor |  |  |
| **8** | Variable displacement ,bidirectional motor |  |  |
| **9** | Oscillating motor |  |  |

**3. DIRECTIONAL CONTROL VALVES (DCVs)**

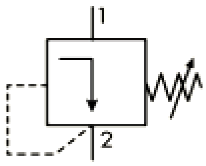
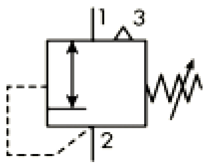
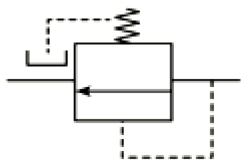
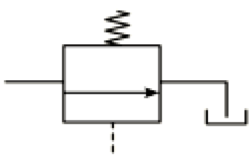
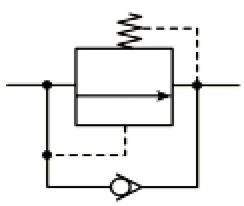
Pneumatic systems require control valves to direct and regulate the flow of fluid from compressor or pump to the various load devices.

| NO | SYMBOL | NAME | DESCRIPTIONS |
|---|---|---|---|
| **1** | <br> | 2/2 way normally closed DCV<br><br>2/2 way normally open DCV | Two closed ports in the closed neutral position and flow during actuated position |
| **2** | <br> | 3/2 way normally closed DCV<br><br>3/2 way normally open DCV | In the first position flow takes place to the cylinder. In the second position flow takes out of the cylinder to the exhaust (single acting cylinder) |
| **3** |  | 4/2 way DCV | For double acting cylinder all the ports are open |
| **4** |  | 4/3 ways DCV with shut off position (center closed) | Two open positions and one closed neutral position |
| **5** |  | 4/3 ways DCV with bypass position (center by pass) | |
| **6** |  | 4/3 ways DCV with floating center | |
| **7** |  | 5/2 way DCV | Two open positions with two exhaust ports |

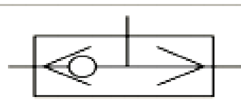
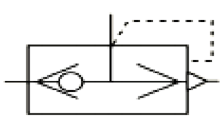
## 4. VALVES ACTUATION SYMBOLS

| | | |
|---|---|---|
| **1** |  | Push button |
| **2** |  | Roller limit switch |
| **3** |  | Spring returned |
| **4** |  | Pressure line pilot |
| **5** |  | Lever actuation |
| **6** |  | Detent hold position |
| **7** |  | Solenoid |

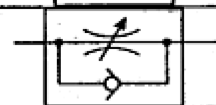
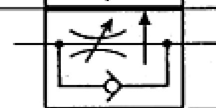
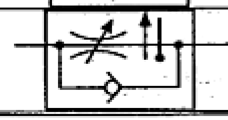
## 5. PRESSURE CONTROL VALVES

| Symbol | Designation | Explanation |
|---|---|---|
|  | Pressure relieving valve | Non relieving type |
|  | Relieving type with overload being vented out | |
|  | Pressure reducing valve | Maintains the reduced pressure at specified location in hydraulic system |
|  | Unloading valve | Allows pump to build pressure to an adjustable pressure setting and then allow it to be discharged to tank |
|  | Counter balance valve | Controls the movement of vertical hydraulic cylinder and prevents its descent due to external load weight |

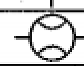
## 6. NON RETURN VALVES

| Symbol | Designation | |
|---|---|---|
|  | Check valve | Allows flow in one direction and blocks flow in other direction |
|  | Spring loaded check valve | |
|  | Shuttle/ OR valve | When any one of the input is given the output is produced |
|  | AND valve | Only when both the inputs are given output is produced |
|  | Quick exhaust valve | For quick exhaust of air to cause rapid extension/ retraction of cylinder |

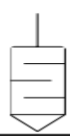
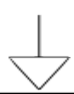
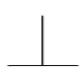
## 7. FLOW CONTROL VALVES

| NO | Description | Diagram |
|---|---|---|
| 1 | Adjustable flow control valve with throttle |  |
| 2 | Adjustable flow control valve with orifice |  |
| 3 | Adjustable with bypass |  |
| 4 | Adjustable and pressure compensated with bypass |  |
| 5 | Adjustable temperature and pressure compensated |  |

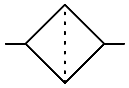
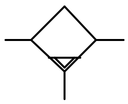
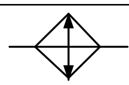
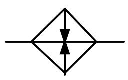
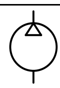
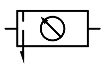
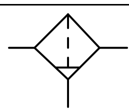
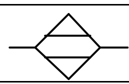
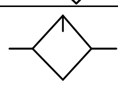
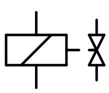
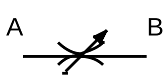
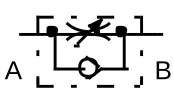
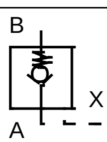
## 8. MEASURING DEVICES

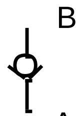
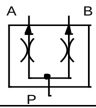
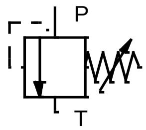
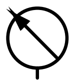
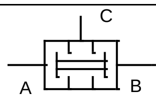
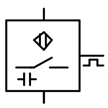
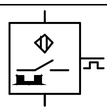
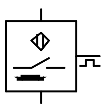
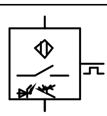
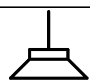
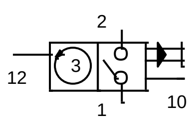
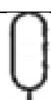
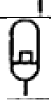
| NO | Description | Diagram |
|---|---|---|
| 1 | Pressure gauge |  |
| 2 | Thermometer |  |
| 3 | Flowmeter |  |
| 4 | Filling level indicator |  |

## 9. AUXILIARY SYMBOLS

| | |
|---|---|
|  | Silencer |
|  | Exhaust |
|  | Plug |
|  | Visual indicator |

## 10. OTHER SYMBOLS

| NO | SYMBOLS | NAMES |
|---|---|---|
| 1 |  | Filter |
| 2 |  | Filter with automatic drain |
| 3 |  | Cooler |
| 4 |  | heater |
| 5 |  | Compressor |
| 6 |  | Compressed air supply |
| 7 |  | Air service unit |
| 8 |  | Manual drain filter |
| 9 |  | Air dryer |
| 10 |  | Lubricator |
| 11 |  | Valve solenoid |
| 12 |  | Throttle valve (adjustable flow control valve) |
| 13 |  | One way flow control valve |
| 14 |  | Non return valve(check valve) spring loaded |

| | | |
|---|---|---|
| **15** |  | Non return valve(check valve) |
| **16** |  | Flow divider |
| **17** |  | Pressure relief valve |
| **18** |  | Manometer |
| **19** |  | Dual pressure valve(AND Valve) |
| **20** |  | Capacitive proximity switch |
| **21** |  | Magnetic proximity switch |
| **22** |  | Inductive proximity switch |
| **23** |  | Optical proximity switch |
| **24** |  | Sucker |
| **25** |  | Pneumatic counter |
| **26** |  | Accumulator |
| **27** |  | Spring loaded accumulator |
| **28** |  | Gas charged accumulator |
| **29** |  | Weighted accumulator |

- **Topic 2: Types of pneumatic/hydraulic drawings and their interpretations**

Several types of drawings are used in showing instrumentation, Control circuits, and hydraulic or pneumatic systems. These include **graphic, Pictorial, Cutaway, and Combination drawings**:

a. **Graphic drawings or schematic drawing** use graphic symbols to show the elements in the system. Schematic drawings are designed to supply the functional information of the system. They do not accurately represent the relative location of the components. Schematic drawings are useful in maintenance work, and understanding them is important part of troubleshooting. (See figure 1).

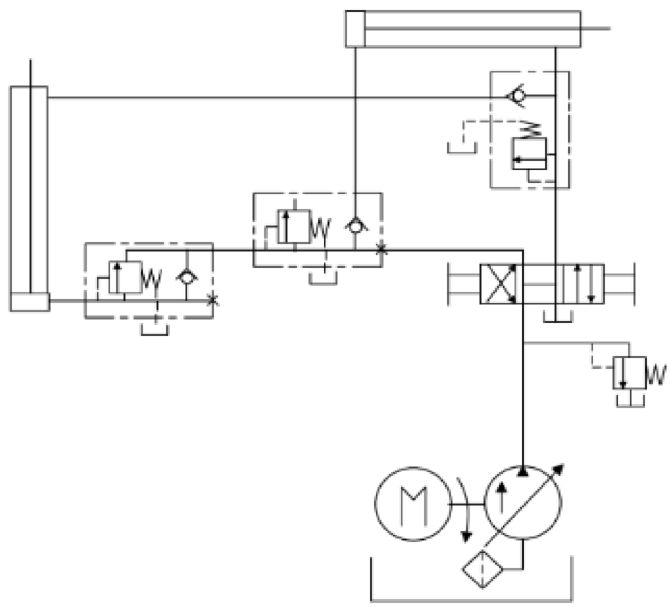


Figure1: Graphic drawings of pneumatic/hydraulic

b. **Pictorial drawings** show the physical arrangement of the elements in a system. the components are outline drawings that show the external shape of each item.(see figure 2)

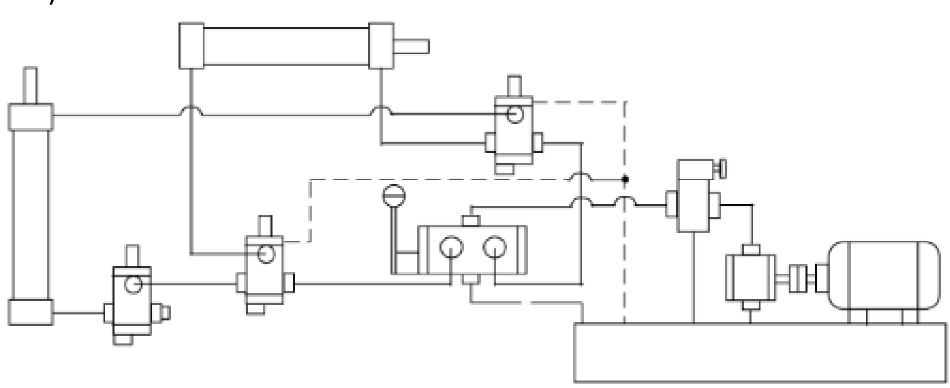


Figure2: Pictorial drawings of pneumatic/hydraulic

c. **Cutaway drawings** show both physical arrangement and the operation of the different components. They are generally used for instructional purposes because they explain the functions while showing how the systems are arranged. Because these diagrams require so much space, they are not usually used for complicated systems. (see figure 3)

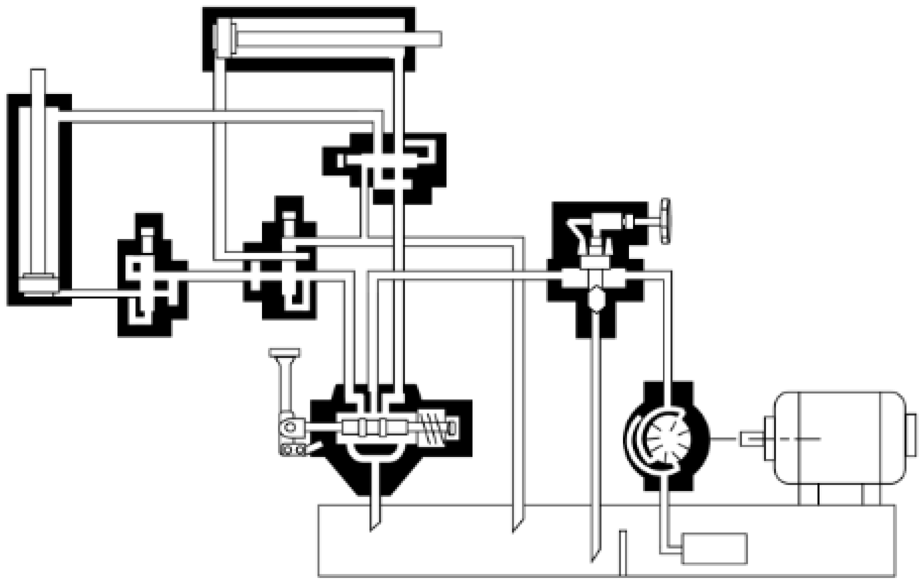


Figure3: Cutaway drawings of pneumatic/hydraulic

d. **Combination drawings** utilize in one drawing the type of component illustration that best suits the purpose of the drawing(see figure 4)

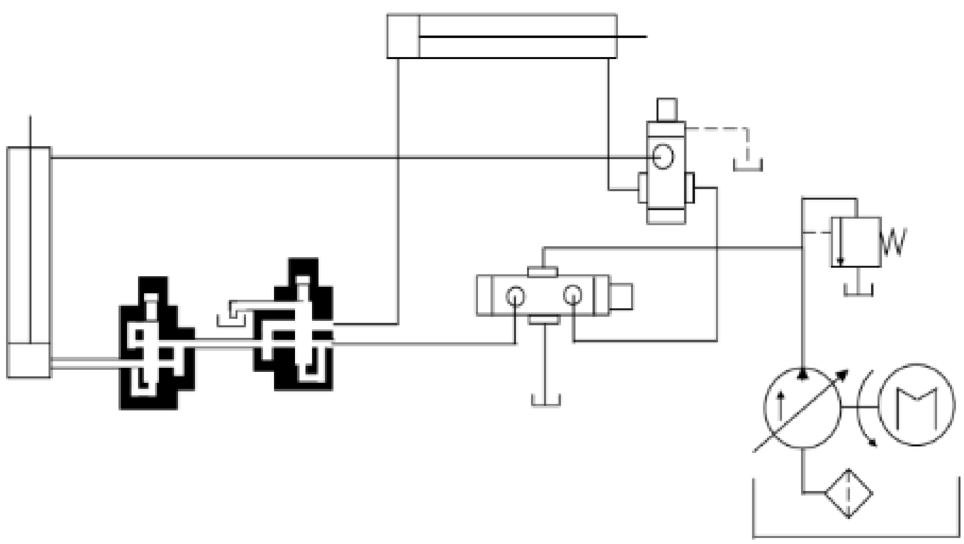


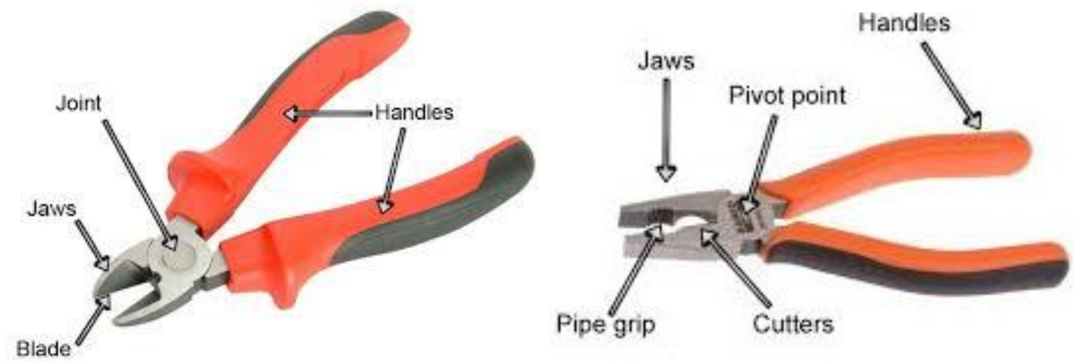
Figure4: Combination drawings of pneumatic/hydraulic

## LEARNING OUTCOME 1.2: IDENTIFY TOOLS AND MEASURING INSTRUMENTS

- Topic 1: Tools used in pneumatic/hydraulic systems

1. **Pliers**

**Figure: Parts of pliers**




a) **Wire strippers**

- Stripping insulation from conductors
- Cutting small conductors
- Crimping wire lugs

b)**Side cutter pliers** (Lineman's pliers)

- Cutting large conductors
- Forming loops on large conductors
- Pulling and holding large conductors

c)**Diagonal pliers** (dykes)

- Cutting small conductors
- Cutting conductors in limited spaces

d)**Needle-nose pliers**

- Forming loops on small conductors
- Cutting and stripping small conductors

**e) Combination pliers:**

- Cutting and gripping wires

2. **Screwdrivers**

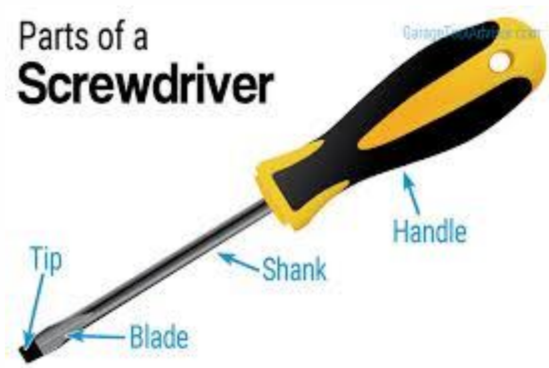
**Screwdrivers and nut drivers**

Electricians need several screwdrivers and nut drivers to work with various types of fasteners and applications.

**Categories of screw drivers**

- Flat head (slotted head) screw driver
- Philips screw driver
- Povidriv screw driver
- Robertson or square screw driver
- Torx screw driver
- Hex screw driver

**Figure: Parts of screw driver**




**a)Flat-blade screwdriver**

- Installing and removing slot-head screws

**b)Phillips screwdriver**

- Installing and removing phillips-head screws

**c)Rotating speed screwdrivers**

- Used for trim work, installing switch and receptacles

d) **Star screwdrivers:**

- Installing and removing special screws with special heads


3. **Electrical knife**
- Opening paper cartons
- Stripping cables and large conductors

4. **Measuring tape**
- Measuring conduit and cable

5. **Sprit level**

Indicate whether a surface is level on horizontal and vertical planes


6. **Power tools**

A power tool is a tool that is actuated by an additional power source and mechanism other than the solely manual labour used with hand tools. The most common types of power tools use electric motors.

Electrical screw driver

Drilling machine

Figure of drilling machine and electrical screw driver

7. Water pipe pliers
8. Adjustable spanner
9. Ring spanner
10. Allen key
11. Centre punch
12. Scissors
13. Open and spanner
14. Ball pain hummer
15. Hacksaw
16. Pipe cutter
17. Threading machine
18. buffers, nailing and stapling guns, grinders,, jack hammers, chipping hammers, riveting guns, sanders and wrenches

Some other tools are shown on the figure below:

- **Topic 2: Types of measuring instruments used in pneumatic/hydraulic systems**

1. **Pressure gauge**: Pressure measurement is the analysis of an applied force by a fluid (liquid or gas) on a surface. Pressure is typically measured in units of force per unit of surface area.


Figure: Pressure gauge

2. **Thermometers**: Thermometer is one of the most common instruments used today to measure temperature.


Figure: Thermometer

3. **Hydraulic flow meters**: A flow meter is an instrument used to measure linear, nonlinear, mass or volumetric flow rate of a liquid or a gas.


Figure: hydraulic flow meter

- **Topic 3: Topic Handling precautions of tools and measuring instruments used in pneumatic and hydraulic installation**

The selection of the right tools and measuring instruments for the right task in order to highlight the risks involved is, as always, critically important and should form part of the risk assessment and risk control procedure. The tools should be kept well maintained and used, in accordance with the manufacturer's instructions by competent operators.

How to use pneumatic /hydraulic tools and instruments safely?

- ✓ Review the manufacturer's instruction before using a tool.
- ✓ Wear safety glasses or goggles, or a face shield (with safety glasses or goggles), and, where necessary, safety shoes or boots and hearing protection.
- ✓ Post warning signs where pneumatic/hydraulics tools are used. Set up screens or shields in areas where nearby workers may be exposed to flying fragments, chips, dust, and excessive noise.
- ✓ Ensure that the compressed air supplied to the tool is clean and dry. Dust, moisture, and corrosive fumes can damage a tool. An in-line regulator filter and lubricator increases tool life.
- ✓ Keep tools clean and lubricated, and maintain them according to the manufacturers' instructions.
- ✓ Use only the attachments that the manufacturer recommends for the tools you are using.
- ✓ Be careful to prevent hands, feet, or body from injury in case the machine slips or the tool breaks.
- ✓ The fluid used should be of an approved fire-resistant type that will retain its operating characteristics at the most extreme temperatures to which it will be exposed.
- ✓ Stored energy may also be present and therefore it is important to safely release the pressure before working on any hydraulic system.
- ✓ The oil is corrosive to body tissue and the damage caused may lead to amputation being required. Therefore, when checking for leaks, extreme caution is required and a safe method must be used rather than the hands (eg running a piece of card along the hose).
- ✓ Reduce physical fatigue by supporting heavy tools with a counter-balance wherever possible.

## LEARNING OUTCOME 1.3: ARRANGE MATERIALS AND TOOLS TO BE USED

- **Topic 1: Selection of tools and materials needed for pneumatic/hydraulic systems operations**

The tools/materials needed for pneumatic/Hydraulic systems must be selected before being used on the workplace according to their safety; according to their location of working place; to quality of jobs; according to the weather conditions and according to the time needed.

- **Topic 2: Arrangement of materials used in pneumatic/hydraulic systems operations into the working area according to their nature:**

✓ In order to keep tools in good working condition, there are some basics preparatory steps that should be taken. It is important to follow the cleaning and storage instruction

i. Clean tools after each use
ii. Dispose of Any Broken or detective tools
iii. Use metal protectant spray on all metal parts
iv. Never store tools near the ground
v. Get creative with storage options
vi. Make a list of all items that are stored

✓ Materials must also be arranged well in their storages according to the nature of tools/materials for the purpose of helping workers to access them easily and to keep their safety as shown below.

CONSUMABLES

MEASURING

INSTRUMENTS

ACCESSORIES

ELECTRO-MECHANICAL TOOLKIT

**Activity:** Make a practical exercise (in work shop) for arranging different materials used in pneumatic/hydraulic systems operations into the working area according to their nature.

# LEARNING OUTCOME 1.4: IDENTIFY PERSONAL PROTECTIVE EQUIPMENT (PPE)

## Topic 1: Identification of hazards due to the use of pneumatic and hydraulic systems

As with all pieces of equipment, pneumatic and hydraulic tools have both advantages and disadvantages from a health and safety perspective, reducing some hazards and introducing others. Therefore, careful selection of the right equipment for the right task in order to highlight the risks involved is, as always, critically important .Pneumatic/hydraulic tools share many of the same general hazards as other tools powered by other sources

**Some of Hazards**

Pneumatic tools are powered by compressed air and include chippers, drills, hammers, and sanders. Dangers involved in their use include the following.

- ✓ Being hit by one of the tool's attachments or by some kind of fastener the worker is using with the tool. Eye, face and foot protection may be required. Checks should be regularly carried out to ensure that the tool is securely fastened to its hose in order to prevent it becoming disconnected, and a safety excess flow valve should be installed at the source of the air supply to reduce the pressure in case of hose failure.

- ✓ Noise levels generated by some tools, such as jackhammers, are high and require hearing protection to be provided.

- ✓ Hand-arm vibration levels from tools such as pneumatic stone working hammers can be high. Older tools and conventional chisels, for example, can generate vibration at approximately 30m/s, although modern vibration-reduced hammers and sleeved chisels can reduce these levels to approximately 8–12m/s .

- ✓ Flying material from the work being carried out can endanger both the worker and those in the nearby area, and screens should be erected to protect those in the immediate area from flying fragments around chippers, riveting guns, staplers and air drills.

- ✓ In addition, compressed air guns should never be pointed toward anyone, and users should never "dead-end" them against themselves or anyone else. Pneumatic tools that shoot nails, rivets, staples, or similar fasteners should be equipped with a device to keep fasteners from being ejected unless the muzzle is pressed against the work surface.

- ✓ Spray guns that atomize paints and fluids at higher pressures should be fitted with automatic or manual safety devices that prevent the trigger being operated until the safety device is released.

**WITH REGARD TO HYDRAULIC TOOLS, THE FOLLOWING SHOULD BE CONSIDERED.**

- ✓ The fluid used should be of an approved fire-resistant type that will retain its operating characteristics at the most extreme temperatures to which it will be exposed.

- ✓ The manufacturer's recommended safe operating pressure for hoses, valves, pipes, filters, and other fittings must not be exceeded.

- ✓ A jet of hydraulic oil from a hose can be at 3000 psi and this will penetrate the skin barrier as easily as if delivered through a hypodermic syringe. Although the external signs of injury may appear slight, serious internal damage may have occurred as the fluid can penetrate muscles and organs and result in the need for surgery. The oil is corrosive to body tissue and the damage caused may lead to amputation being required. Therefore, when checking for leaks, extreme caution is required and a safe method must be used rather than the hands (eg running a piece of card along the hose).

- ✓ Stored energy may also be present and therefore it is important to safely release the pressure before working on any hydraulic system.

**Topic 2: On safety equipment used in pneumatic and hydraulic operations**

PPE means personal protective equipment or equipment you use to guarantee your (own) safety.

Use PPE always and anywhere where necessary. Observe the instructions for use, maintain them well and check regularly if they still offer sufficient protection. But when do you use what type of protection?

**These 7 tips will help you on your way.**

1. SAFETY FOR THE HEAD

Wearing a **helmet** offers protection and can prevent head injuries. Select a sturdy helmet that is adapted to the working conditions. These days you can find many elegant designs and you can choose extra options such as an adjustable interior harness and comfortable sweatbands.

2. PROTECT YOUR EYES

The eyes are the most complex and fragile parts of our body. Each day, more than 600 people worldwide sustain eye injuries during their work. Thanks to a good pair of **safety glasses**, these injuries could be prevented. Do you come into contact with bright light or infrared radiation? Then **welding goggles or a shield** offer the ideal protection

3. HEARING PROTECTION

Do you work in an environment with high sound levels? In that case it is very important to consider hearing protection. **Earplugs** are very comfortable, but earmuffs are convenient on the work floor as you can quickly put these on or take them off.

4. MAINTAIN A GOOD RESPIRATION

Wearing a **mask** at work is no luxury, definitely not when coming into contact with hazardous materials. 15% of the employees within the EU inhale vapors, smoke, powder or dusk while performing their job. **Dust masks** offer protection against fine dust and other dangerous particles. If the materials are truly toxic, use a **full-face mask**. This adheres tightly to the face, to protect the nose and mouth against harmful pollution.

5. PROTECT YOUR HANDS WITH THE RIGHT GLOVES

Hands and fingers are often injured, so it is vital to protect them properly. Depending on the sector you work in, you can choose from gloves for **different applications**:

- protection against vibrations
- protection against cuts by sharp materials
- protection against cold or heat
- protection against bacteriological risks
- Protection against splashes from diluted chemicals.

6. PROTECTION FOR THE FEET

Even your feet need solid protection. **Safety shoes** (type Sb, S1, S2 or S3) **and boots** (type S4 or S5) are the ideal solution to protect the feet against heavy weights. An **antiskid sole** is useful when working in a damp environment, definitely if you know that 16,2% of all industrial accidents are caused by tripping or sliding. On slippery surfaces, such as snow and ice, **shoe claws** are recommended. Special socks can provide extra comfort.

7. WEAR THE CORRECT WORK CLOTHING

Preventing accidents is crucial in a crowded workshop. That is why a good visibility at work is a must: a **high-visibility jacket and pants made of a strong fabric** can help prevent accidents. Just like the hand protection, there are versions for different applications.

**Summary of PPE**


- <u>Topic 3: Care – taking of PPE</u>

PPE is sometimes the last barrier between you and workplace hazard related injury that is why People must focus on proper selection and use of Personal Protective Equipment, Care and maintenance of PPE is an important .PPE that is not properly maintained will more quickly become worn or damaged.PPE that is not in good condition will not properly protect you from hazards.

**a. Heads up on hard hat care**

Clean hard hats regularly with warm water and soap, and allow to air dry. Do not use solvents or harsh detergents. Store hard hats out of the sun, away from extreme temperatures, and in a safe place to avoid getting knocked around and damaged .Check the headband to make sure that it is not worn and that the hat fits comfortably on your head. Replace a hard hat if it is cracked, dented, or has taken a heavy blow.

b. **Keep an eye on safety eyewear maintenance.**

Clean safety glasses and goggles regularly with mild soap and water or a lens wipe .Wash lenses with water before wiping to prevent scratching. If no access to clean water, then blow dust and grit from lenses before wiping .Store eye protection preferably in a clean, a safe place where they will not get scratched or damaged. Replace safety glasses if frames are bent, and replace goggles if headbands are loose, twisted, knotted, or worn. Replace any kind of eye protection if lenses are scratched or pitted and impair vision.

c. **Take good care of hearing protection**

Wipe earmuffs with a damp cloth after each use, store them in a safe place, and replace when cushions lose their resilience .Wash reusable earplugs every day, store them in a clean case, and replace if plugs are hard or discoloured. Do not put dirty or waxy disposable pugs back in your ears. Get new ones to use.

d. **Breathe easy with well-maintained respirators.**

Clean & disinfect respirators according to maker's instructions. Dismantle, wash in warm water, air dry, reassemble & then check seal .Check for holes, cracks, deterioration, and any other problems that could interfere with the effectiveness of protection .Store in a bag/case in a safe location, protected from dust, light, heat, cold, moisture, and chemicals .Place the respirator so that rubber and plastic parts are in a normal position and hold their shape. Do not reuse dirty, wet or overly sweaty disposable respirators/dust masks. Get a new one.

e. **Lend a hand to keep gloves in good shape.**

Keep gloves clean and dry. Check for holes, cracks, and other damage before each use. Have a backup pair in case gloves get wet (or must be washed) and need to dry. Use Nitrile for wet work. Replace worn or damaged gloves right away. Wash & air dry dirty gloves that can be reused.

f. **Put your best foot forward for foot protection.**

Safety shoes and other work footwear protect employees against foot hazards. But to adequately protect, shoes need proper care and maintenance just like any other kind of PPE. To get the best protection from work shoes, employees should:

1. Wipe wet or soiled shoes with a clean cloth or paper towel.
2. Air out work shoes after work, and check regularly for signs of damage or wear.
3. Have worn or damaged shoes repaired, or replace them. Apply sealants to dry leather boots.

4. Change socks during the lunch break to keep feet and shoes dry if feet sweat a lot or get wet.

# LEARNING UNIT 2: IDENTIFY DIFFERENT COMPONENTS USED IN PNEUMATIC/HYDRAULIC SYSTEMS

## LEARNING OUTCOME 2.1: IDENTIFY ENERGY SOURCES SYSTEMS

- Topic 1 : Hydraulic and pneumatic symbols and drawings
  a. **Basic Components of a hydraulic System**

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

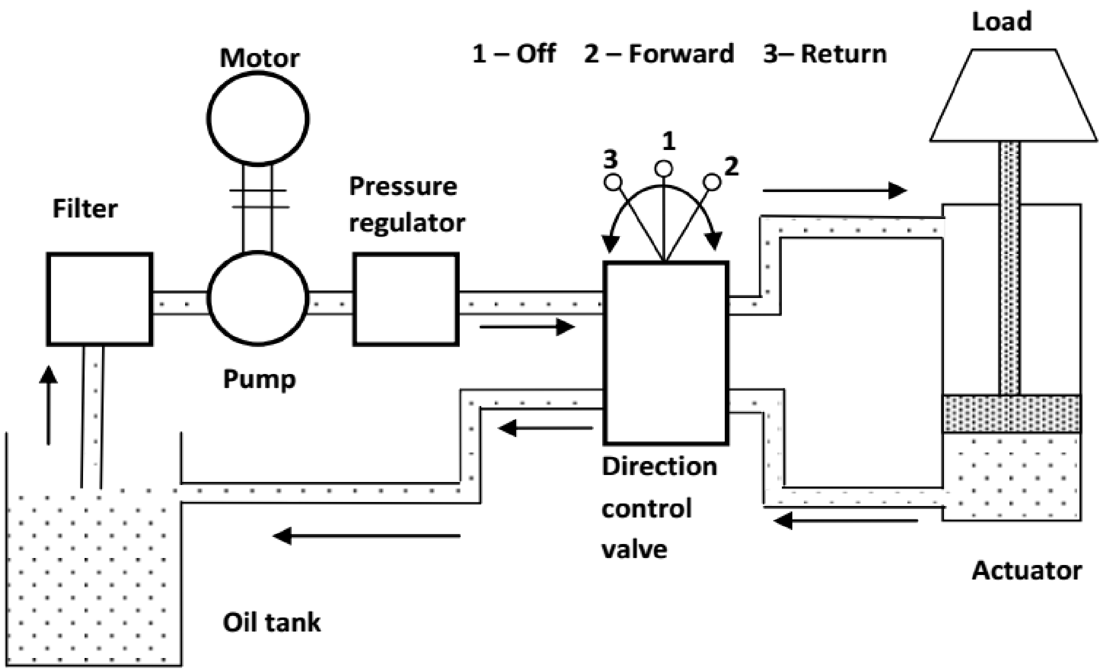



**Figure 1.1** Components of a hydraulic system

**Functions of the components shown in Fig. 1.1 are as follows:**

1. The hydraulic actuator is a device used to convert the fluid power into mechanical power to do useful work. The actuator may be of the linear type (e.g., hydraulic cylinder) or rotary type (e.g., hydraulic motor) to provide linear or rotary motion, respectively.
2. The hydraulic pump is used to force the fluid from the reservoir to rest of the hydraulic circuit by converting mechanical energy into hydraulic energy.

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

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

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

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

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

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

The piping shown in Fig. 1.1 is of closed-loop type with fluid transferred from the storage tank to one side of the piston and returned back from the other side of the piston to the tank. Fluid is drawn from the tank by a pump that produces fluid flow at the required level of pressure. If the fluid pressure exceeds the required level, then the excess fluid returns back to the reservoir and remains there until the pressure acquires the required level.

**Cylinder movement is controlled by a three-position change over a control valve.**

1. When the piston of the valve is changed to upper position, the pipe pressure line is connected to port A and thus the load is raised.
2. When the position of the valve is changed to lower position, the pipe pressure line is connected to port B and thus the load is lowered.
3. When the valve is at center position, it locks the fluid into the cylinder (thereby holding it in position) and dead-ends the fluid line (causing all the pump output fluid to return to tank via the pressure relief).

In industry, a machine designer conveys the design of hydraulic systems using a circuit diagram. Figure 1.2 shows the components of the hydraulic system using symbols. The working fluid, which is the hydraulic oil, is stored in a reservoir.
When the electric motor is switched ON, it runs a positive displacement pump that draws hydraulic oil through a filter and delivers at high pressure. The pressurized oil passes through the regulating valve and does work on actuator.

Oil from the other end of the actuator goes back to the tank via return line. To and fro motion of the cylinder is controlled using directional control valve.

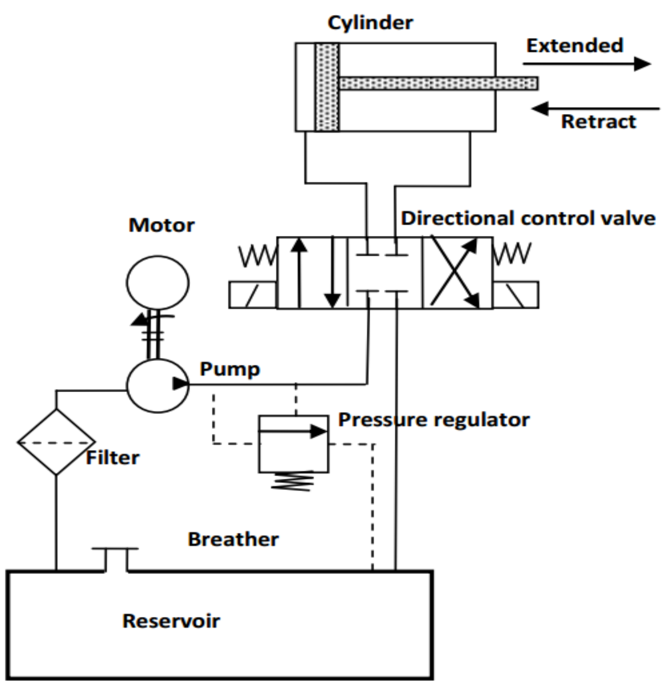



**Figure 1.2** Components of a hydraulic system (shown using symbols).

The hydraulic system discussed above can be broken down into four main divisions that are analogous to the four main divisions in an electrical system.

1. The power device parallels the electrical generating station.
2. The control valves parallel the switches, resistors, timers, pressure switches, relays, etc.
3. The lines in which the fluid power flows parallel the electrical lines.
4. The fluid power motor (whether it is a rotating or a non rotating cylinder or a fluid power motor) parallels the solenoids and electrical motors.

### b. Basic Components of a Pneumatic System

A pneumatic system carries power by employing compressed gas, generally air, as a fluid for transmitting energy from an energy-generating source to an energy-using point to accomplish useful work. Figure 1.3 shows a simple circuit of a pneumatic system with basic components.

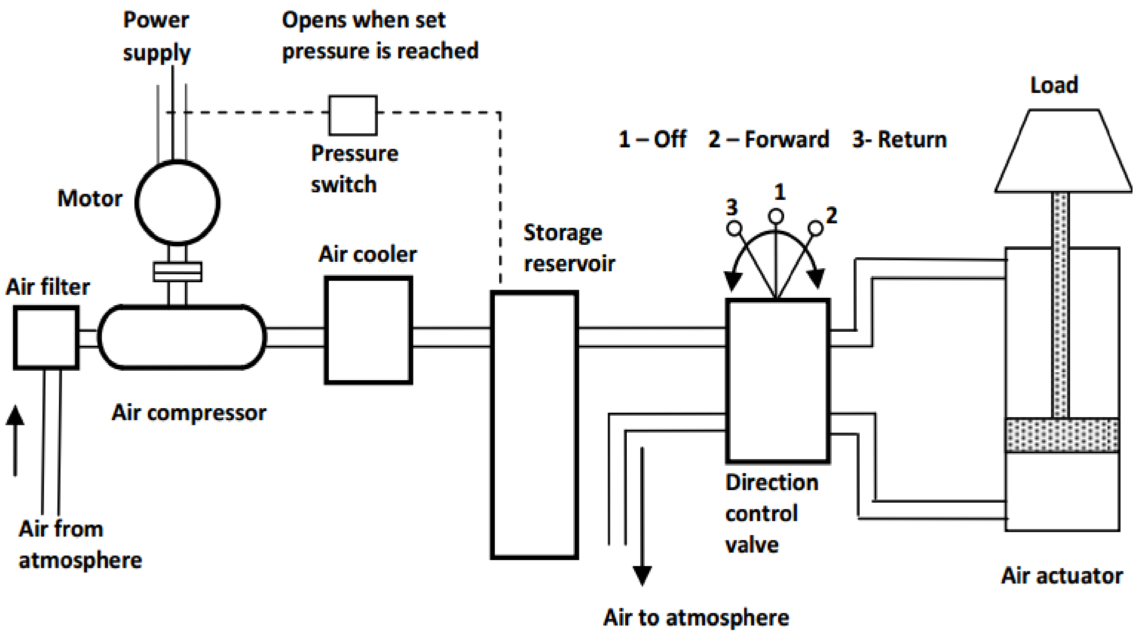



**Figure 1.3** Components of a pneumatic system.

**The functions of various components shown in Fig. 1.3 are as follows:**

**1.** The pneumatic actuator converts the fluid power into mechanical power to perform useful work.
**2.** The compressor is used to compress the fresh air drawn from the atmosphere.
**3.** The storage reservoir is used to store a given volume of compressed air.
**4.** The valves are used to control the direction, flow rate and pressure of compressed air.
**5.** External power supply (motor) is used to drive the compressor.
**6.** The piping system carries the pressurized air from one location to another.
Air is drawn from the atmosphere through an **air filter** and raised to required pressure by an **air compressor**.

As the pressure rises, the temperature also rises; hence, an **air cooler** is provided to cool the air with some preliminary treatment to remove the moisture. The treated pressurized air then needs to get stored to maintain the pressure.

With the **storage reservoir**, a **pressure switch** is fitted to start and stop the electric motor when pressure falls and reaches the required level, respectively.

The **three-position** change over the valve delivering air to the cylinder operates in a way similar to its hydraulic circuit.

**Comparison between a hydraulic and a pneumatic system**

| S. No. | Hydraulic System | Pneumatic System |
|---|---|---|
| 1. | It employs a pressurized liquid as a fluid | It employs a compressed gas, usually air, as a fluid |
| 2. | An oil hydraulic system operates at pressures up to 700 bar | A pneumatic system usually operates at 5–10 bar |
| 3. | Generally designed as closed system | Usually designed as open system |
| 4. | The system slows down when leakage occurs | Leakage does not affect the system much |
| 5. | Valve operations are difficult | Valve operations are easy |
| 6. | Heavier in weight | Lighter in weight |
| 7. | Pumps are used to provide pressurized liquids | Compressors are used to provide compressed gases |
| 8. | The system is unsafe to fire hazards | The system is free from fire hazards |
| 9. | Automatic lubrication is provided | Special arrangements for lubrication are needed |

Table: shows a brief comparison of hydraulic and pneumatic systems.

A basic pneumatic system consists of two main sections:

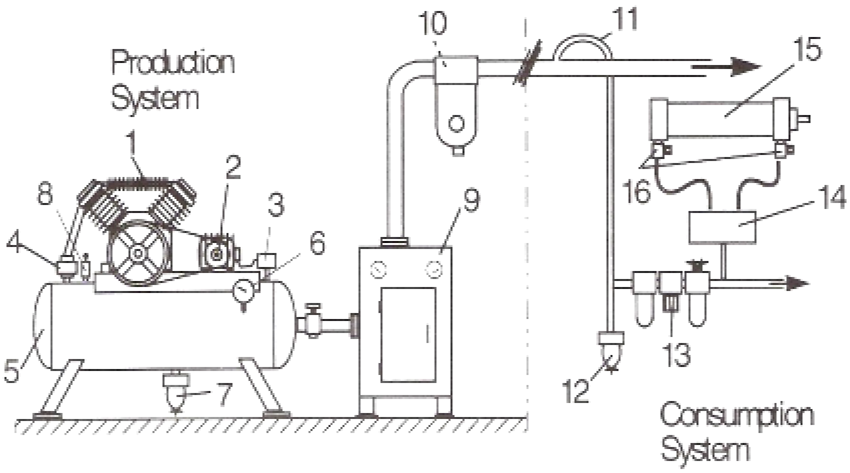



**Figure:** Basic Pneumatic System

- **The Air Production and Distribution System**

(1) **Compressor**: Air taken in at atmospheric pressure is compressed and delivered at higher pressure to the pneumatic system. It thus transforms mechanical energy into pneumatic energy.

(2) **Electric Motor**: Transforms electrical energy into mechanical energy

(3) **Pressure Switch**: Controls the electric motor by sensing the pressure in the tank.

(4) **Check valve**: Lets the compressed air from the compressor into the tank. It is set to a maximum pressure at which it stops the motor and a minimum pressure at which it restarts it.

(5) **Tank**: Stores the compressed air.

(6) **Pressure Gauge**: Indicates the Tank Pressure.

(7) **Auto Drain**: Drains all the water condensing in the tank without supervision.

(8) **Safety Valve**: Blows compressed air off if the pressure in the tank should rise above the allowed pressure.

(9) **Refrigerated Air Dryer**: Cools the compressed air to a few degrees above freezing point and condenses most of the air humidity.

(10) **Line Filter**: It helps to keep the line free from dust, water and oil.

- **The Air Consuming System**

(1) Air Take Off.
(2) Auto Drain.
(3) Air Service Unit.
(4) Directional Valve: Alternatively pressurizes and exhaust the cylinder connections to control the direction of movement.
(5) Actuator.
(6) Speed Controllers: Allows easy speed adjustment of the actuator movement.

## **Topic 2:** Identification of different types of air compressor

**What is a compressor?**

- ✓ A compressor is a device used to compress air (or any gas) from a low inlet pressure (usually atmospheric pressure) due to a higher desired pressure level.
- ✓ A compressor is a mechanical device that increases the pressure of a gas by reducing its volume. An air compressor is a specific type of gas compressor.

**Uses of compressed air:**

The applications of compressed air are listed below:
1) It is used in gas turbines and propulsion units.
2) It is used in striking type pneumatic tools for concrete breaking, clay or rock drilling, chipping, caulking, riveting etc.
*3)* It is used in rotary type pneumatic tools for drilling, grinding, hammering etc.
4) Pneumatic lifts and elevators work by compressed air.
*5)* It is used for cleaning purposes
*6)* It is used as an atomiser in paint spray and insecticides spray guns.
7) Pile drivers, extractors, concrete vibrators require compressed air.
8) Air-operated brakes are used in railways and heavy vehicles such as buses and Lorries.
9) Sand blasting operation for cleaning of iron castings needs compressed air.
10) It is used for blast furnaces and air-operated chucks.
11) Compressed air is used for starting I.C.engines and also super charging them.

There are two basic types of compressors, based on their method of energy transfer and pressure generation. They are:

a. Positive displacement compressors
   i. **Positive displacement compressors** work on the principle of increasing the pressure of a definite volume of it by reducing that volume in an enclosed chamber.
b. Dynamic type compressors
   ii. **Dynamic type compressors** also known as turbo compressors, employs rotating vanes or impellers to increase the pressure of the air.

Air compressors may be classified as follows:

**1.According to design and principle of operation:**

(a) Reciprocating compressors in which a piston reciprocates inside the cylinder.

(b) Rotary compressors in which a rotor is rotated.

**2. According to number of stages:**

(a) Single stage compressors in which compression of air takes place in one cylinder only.

(b) Multi stage compressors in which compression of air takes place in more than one cylinder.

**3.According to pressure limit:**

(a) Low pressure compressors in which the final delivery pressure is less than 10 bar,

(b) Medium pressure compressor in which the final delivery pressure is 10 bar to 80 bar and

(c) High pressure compressors in which the final delivery pressure is 80 to 100 bar.

**4. According to capacity:**

(a) Low capacity compressor (delivers 0.15m3 /s of compressed air),

(b) Medium capacity compressor (delivers 5m3 /s of compressed air) and

(c) High capacity compressor (delivers more than 5m3 /s of compressed air).

**5. According to method of cooling:**

*(a)*Air cooled compressor (Air is the cooling medium) *and*

*(b)*Water cooled compressor (Water is the cooling medium).

**6. According to the nature of installation:**

(a) Portable compressors (can be moved from one place to another).

(b) Semi-fixed compressors and

(c) Fixed compressors (They are permanently installed in one place).

**7. According to applications:**

(a)Rock drill compressors (used for drilling rocks),

(b)Quarrying compressors (used in quarries),

(c) Sandblasting compressors (used for cleaning of cast iron) and

(d) Spray painting compressors (used for spray painting).

**8. According to number of air cylinders**

(a) Simplex - contains one air cylinder

(b) Duplex - contains two air cylinders

(c) Triplex - contains three air cylinders

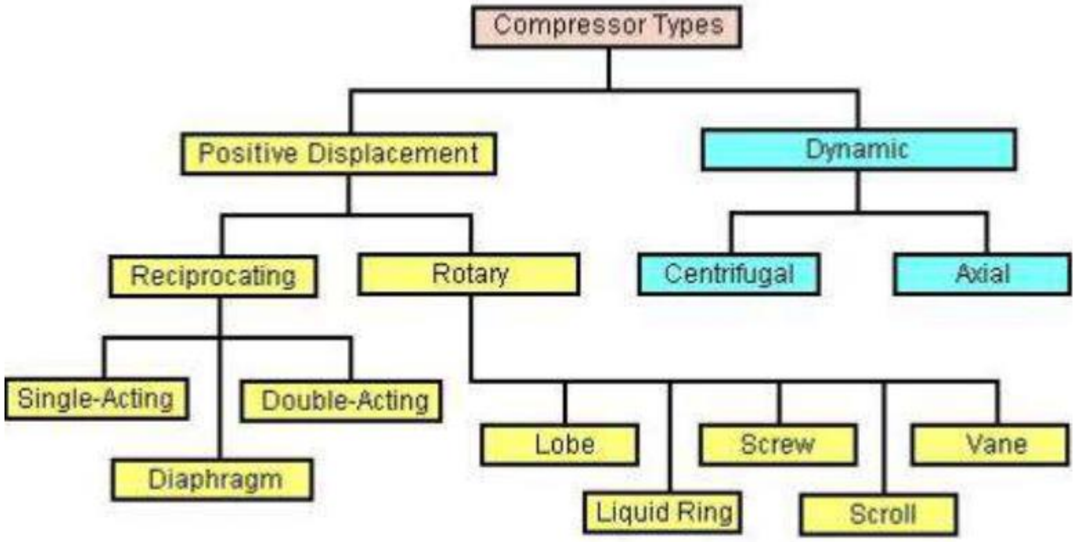



Figure: Air Compressor Family Tree

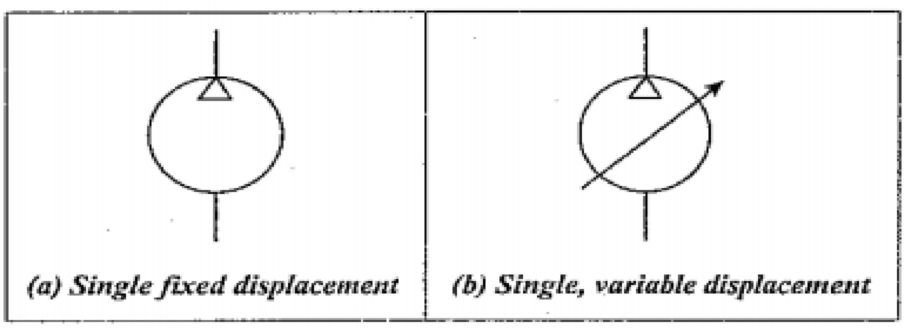



Figure: Graphical symbol of compressor

- ✓ **PISTON-TYPE RECIPROCATING COMPRESSORS**

Piston compressors are the most commonly used compressors in the fluid power industry. It has the same construction and working as an internal combustion(IC) engine.

In a reciprocating compressor, a volume of air is drawn into a cylinder; it is trapped, and compressed by piston and then discharged into the discharge line. The cylinder valves control the flow of air through the cylinder; these valves act as check valves.

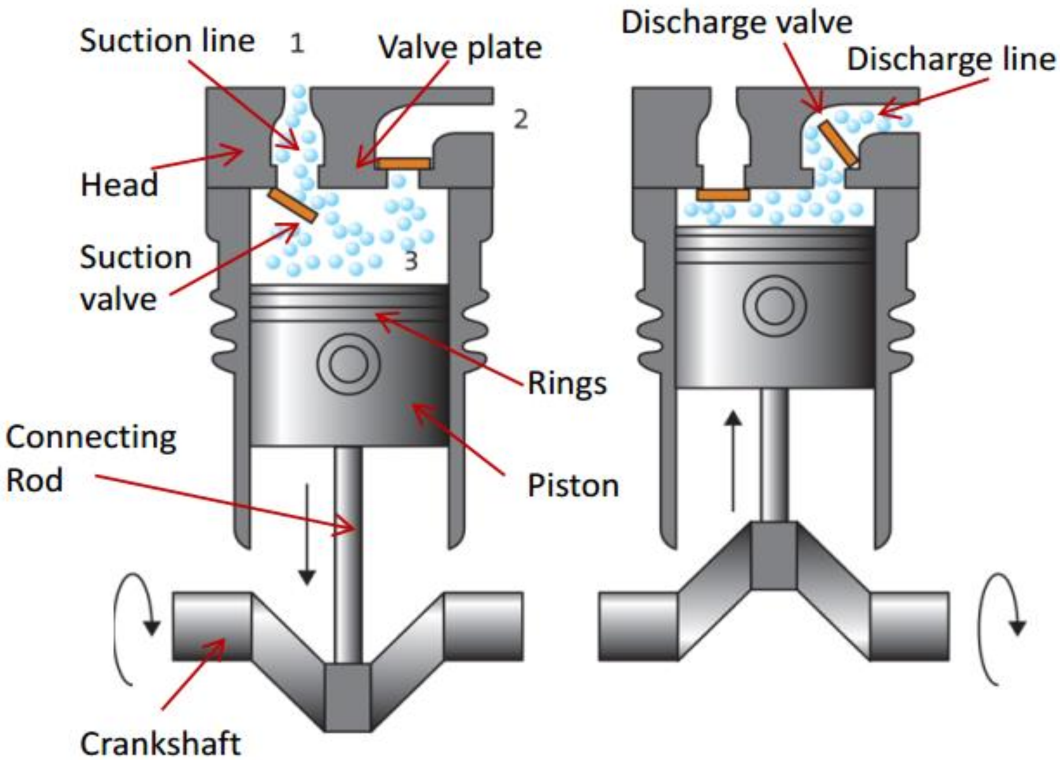



Figure: Reciprocating piston compressor

**Reciprocating compressor working principle:**

A typical reciprocating compressor consists of housing with an internal piston connected to a crankshaft. As the crankshaft turns, a piston reciprocates within the cylindrical housing. There are two valves at the head of the cylinder, an inlet and an outlet. The inlet (sometimes called the suction valve), allows atmospheric air to enter the cylinder. The outlet (sometimes called the discharge valve), ejects the newly compressed air from the cylinder. As the crankshaft turns, the piston lowers and rises changing the available volume within the cylinder.

The downward stroke of the piston is called the suction stroke. The upward stroke is called the compression stroke. As the piston moves downward on its suction stroke the volume increases within the cylinder. As the volume increases the pressure within, the cylinder air pressure becomes lower than the inlet air pressure. This allows the higher pressure outside air to push open the inlet valve and allow more air into the cylinder. As the piston begins its upward compression stroke , the volume within the cylinder decreases. The decrease in volume causes the pressure within the cylinder to increase. The increase in pressure opens the outlet valve and compressed air discharges from the cylinder.

**Piston-type Reciprocating compressors may be classified as follows:**

(a)**Single acting compressors** It is a compressor that has one discharge per revolution of crankshaft.

(b) **Double acting compressors** It is a compressor that completes two discharge strokes per revolutions of crankshaft. Most heavy duty compressors are double acting.

**(c) Single stage reciprocating air compressor:**

In a single stage compressor, the compression of air (or gas)from the initial pressure to the final pressure takes place in a single cylinder. In a single-stage compressor, all cylinders will be the same size and have their own inlet valves. They are often small units that can easily be transported from one room to another.

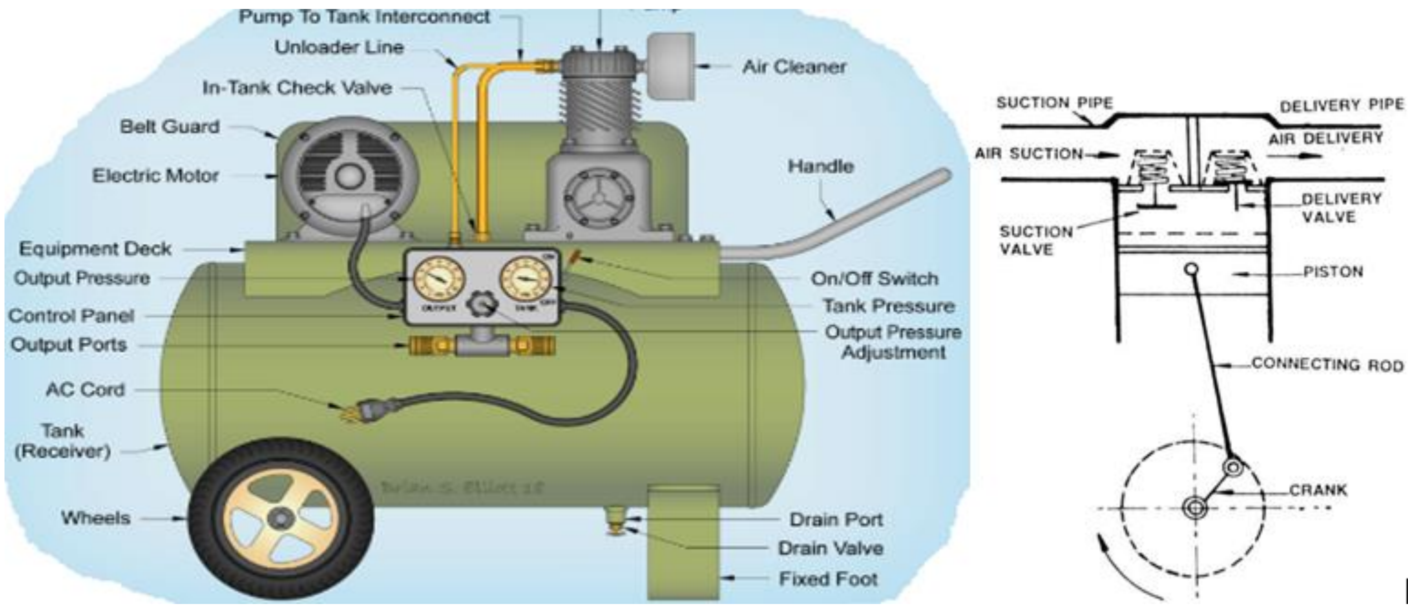



Figure: single stage compressor

**(d) Two stage compressor**

Some air compressors come in two types: single and two-stage. When it comes to buying a single-stage or dual-stage air compressor, the first question that prospective buyers often ask is, “What are the differences between the two?”

The main difference between single- and two-stage compressors is the number of times that air gets compressed between the inlet valve and the tool nozzle. In a single-stage compressor, the air is compressed one time; in a two-stage compressor, the air is compressed twice for double the pressure.

The process within a two-stage compressor alternately referred to as a dual-stage compressor is similar to that of a single-stage, but with one variation: the compressed air isn’t sent to a storage tank; it’s instead sent to a smaller piston for a second stroke, this time at roughly 175 psi. From there, the double-pressurized air is cooled and delivered to a storage tank, where it serves as energy for vast arsenals of high-powered equipment.

You can tell how many stages your air compressor has based on the size of the cylinders and the number of air intakes.  On the other hand, in two-stage compressors, there is only one inlet, and the second piston is shorter than the first, and the two are linked by a cooling tube, which brings the temperature of the air down before the second round of compression. Multi-stage compressors are typically larger and somewhat heavier.

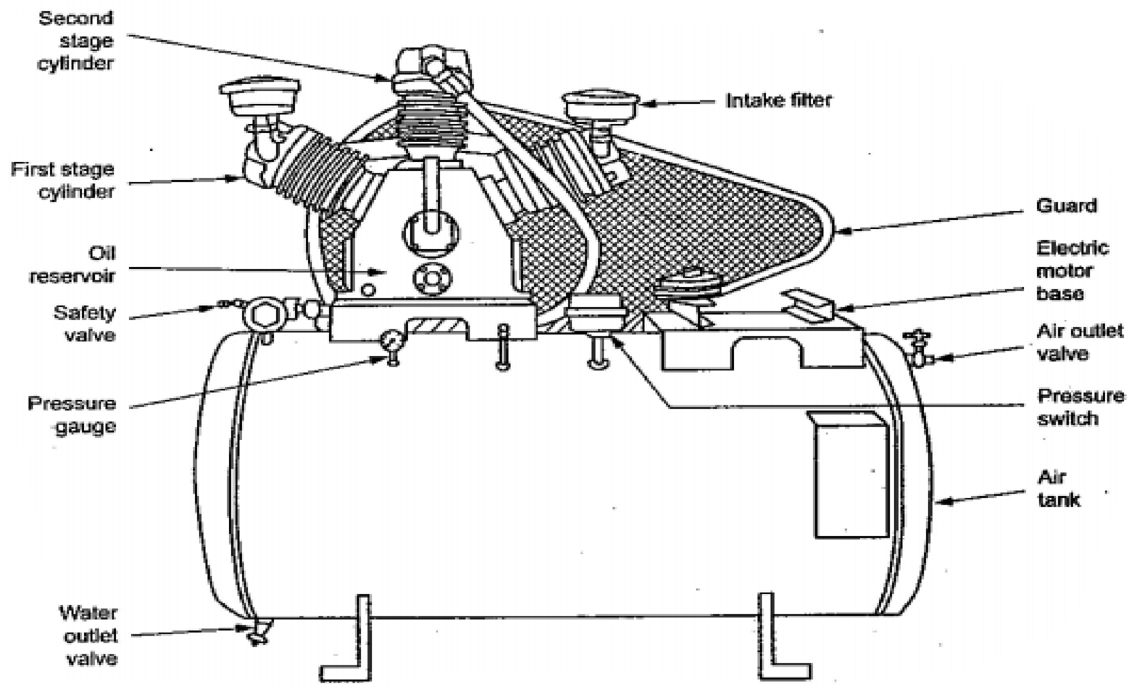



Figure : part of  two stage piston compressor

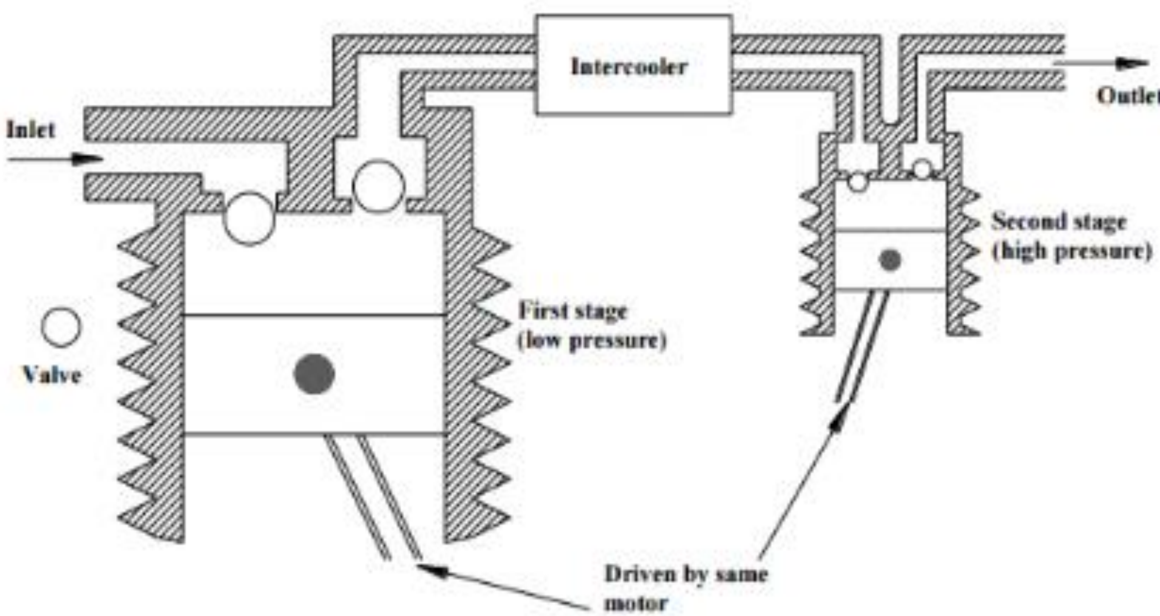
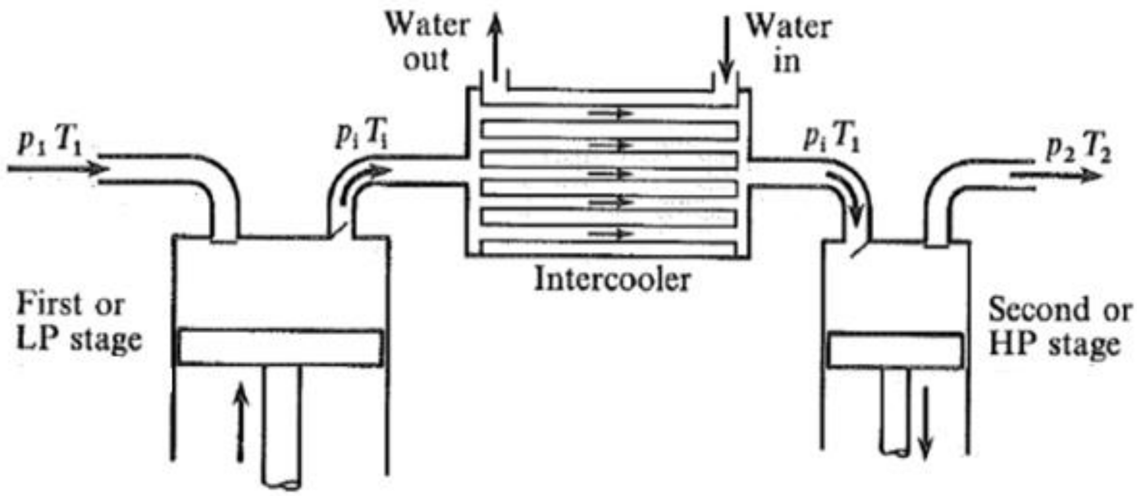



Figure :  Two stages of compressor

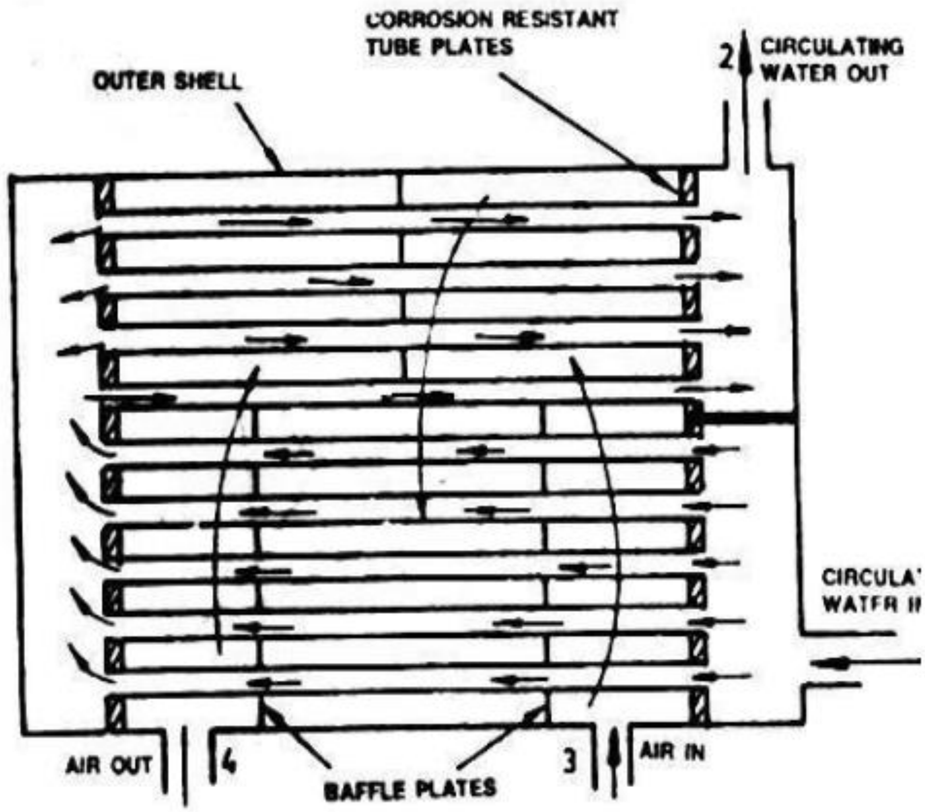
**Note:**

- With multistage compression, the air can be cooled as it is being transferred from one cylinder to the next, by passing it through an *intercooler.*
- The process of cooling the air is called the *intercooling* process.
- With intercooling process, temperature is reduced, therefore internal energy of delivered air reduced. Since energy must have come from the input energy required to drive the machine, this results in a decrease in input work requirement for a given mass of delivered air. Thus the power supplied to the compressor can be reduced.




- **Intercoolers**:

An intercooler is a simple heat exchanger. It exchanges the heat of compressed air from the LP compressor to the circulating water before the air enters the HP compressor. It consists of a number of special metal tubes connected to corrosion resistant plates at both ends. The entire nest of tubes is covered by an outer shell.




**Working:** Cold water enters the bottom of the intercooler through water inlet (1) and flows into the bottom tubes. Then they pass through the top tubes and leaves through the water outlet (2) at the top. Air from LP compressor enters through the air inlet (3) of the intercooler
and passes over the tubes. While passing over the tubes, the air is cooled (by the cold water circulated through the tubes). This cold air leaves the intercooler through the air outlet (4). Baffle plates are provided in the intercooler to change the direction of air. This provides a better heat transfer from air to the circulating water.

- **Staging:** Staging means dividing the total pressure among two or more cylinders by allowing the outlet from one cylinder into the inlet of the next cylinder and s on.
- **Why should we go for staging?**

As we know, as per the general gas laws, the compression of air will result in significant increase in temperature. For instance, if a single- stage compressor gives the compressed air of about 5 bar, the compressed air temperature can rise to over $200^0$C . This in turn increase the motor power needed to drive the compressor. Thus the effective cooling of compressor is necessary.

When the multistage compressors are used, the effective cooling can be implemented between stages. This effective cooling:

1. Reduce input power requirements, and
2. Increases the efficiency of the compressor.

**e. Multi-cylinder piston compressors**

Though a single-cylinder compressor can provide pressure up to about 10 bars, usually multi-cylinder compressors having (2 to 16 cylinders) are used for increasing compression capacity and also due to many practical reasons.

**f. Multi-stage compressors**

When the compression of air from the initial pressure to the final pressure is carried out in more than one cylinder into the inlet of the next cylinder and so on

iii. Advantages of piston type compressor

1. Piston type compressors are available in wide range of capacity and pressure
2. The overall efficiency of piston compressors are high when compared to other compressors.
3. Very high air pressure and air volume flow rate can be obtained by using the multistage compressors
4. Better mechanical balance can be achieved with multistage compressors


Figure: Multi-stage compressor

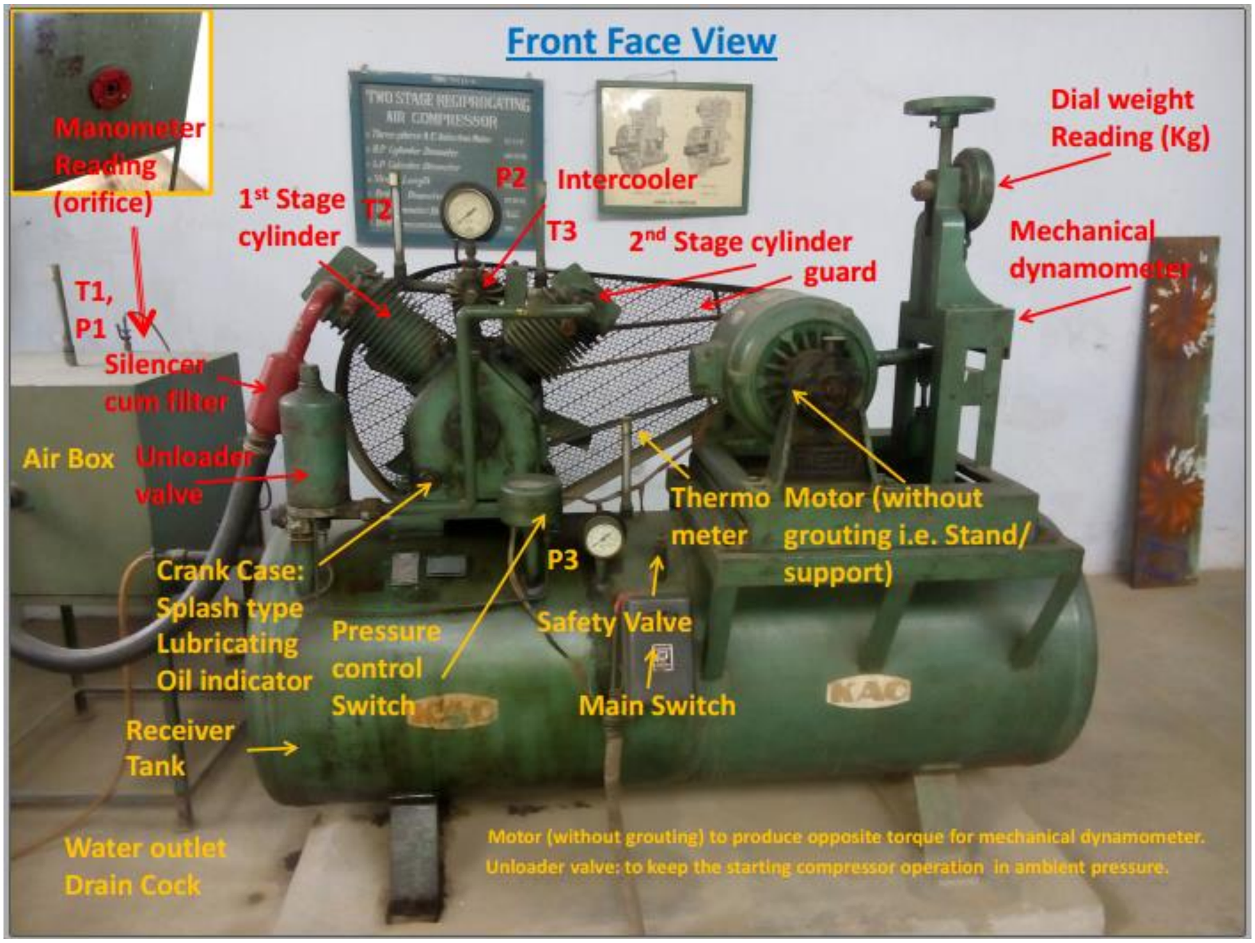



Figure: Multi-stage compressor

- ✓ **SCREW COMPRESSOR**

Screw compressors are used in many applications where medium pressure (<10 bar) and medium volumes of air (up to 5000 $m^3$/h) are required.

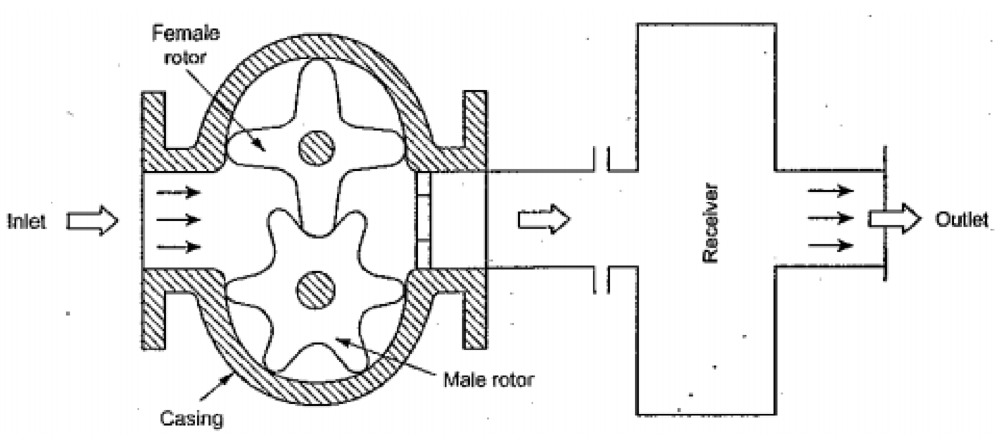



Figure: Screw compressor

## a. Operation

A rotary-screw compressor is a type of gas compressor that uses a rotary-type positive displacement mechanism. They are commonly used to replace piston compressors where large volumes of high pressure air are needed, either for large industrial applications or to operate high power air tools. Rotary-screw compressors use two meshing helical screws, known as rotors, to compress the gas. In a dry-running rotary-screw compressor, timing gears ensure that the male and female rotors maintain precise alignment. In an oil-flooded rotary-screw compressor, lubricating oil bridges the space between the rotors, both providing a hydraulic seal and transferring mechanical energy between the driving and driven rotor. Gas enters at the suction side and moves through the threads as the screws rotate. The meshing rotors force the gas through the compressor, and the gas exits at the end of the screws.

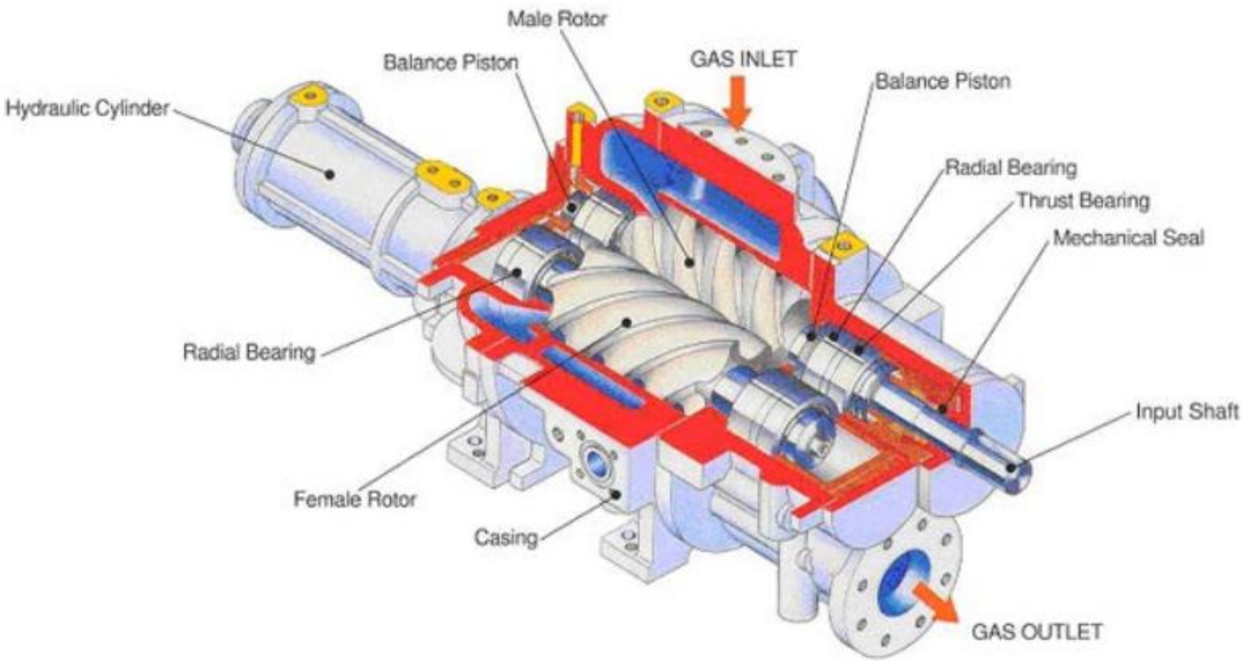



Figure: Part of screw compressor

## b. Advantages

The advantages of screw compressors are:

i. Simplicity
ii. Fewer moving parts rotating at a constant speed.
iii. Steady delivery of air without pressure pulses.

- ✓ **ROTARY COMPRESSOR**
  - **VANE COMPRESSOR**

The rotary vane type compressors are used in applications where low-pressure and low-volume are needed. For example, they are used for instrument and other laboratory-type air needs.

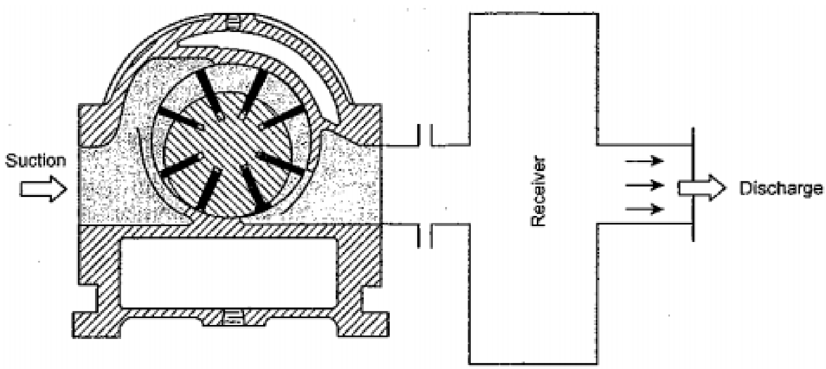



Figure: Rotary vane compressor

**a. Operation**

The air at atmospheric pressure is entrapped between two vanes. As the rotor rotates, the entrapped air is compressed between the vanes and then discharged through a port to the receiver.

**b. Advantages**

1. Rotary vane compressors are pulse free and therefore can be used without a receiver if needed.
2. They are smaller in size and lighter in weight
3. They can work at high speed

**c. Specification of compressors**

Air compressors are generally specified /rated by the following:

- Outlet pressure of air that can be delivered by the compressor
- Capacity or volume of air that can be delivered by the compressor
- Compressor configuration and cylinder geometry

**LOBE COMPRESSOR**

The Lobe type air compressor is very simpler type with no complicated moving parts. There are single or twin lobes attached to the drive shaft driven by the prime mover. The lobes are displaced by 90 degrees. Thus if one of the lobes is in horizontal position, the other at that particular instant will be in vertical position. Thus the air gets trapped in between these lobes and as they rotate they get compressed and delivered to the delivery line.

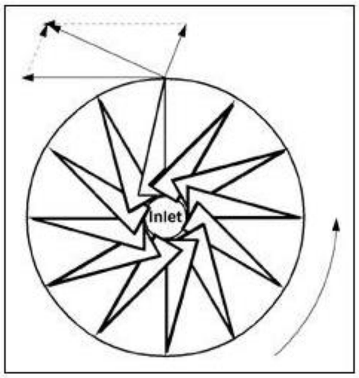
Figure: Lobe compressor

- ✓ **DYNAMIC COMPRESSOR**

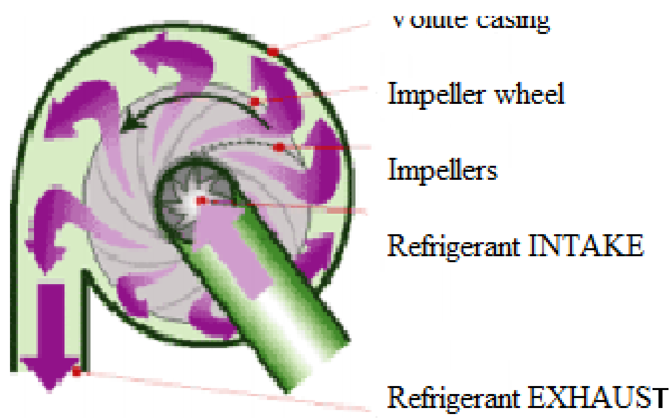
Dynamic air compressors generate horsepower by bringing in the air with rapidly rotating blades and then restricting the air to create pressure. The kinetic energy is then stored as static within the compressor.

- ✓ **CENTRIFUGAL TYPE COMPRESSOR**

A Centrifugal type of air compressor has a simple rotating element, mounted onto the shaft which is usually connected directly to the prime mover. These types of compressors are usually used for gas compression in oil platforms and LNG/LPG storage and transport installations. A typical example for the use of centrifugal air compressors are in turbochargers of diesel engines. The compressor in a whole has inducer, which sucks the air in, the impeller, which rotates at high speed, and the diffuser, which increases the pressure of the compressed air. The centrifugal compressors are best suited for constant load requirements. One of the remarkable characteristics of a centrifugal compressor is as the speed of the impeller reduces the capacity of the compressor increases. The air is sucked in axially by the impeller and the blades of the impeller impart additional energy which is converted into pressure energy and delivered out of the compressor casing. The centrifugal compressor may be of a single-stage or two and sometimes three-stage, which is more efficient than some screw and other positive displacement types.




Centrifugal Compressor Impeller Diagram




### ✓ AXIAL TYPE COMPRESSOR

These are similar to centrifugal compressors except the direction of air flow is axial. The blades of the compressor are mounted onto the hub and in turn onto the shaft. As the shaft rotates at a high speed, the ambient air is sucked into the compressor and then gets compressed (high speed of rotation of the blades impart energy to the air) and directed axially for further usage. An axial flow compressor, in its very simple form is called as axial flow fan, which is commonly used for domestic purposes. The pressure built depends on the number of stages. These are commonly used as vent fans in enclosed spaces, blower ducts, etc. One can find its main application in the aerospace industry, where the gas turbines drive the axial flow air compressors.

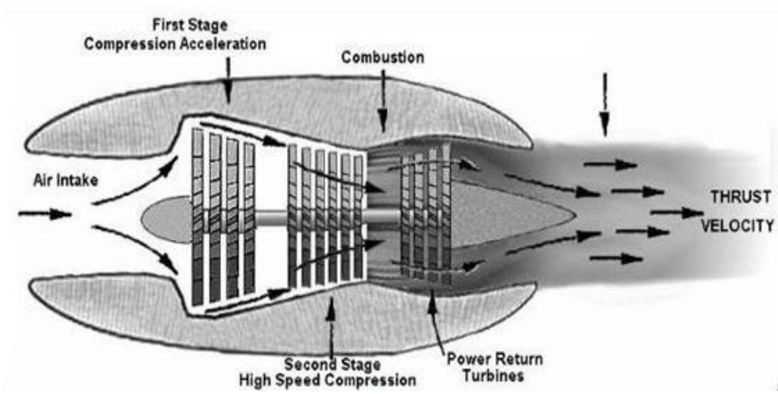



Figure: Axial type compressor

### ❖ ANALYSIS OF AIR CAPACITY RATING OF COMPRESSORS

**Q1 and Q2 =** Volume flow rate of air at the compressor inlet and outlet respectively ($m^3$/min)

P1and P2 = Absolute pressure of air at the compressor inlet and outlet respectively (kPa abs)

T1 and T2 = Absolute temperature of air at the compressor inlet and outlet respectively ($^0$K)

Then, $\boldsymbol{Q1} = \boldsymbol{Q2}\left(\frac{\boldsymbol{P2}}{\boldsymbol{P1}}\right)\left(\frac{\boldsymbol{T1}}{\boldsymbol{T2}}\right)$

❖ **ANALYSIS OF SIZING OF AIR RECEIVERS**

The air receiver size can be determined by using the following equation:

$$\boldsymbol{Vr = \frac{101\, t(Qr - Qc)}{Pmax - Pmin}}$$

Where, Vr = Receiver size ($m^3$)

**T** = Time that receiver can supply required amount of air (min)

**Qr** = Consumption rate of pneumatic system (standard $m^3$ /min)

**QC** = Output flow rate of compressor (standard $m^3$ /min)

**Pmax** = Maximum pressure level in receiver (kPa)

**Pmin** = Minimum pressure level in receiver (kPa)

❖ **ANALYSIS OF POWER REQUIRED TO DRIVE COMPRESSORS**

The theoretical power required to drive an air compressor can be determined by the following equations:

(i) **Theoretical power(kW)=**$\boldsymbol{Pin\,\frac{Q}{17.1}\,[\left(\frac{Pout}{Pin}\right) - 1}$

Where; **Pin** = Inlet atmospheric pressure (kPa abs)

**Pout** = Outlet pressure (kPa abs), and

**Q**= Flow rate (standard $m^3$ /min)

(ii) **Actual power (kW) =**$\{\mathbf{Overall\ compressor\ efficiency}(\boldsymbol{\eta}\mathbf{o})\} \times \{\boldsymbol{Theoretical\ power}\}$

- **Topic 3: AIR CONDITIONING SYSTEM**

**0. Introduction**

The atmospheric air that is compressed in the compressor is obviously not clean because the atmospheric air contains many contaminants such as **smoke, dirt, water vapor,** etc. This contaminated air may lead to excessive wear and failure of pneumatic components. The system performance and accuracy depend mainly on the supply of clean, dry and contamination – free compressed air. Therefore fluid conditioners are used to condition the compressed air before leaving into various pneumatic components.

- The purpose of air conditioning system is to make the compressed air more acceptable and suitable fluid medium for the pneumatic system components as well as for operating personnel.
- The important elements of air conditioners are:
  1. Filters
  2. Regulators
  3. Lubricators
  4. Mufflers
  5. Air dryers

In these, the first three units together are called **FRL** (Filter-Regulator-Lubricator) **unit or air service unit.**

✓ **Air service unit**

In most pneumatic systems, the compressed air is first filtered and then regulated to the specific pressure and made to pass through a lubricator for lubricating the oil. Thus usually a filter, regulator and lubricator are placed in the inlet line to each air circuit. These may be installed as separate units, but more often they are used in the form of a combined unit.

The combination of filter, regulator, and lubricator is often labeled as **FRL Unit or Service unit.**

- Figure below illustrate the arrangement of a FRL Unit.

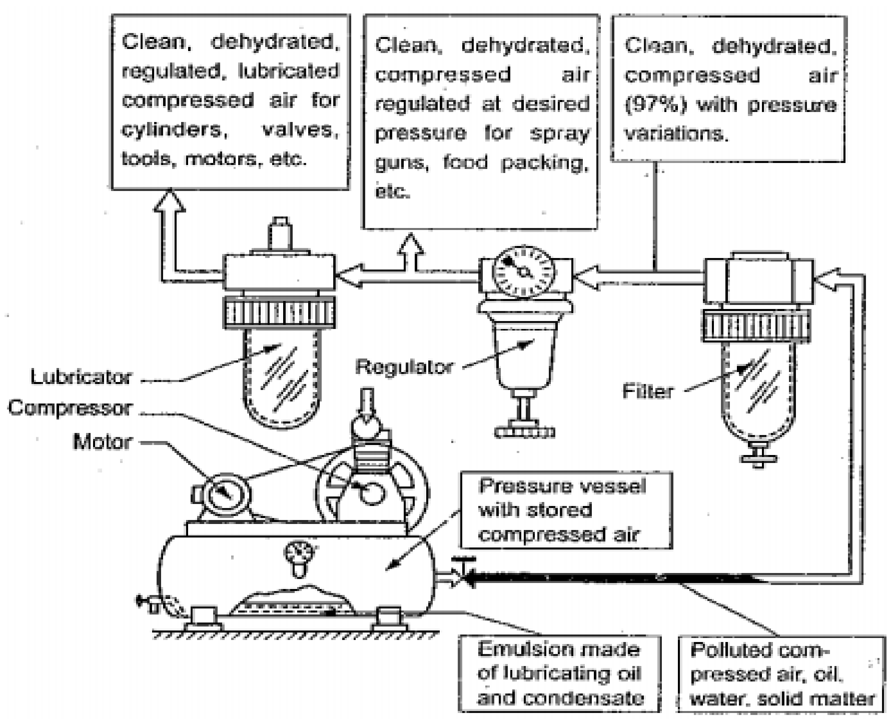



Figure: compressed air generation and distribution system showing a FRL Unit

- **Composite symbol:** figure below illustrate how individual component symbols form a composite symbol of a FRL Unit.

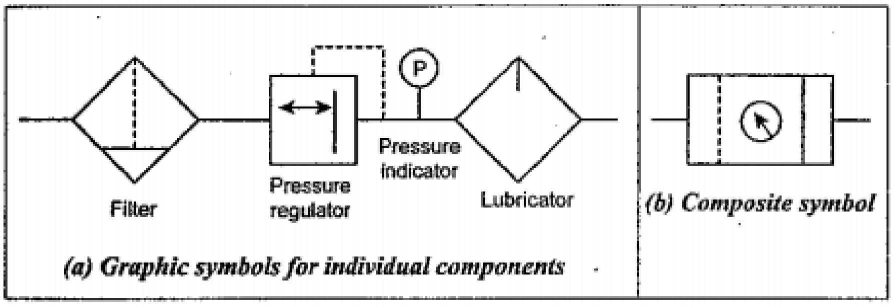



Figure: FRL unit graphic symbol


Figure: FRL image

**i. Filter**

- **Function :** The function of air filter is to remove all foreign matter and allow dry, clean air to flow without restriction to the regulator and then on to the lubricator.
- Filters are available in wide ranges starting from a fine mesh wire cloth (which only strains out heavier foreign particles) to elements made of synthetic materials(which are designed to remove very small particles)
- Usually in-line filter elements can remove contaminants in the 5 to 50 µm ranges.

❖ **FACTORS AFFECTING SELECTION OF FILTERS**

While selecting the filters, the following factors at least should be taken into account:

- Size of particles to be filtered from the system
- Capacity of the filter
- Accessibility and maintenability
- Life of the filter
- Ability to drain the condensate

### ❖ The construction and operation of a typical cartridge-type filter system

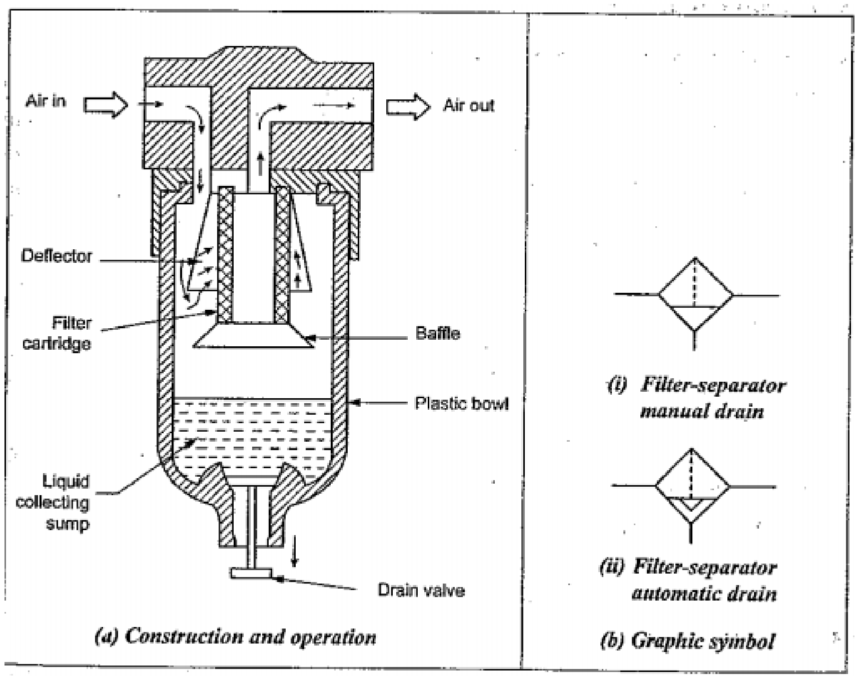



Figure: typical air- filter system

Figure : Image of filter

### ❖ Operation

The air to be filtered is allowed downward with a swirling motion that forces the moisture and the heavier particles to fall down. The deflector used in the filter mechanically separates the contaminants before they pass through the cartridge filter.

The filter cartridge provides a random zig-zag passage for the air flow. This type of air flow arrests the solid particles in the cartridge passage .

The water vapour gets condensed inside the filter and is collected at the bottom of the filter bowl. Also heavier foreign particles that are separated from the air are collected at the bottom of the bowl. Then the accumulated water and other solid particles at the bottom of the filter bowl are drained off with the use of an on-off drain valve located at the bottom of the filter bowl.

❖ TYPES OF AIR FILTERS

There are three general types of air filters: 1. ***General purpose***; 2. ***coalescing (oil removal)***;

3. ***Vapour removal***

General Purpose, are used to remove water and particles, while Coalescing filters remove oil, and Vapour Removal filters remove oil vapour and odour.

ii. **Pressure regulator**

- **Function:** The function of the air pressure regulator is to regulate the pressure of the incoming compressed air so as to achieve the desired air pressure at a steady condition.
- The compressed air leaving the compressor should be properly prepared before it goes into the circuit. The air should have the proper operating pressure for the circuit. Improper fluctuation pressure level in the piping system can adversely affect the operating characteristics of the system components such as valves, cylinders, etc.

Therefore, air pressure regulators are fitted to ensure the constant supply pressure irrespective of the pressure fluctuations in the compressor unit.

- For example, the line from the compressor may carry a pressure of 10 bar, the air pressure regulator can reduce this pressure to 0 bar to any point between the full line pressure and zero pressure.
- Thus the air pressure regulators act as pressure guards by preventing surges or drops from entering the air circuits.
-

❖ **Types :** The two types of air pressure regulators are:

**1.** Diaphragm-type regulator

**2.** piston-type regulator

❖ SELECTING THE RIGHT PRESSURE REGULATORS

Once a minimum suitable operating pressure has been determined for any compressed air application, it is essential to supply the air at a constant pressure, regardless of upstream flow and pressure fluctuations. Thus, it is critical to install the proper regulator or pressure-reducing valve in the airline.

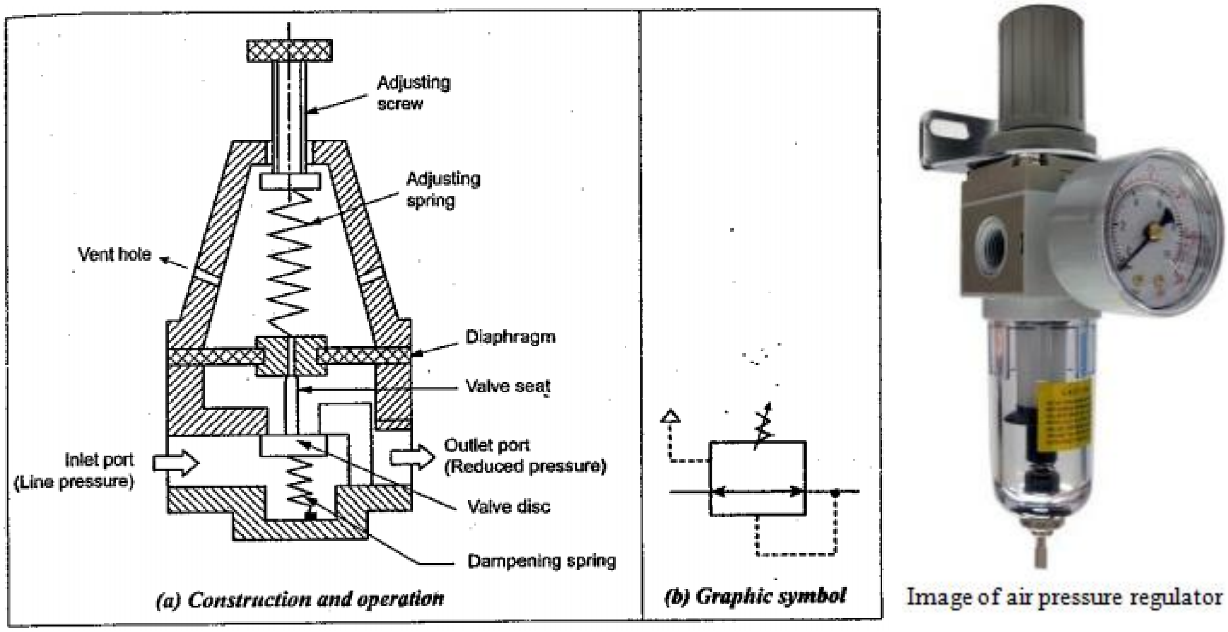
Air regulators are special valves that reduce supply pressure to the level required for efficient operation of downstream pneumatic equipment. A filter to protect the regulator's internal passages from damage should always be installed upstream from it.

❖ Construction and operation

It consists of **diaphragm, valve, main and dampening springs**, etc. Usually the **diaphragm** is made of oil-resistant synthetic rubber with nylon cloth reinforcements

**A pressure regulator is comprised of three functional elements**

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




*(a) Construction and operation* *(b) Graphic symbol* Image of air pressure regulator

Fig: Typical air pressure regulator and the graphical symbol of the air pressure regulator

- ❖ Operation

The diaphragm allows the proper amount of movement for opening and closing at the valve seat. When the adjusting screw is turned to compress the adjusting and dampening springs, the valve is opened. Thus the air is allowed from inlet port to the outlet port.

The pressure of the outlet air depends upon the size of the valve opening that is maintained. This is determined by the compression of the adjustable spring. Higher the spring compression, more will be the amount of opening and hence more the pressure and vice versa.

The vent-holes are provided to let out the undesirable excessive outlet pressure, if any, into the atmosphere. The dampening spring is provided to act as a dampening device needed to stabilize the pressure.

- ❖ **When selecting a pressure regulator, the important factors to consider are:**

1. Normal line pressure.

2. Minimum and maximum regulated pressure required: Regulators can have a broad adjustment range and may require a specific spring or accessory to match the requirements. Also, minimum and maximum pressure should be within the middle third of the regulator range.

3. Maximum flow required at regulated pressure.

4. Pipe size: Not all regulators are available in all pipe sizes; note where adapters are required. Also, pipe size should be consistent with flow requirements.

5. Regulator adjustment frequency: A number of different adjusting methods are possible. When selecting a regulator, consider the location, application, adjusting method, and user.

6. Degree of pressure precision required.

7. Accessories or options include gages and panel mounting.

8. Environmental or fluid conditions that could be incompatible with materials used in the regulator.

9. Special features such as high relief or remote control.

10. The consequences of a regulator malfunction or failure: A damper or relief valve might be needed to protect personnel or equipment. Also, dead-end service or intermittent actuation may require positive valve shutoff, bleed units, or close control of pressure-relief points. Filters, lubricators, relief devices, and other system options should be considered in the selection process.

**iii. Lubricator**

- **Function**: the function of air lubricator is to add controlled quantities of tool oil with air to ensure proper lubrication of internal moving parts of pneumatic components.
- The lubricator adds the lubrication oil in the form of a fine mist to reduce the friction and wear of the moving parts of pneumatic components such as valves, packing used in air cylinders, etc.
- At the same time excessive lubrication is also undesirable. Excessive lubrication may result: **i. Malfunction components; ii. Increased environmental problems, and iii. Seizing of components after prolonged downtime**

❖ What is the best type of Lubricant for a Pneumatic System?

1. Generally a good-quality, light-grade spindle oil is used in pneumatic systems
2. Sometimes a mixture of 50% kerosene and 50% SAE 30 oil is also used as lubricant.

❖ TYPES OF AIR LUBRICATORS

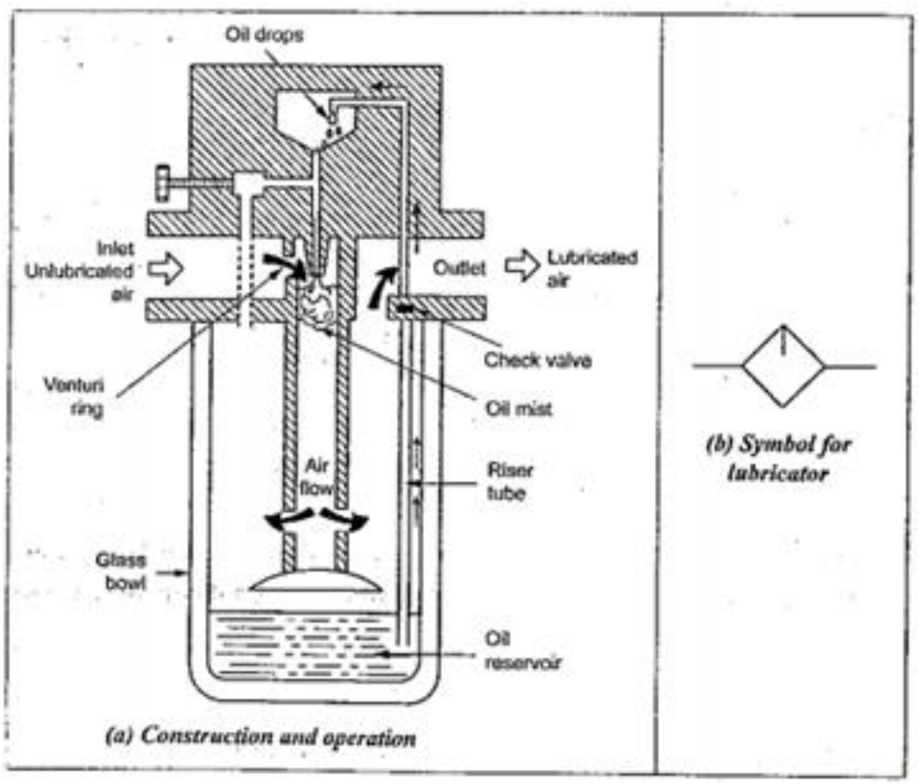
a. Air lubricators come in one of two types:
b. Oil-Fog
c. Micro-Fog

Oil-Fog air lubricators are used for heavy applications such as single tools, cylinders and valves, while Micro-Fog lubricators are used for multiple applications, several cylinders or valves.

In oil-fog lubricators, all the oil droplets visible in the sight dome are added directly into the air flow. This results in relatively large oil droplets passing downstream. In micro-fog lubricators, the oil droplets visible in the sight dome are atomized and collected in the area above the oil in the bowl. The smaller, lighter particles are drawn into the air flow and pass downstream. As a result, typically only 10% of the visible oil drops in the sight dome is passed downstream.

- Construction

The construction and operation of a typical force-feed type air lubricator is illustrated in the figure below. Its operation is similar to the principle of simple carburetor used in the petrol engines to obtain air-fuel mixture.




picture of air lubricator

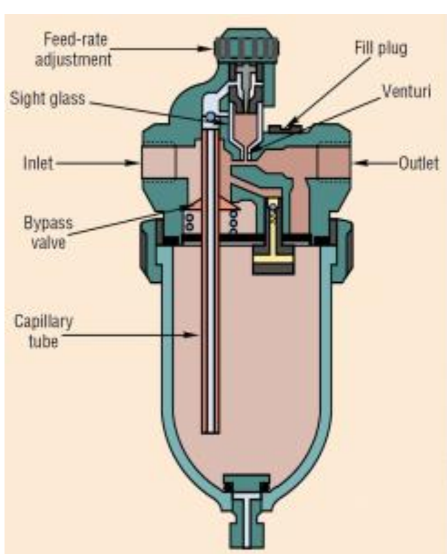



Figure: Air lubricators and its graphical symbol

❖ Operation

As the air to be lubricated enters into the inlet pipe, the venture ring located in the pipe increases its velocity of low. It causes a local reduction in the upper chamber. This pressure differential between upper and lower chambers causes suction of lubrication oil from the oil reservoir to the upper chamber. Now the oil in the form of mist is sprayed in the air stream and the air-oil mixture is obtained. This air-oil mixture is forced to swirl as it leaves the central cylinder causing more oil particles to be spread out of the air stream. The amount of oil dropping into the upper chamber can be controlled by a needle valve.

✓ WATER SEPARATOR

**a. AIR DRYER**

- **Function :** the function of air dryers is to remove all water vapour/moisture from the air leaving the compressor
- As we know, the atmospheric air contains moisture to a varying amount depending on the prevailing atmospheric conditions. Even after compression in the compressor, the air contains the same amount of moisture. This moisture should be removed before the air is fed into any pneumatic system components. Thus air dryers are placed at suitable points in the pressure air line to safeguard the pneumatic components from the corrosive effects of moisture.

❖ **Types of air dryers**

There are various types of compressed air dryers. These dryers are generally fall into two different classes:

a. Primary which includes Refrigerated and Deliquescent
b. Secondary which includes desiccant ; Absorption and membrane

The three main types of air dryers are used to remove the moisture in the compressed air are:

a. Refrigerated dryer
b. Deliquescent dryer
c. Absorption dryer

❖ Refrigerated dryer

Humid, hot air coming into the air dryer will be cooled down by a cooler re-heater (heat exchanger). Water condensed at this time will be removed from the air by an auto drain and drained out automatically. Air separated from the water will be heater by a cooler re-heater (heat exchanger) to obtain the dried air, which goes through to the outlet side.

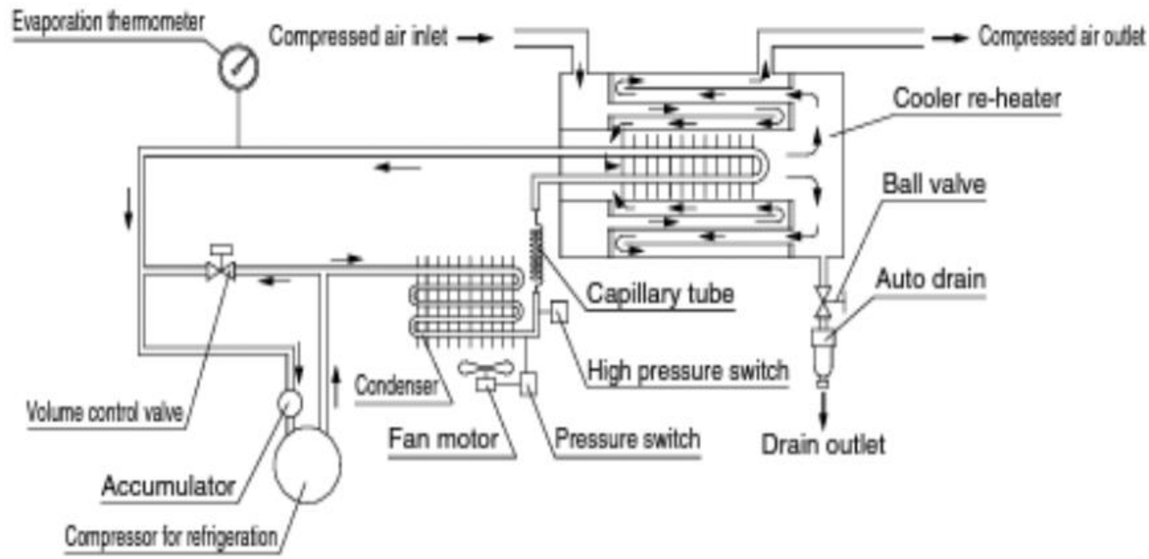



Figure: Refrigerated air dryer

- ❖ Deliquescent dryer

Deliquescent dryers are used for removing water vapor from compressed air, natural gas, and waste gases such as landfill gas and digester gas.

The performance of a deliquescent dryer as measured by outlet dew point (dew point is defined as the temperature at which water vapor will begin to condense into liquid water.), is highly dependent on the temperature of the air or gas being processed, with cooler temperatures resulting in better performance

- ❖ **Construction and operation**

The construction and operation of a typical deliquescent –type dryer is illustrated in figure below

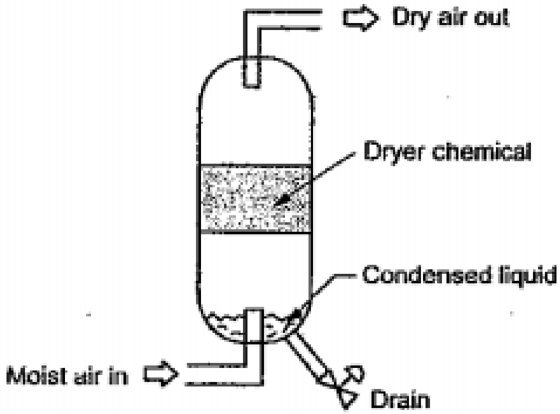



Figure: Deliquescent dryer

It uses a chemical agent called a dessicant. As shown on figure, the moisture air enters at one end, passes through the chemical agent, and passes out at the other end. The chemical agent absorbs water vapour/moisture and slowly dissolves it as a liquid. The liquid is collected at the bottom of the unit where it can be drained.

- ✓ Heat exchangers

Energy generated by prime movers transforms to thermal energy which increases the temperature
of the working fluid. High temperatures deteriorate the fluid properties and result in shorter fluid life. Hence it is required to cool the oil to certain level for smooth operation.

**Typical heat exchangers used are**:

- **Tubular heat exchangers:** This delivers cooling fluid through copper tubes to accomplish heat exchange between fluid and cooling water.
- **Plate heat exchanger:** This consists of many thin cooling plates which exchange heat with cooling water.
- **Air cooing radiator:** Forced air flows through tubes and cools the fluid
- **Refrigerant exchanger:** This is like a domestic refrigerator and dissipates heat from fluid. It consists of a hydraulic pump, a motor and thermos stat . It is used when accurate temperature control is needed.

**Heaters**: In cold regions, viscosity becomes high causing high pressure loss in the system. Hence electronic heater or steam heaters are used for heating the oil to the desired temperature.

- **TOPIC 4: IDENTIFICATION OF DIFFERENT TYPES OF HYDRAULIC PUMPS**

  0. **Introduction**

Moving fluids plays a major role in the process of a plant. Liquid can only move on its own power, and then only from top to bottom or from a high pressure to a lower pressure system.

This means that energy to the liquid must be added, to moving the liquid from a low to a higher level.
To add the required energy to liquids, pumps are used. There are many different definitions of a pump but this is best described as:

- A machine used for the purpose of transferring quantities of liquids, gases and even solids from one location to another.
- A hydraulic pump is a device which converts mechanical energy into hydraulic energy.

The pump is used to impact motion to a liquid. It provides the force required to transmit power and motion. The pump does not produce pressure. It produces only fluid flow

**1. Pump theory(Principle of Pump)**

Normally the powered electric motor converts the electrical energy into mechanical energy which is used to drive the shaft of the pump. The pump in turn converts the mechanical energy into hydraulic energy by creating a partial vacuum at the inlet, which induces the atmospheric pressure to force the fluid through the inlet line. Then the internal design of the pump mechanically pushes the fluid to the outlet line.

**2. How a pump works?**

The working principle of the pump can be better explained by referring to the simple piston pump as shown on the figure below:

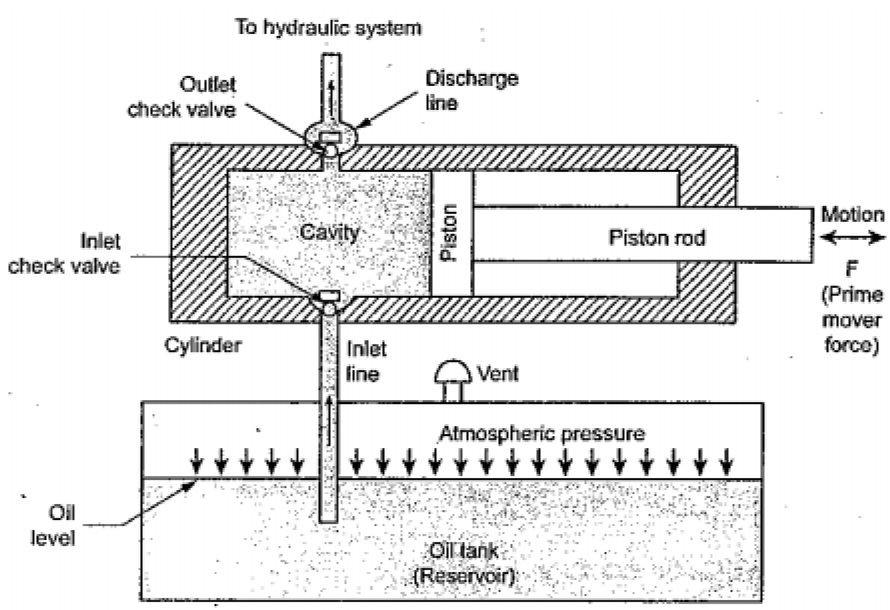



Figure: Pumping action of a simple piston pump

The pump has the following two ball-check valves:

**Inlet check valve**: It is connected to the pump inlet to allow fluid to enter the pump

**Outlet check valve:** It is connected to the pump outlet to allow fluid to leave the pump

When the piston is pulled to the right, a partial vacuum is generated in pump cavity. The vacuum created in the cavity makes the outlet check valve to close the outlet line and allows the atmospheric pressure to push fluid from the reservoir into the pump via the inlet check valve.

When the piston is pushed to the left, the fluid movement forces the inlet check valve to close and open the outlet check valve. The quantity of fluid displaced by the piston is ejected out through the outlet line. Thus the pump produces flow of fluid.

### 3. Applications of pumps

The most popular application of pumps are shown below:

- Pumping water from the wells
- Water cooling and fuel injection in automobile
- Pumping oil or gas and operating cooling towers in energy industry
- They also have their uses in waste water recycling, pulp and paper, chemical industry etc.

### 4. PUMP CLASSIFICATION

With reference to the fluid power applications, pumps can be broadly classified into different ways and must be considered in any discussion of fluid power equipment.

1. **Classification based on displacement:**
    - Non-positive displacement pumps (hydrodynamic pumps).
    - Positive displacement pumps (hydrostatic pumps).
2. **Classification based on delivery:**
    - Constant delivery pumps.
    - Variable delivery pumps.
3. **Classification based on motion:**
    - Rotary pump.
    - Reciprocating pump.
4. **Classify the positive displacement pumps**
   Based on the construction, Hydrostatic pumps are classified

    1) Gear Pumps ( fixed displacement pumps
       (a) External gear pump
       (b) Internal gear pump

a. Lobe pump

b. Gerotor pump

(c) Screw pump

2) Vane Pumps ( fixed or variable displacement pumps)
   (a) Balanced Vane pump
   (b) Unbalanced Vane pump
3) Piston Pumps ( fixed or variable displacement pumps)
   (a) Axial piston pump b)Radial piston pump

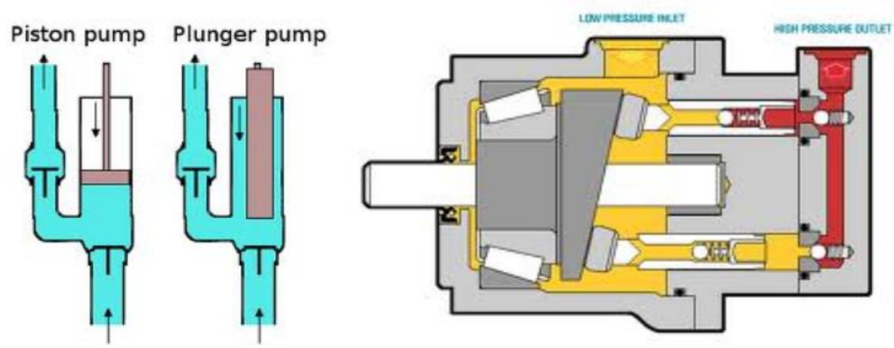



Figure: Some reciprocating pumps

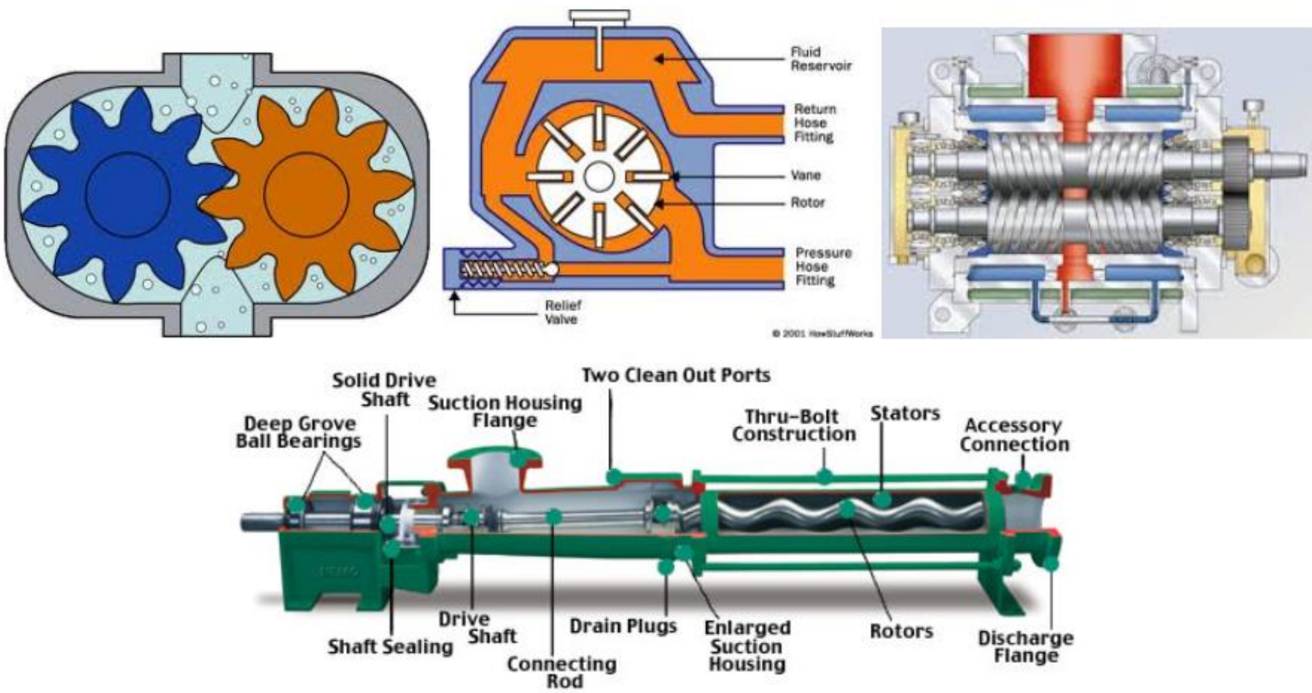



Figure: Some rotary pumps

## A. CLASSIFICATION BASED ON DISPLACEMENT

### 1. Non-Positive Displacement Pumps

Non-positive displacement pumps are primarily velocity-type units that have a great deal of clearance between rotating and stationary parts. Non-displacement pumps are characterized by a high slip that increases as the back pressure increases, so that the outlet may be completely closed without damage to the pump or system.

Non-positive pumps do not develop a high pressure but move a large volume of fluid at low pressures. They have essentially no suction lift. Because of large clearance space, these pumps are not self-priming. In other words, the pumping action has too much clearance space to seal against atmospheric pressure. The displacement between the inlet and the outlet is not positive. Therefore, the volume of fluid delivered by a pump depends on the speed at which the pump is operated and the resistance at the discharge side.

These pumps are not used in fluid power industry as they are not capable of withstanding high pressure. Their maximum capacity is limited to 17–20 bars. These types of pumps are primarily used for transporting fluids such as water, petroleum, etc., from one location to another considerable apart location.

The two most common types of hydrodynamic pumps are **the centrifugal and the axial flow propeller pumps.**

### ❖ Advantages and disadvantages of non-positive displacement pumps

**The advantages are as follows:**

- Non-displacement pumps have fewer moving parts.
- Initial and maintenance cost is low.
- They give smooth continuous flow.
- They are suitable for handling almost all types of fluids including slurries and sledges.
- Their operation is simple and reliable.

**The disadvantages are as follows:**

- Non-displacement pumps are not self-priming and hence they must be positioned below the fluid level.
- Discharge is a function of output resistance.
- Low volumetric efficiency.
-

## B. Positive (or Hydrostatic) Displacement pumps

- ✓ As the name implies, the functioning of a positive-displacement pump derives from changes of the volume occupied by the fluid within the pump.
- ✓ Since the operation of the pumps depend only on mechanical and hydrostatic principles, these pumps are also called as ***hydrostatic displacement pumps.***
- ✓ Positive displacement pumps are primarily used where pressure development is the prime requirement. This type of pumps is capable of delivering high pressure fluid, so it is universally used in fluid power systems.
- ✓ These pumps discharge a fixed quantity of fluid into the hydraulic system per revolution of pump shaft rotation. Since the flow of fluid is guaranteed on every revolution of the shaft, this type of pump is named as ***'positive displacement pump'***.
- ✓ ***Types :*** Positive displacement pumps can be further divided into :
  1. Fixed displacement pumps, and 2. Variable displacement pumps.

  ***1. Fixed Displacement Pumps :*** In fixed displacement pumps, the amount of fluid ejected per revolution (displacement) is constant and it cannot be varied.

  ***2. Variable Displacement Pumps :*** In variable displacement pumps, the displacement can be varied by changing the physical relationships of various pump elements. This change in pump displacement produces a change in output of fluid flow even though pump speed remains constant.

Examples: Some of the positive displacement pumps are gear; vane; piston and screw pumps

Positive displacement pumps are classified based on the following characteristics:

**1. Type of motion of pumping element:** Based on the type of motion of pumping element, positive displacement pumps are classified as follows:

•Rotary pumps, for example, gear pumps and vane pumps.

•Reciprocating pumps, for example, piston pumps.

**2. Displacement characteristics:** Based on displacement characteristics, positive displacement pumps are classified as follows:

•Fixed displacement pumps.

•Variable displacement pumps.

**3. Type of pumping element**.

The advantages of positive displacement pumps over non-positive displacement pumps are as follows:
**1.** They can operate at very high pressures of up to 800 bar (used for lifting oils from very deep oil wells).
**2.** They can achieve a high volumetric efficiency of up to 98%.

**3.** They are highly efficient and almost constant throughout the designed pressure range.
**4.** They are a compact unit, having a high power-to-weight ratio.
**5.** They can obtain a smooth and precisely controlled motion.
**6.** By proper application and control, they produce only the amount of flow required to move the load at the desired velocity.
**7.** They have a great flexibility of performance. They can be made to operate over a wide range of pressures and speeds.

Table1. Differences between positive displacement pumps and non-positive displacement pumps

| Positive Displacement Pumps | Non-positive Displacement Pumps |
|---|---|
| The flow rate does not change with head | The flow rate decreases with head |
| The flow rate is not much affected by the viscosity of fluid | The flow rate decreases with the viscosity |
| Efficiency is almost constant with head | Efficiency increases with head at first and then decreases |

- The **four parameters that affect noise level of hydrostatic pump**
  - o Pressure
  - o Size of the pump
  - o Speed of the pump
  - o Entrained air bubbles

## 1. Gear pumps

This is the simplest of rotary positive displacement pumps consisting of two meshed gears rotating in a closely fitted casing. Fluid is pumped around the outer periphery by being trapped in the tooth spaces. It does not travel back on the meshed part, since the teeth mesh closely in the centre. It is widely used on car engine oil pumps, and also in various hydraulic power packs. There are two main variations; external gear pumps which use two external spur gears and internal gear pumps which use an external and an internal spur gear. Some gear pumps are designed to function as either a motor or a pump.

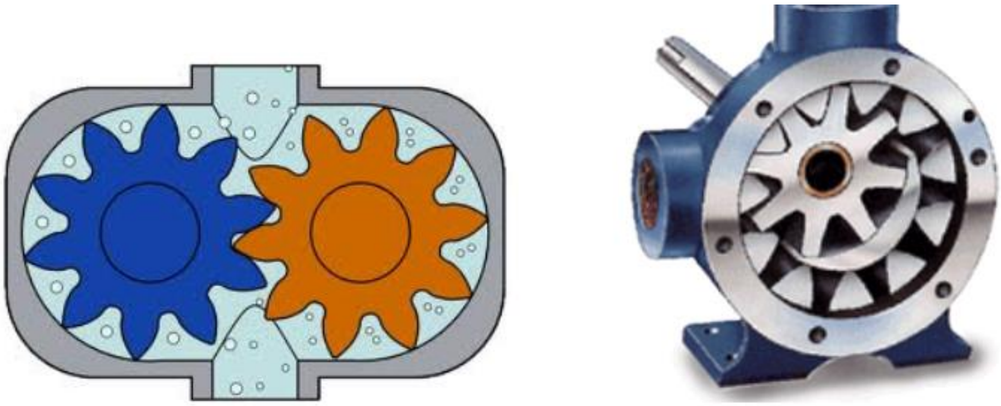


Figure: (left) external gear pump (right) internal gear pump

a. **External gear**

External gear pumps are the most popular hydraulic pumps in low-pressure ranges due to their long operating life, high efficiency and low cost. They are generally used in a simple machine. The most common form of external gear pump is shown in Figs1. It consist of a pump housing in which a pair of precisely machined meshing gears runs with minimal radial and axial clearance .One of the gears, called a driver, is driven by a prime mover. The driver drives another gear called a follower. As the teeth of the two gears separate, the fluid from the pump inlet gets trapped between the rotating gear cavities and pump housing. The trapped fluid is then carried around the periphery of the pump casing and delivered to outlet port. The teeth of precisely meshed gears provide almost a perfect seal between the pump inlet and the pump outlet when the outlet flow is resisted; pressure in the pump outlet chamber builds up rapidly and forces the gear diagonally outward against the pump inlet.

When the system pressure increases, imbalance occurs. This imbalance increases mechanical friction and the bearing load of the two gears. Hence, the gear pumps are operated to the maximum pressure rating stated by the manufacturer. It is important to note that the inlet is at the point of separation and the outlet at the point of mesh. These units are not reversible if the internal bleeds for the bearings are to be drilled to both the inlet and outlet sides' .So that the manufacturer's literature should be checked before attempting a reversed installation.

If they are not drilled in this manner, the bearing may be permanently damaged as a result of inadequate lubrications.

**Advantages and disadvantages of gear pumps**

1. They are self-priming.
2. They give constant delivery for a given speed.
3. They are compact and light in weight.
4. Volumetric efficiency is high.

**The disadvantages are as follows:**

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

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

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

**Expression for the theoretical flow rate of an external gear pump**

Let

***Do*** =the outside diameter of gear teeth

***D*i**= the inside diameter of gear teeth

***L*** =the width of gear teeth

***N***=the speed of pump in RPM

***V*D**=the displacement of pump in m/rev

***M***= module of gear

***z***=number of gear teeth

**α**= pressure angle

Volume displacement is:

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

$$D_i = D_o - 2(\text{Addendum} + \text{Dendendum})$$

Theoretical discharge is

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

If the gear is specified by its module and number of teeth, then the theoretical discharge can be found by:

$$\boxed{Q_T = 2\pi L m^2 N\left[z + \left(1 + \frac{\pi^2 \cos\alpha}{12}\right)\right] \text{m}^3/\text{min}}$$

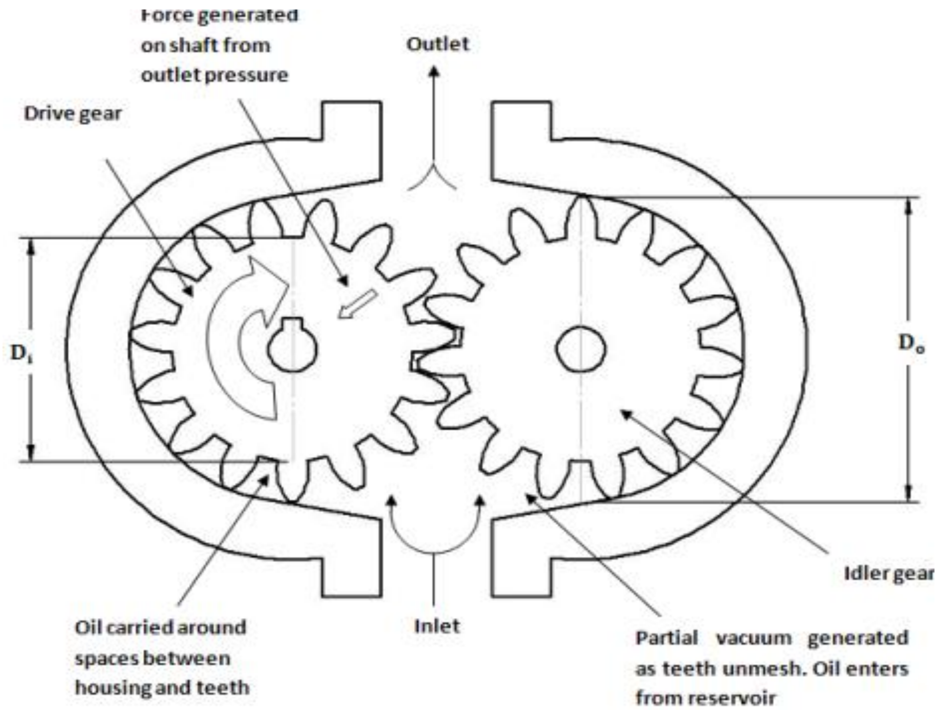



**Figure:** Operation of an external gear pump

**Volumetric Efficiency**

Obviously there will be a small radial clearance between the gear teeth and the casing so as to achieve the gears rotation. As a result, some of the fluid may leak inside the system without discharging at the outlet port. This internal leakage, also known as ***'pump slippage'***, results in lesser flow rate ($Q_A$) than the theoretical flow rate ($Q_T$). This is represented by the volumetric efficiency.

$$\text{Volumetric efficiency, } \eta_v = \frac{\text{Actual flow rate of the pump}}{\text{Theoretical flow rate of the pump}} = \frac{Q_A}{Q_T}$$

$$\boxed{\text{Volumetric efficiency, } \eta_{vol} = \frac{Q_A}{Q_T} \times 100}$$

where $Q_A$ and $Q_T$ are actual and theoretical flow rate of the pump respectively.

Since the internal leakage increases with the increase in discharge pressure, the volumetric efficiency will be lower for the high discharge pressure.

**b. Internal gear pumps**

Another form of gear pump is the internal gear pump, which is illustrated in Fig.2. They consist of two gears: An external gear and an internal gear. The crescent placed in between these acts as a seal between the suction and discharge. When a pump operates, the external gear drives the internal gear and both gears rotate in the same direction.

The fluid fills the cavities formed by the rotating teeth and the stationary crescent. Both the gears transport the fluid through the pump. The crescent seals the low-pressure pump inlet from the high-pressure pump outlet. The fluid volume is directly proportional to the degree of separation and these units may be reversed without difficulty. The major use for this type of pump occurs when a through shaft is necessary, as in an automatic transmission. These pumps have a higher pressure capability than external gear pumps.

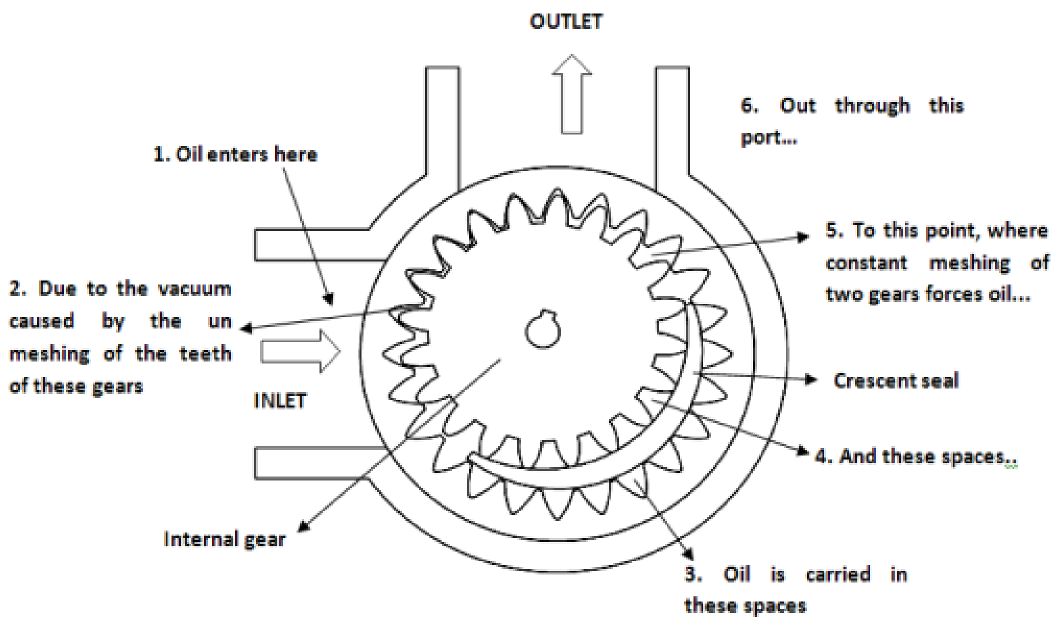



**Figure 2.**Operation of an internal gear pump

**What are the reasons for the popularity of external gear pumps?**

- Simple to design
- Because gear pumps have only two moving parts, they are reliable, simple to operate, and easy to maintain.
- Low cost compared to other pumps

❖ **What is the most important application for internal gear pumps?**

- The speed of the internal gear pumps is considered relatively slow compared to centrifugal types. Speeds up to 1,150 rpm are considered common. Because of their ability to operate at low speeds, internal gear pumps are well suited for high – viscosity applications and where suction conditions call for a pump with minimal inlet pressure requirements.

- They're also bi-rotational, meaning that the same pump can be used to load and unload applications

### c. Gerotor Pumps

Gerotor pumps operate in the same manner as internal gear pumps. The inner gear rotor is called a gerotor element. The gerotor element is driven by a prime mover and during the operation drives outer gear rotor around as they mesh together. The gerotor has one tooth less than the outer internal idler gear. Each tooth of the gerotor is always in sliding contact with the surface of the outer element. The teeth of the two elements engage at just one place to seal the pumping chambers from each other. On the right-hand side of the pump, shown in Fig.3, pockets of increasing size are formed, while on the opposite side, pockets decreases in size. The pockets of increasing size are suction pockets and those of decreasing size are discharge pockets. Therefore, the intake side of the pump is on the right and discharge side on the left.

Pumping chambers are formed by the adjacent pair of teeth, which are constantly in contact with the outer element, except for clearance. Refer to Fig 3,as the rotor is turned, its gear tips are accurately machined so that they precisely follow the inner surface of the outer element. The expanding chambers are created as the gear teeth withdraw. The chamber reaches its maximum size when the female tooth of the outer rotor reaches the top dead center. During the second half of the revolution, the spaces collapse, displacing the fluid to the outlet port formed at the side plate.

The geometric volume of the gerotor pump is given as:

$$V_D = b\,Z(A_{max} - A_{min})$$

where *b* is the tooth height, *Z* is the number of rotor teeth, *A*max is the maximum area between male and female gears (unmeshed – occurs at inlet) and *A*min is the minimum area between male and female gears (meshed – occurs at outlet).

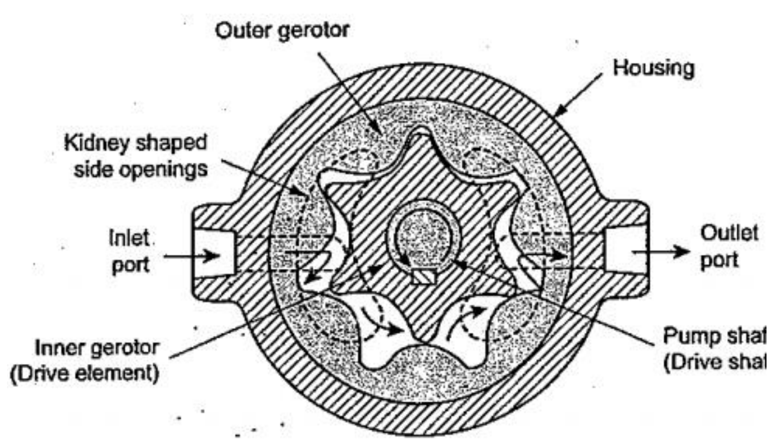



**Figure 3.**Gerotor gear pump

E.g 1: A gear pump has an outside diameter of 80mm, inside diameter of 55mm and a width of 25mm. If the actual pump flow is 1600 RPM and the rated pressure is 95 LPM what is the volumetric displacement and theoretical discharge.

**Solution:** We have

Outside diameter

*Do* = 80 mm

Inside diameter

*Di* = 55 mm

Width *d* =25mm

Speed of pump *N* = 1600 RPM

Actual flow rate = 95 LPM

Now

$$Q_A = 95\,\text{LPM} = 95 \times 10^{-3}\,\text{m}^3/\text{min}$$

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

$$V_D = \frac{\pi}{4} \times (0.080^2 - 0.055^2) \times 0.025 = 6.627 \times 10^{-5}\, m^3/rev$$

Theoretical flow rate

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

$$= \frac{\pi}{4} \times (0.080^2 - 0.055^2) \times 0.025 \times 1600$$

$$= 0.106\,\text{m}^3/\text{min}$$

**Eg2.** Calculate the theoretical delivery of a gear pump. Module of the gear teeth is 6mm and width of gear teeth is 25mm. Number of teeth on driver gear is 18 and pressure angle of the gear is 20. Pump speed is 1000 RPM. Volumetric efficiency is 90%.

**Solution**: If the gear is specified by its module and number of teeth, then the theoretical discharge can be found by

$$Q_T = 2\pi L m^2 N \left[ z + \left( 1 + \frac{\pi^2 \cos\alpha}{12} \right) \right] \text{m}^3/\text{min}$$

$$= 2\pi (0.025)(6 \times 10^{-3})^2 \times 1000 \times \left[ 18 + \left( 1 + \frac{\pi^2 \cos^2 20}{12} \right) \right] \text{m}^3/\text{min}$$

$$= 0.1118\,\text{m}^3/\text{min}$$

**Eg3**. Calculate the theoretical delivery of a gear pump. Module of the gear teeth is 6mm and width of gear teeth is 65mm. Number of teeth on driver gear is 16 and pressure angle of the gear is 20 . Pump speed is 1600 RPM. Outer diameter of gear is 108 mm and Dedendum circle diameter is 81 mm. volumetric efficiency is 88%at 7 MPa.

**Solution:** If the gear is specified by its module and number of teeth, then the theoretical discharge can be found by

$$Q_T = 2\pi L m^2 N\left[z+\left(1+\frac{\pi^2\cos^2 20}{12}\right)\right]\ \mathrm{m^3/min}$$

$$= 2\pi(0.065)(6\times10^{-3})^2\times1600\times\left[16+\left(1+\frac{\pi^2 0.939^2}{12}\right)\right]\ \mathrm{m^3/min}$$

$$= 0.416\ \mathrm{m^3/min}$$

**Alternatively we can use**

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

$$Q_T = \frac{\pi}{4}\times(0.108^2 - 0.081^2)\times0.065\times1600 = 0.416\ \ \mathrm{m^3/rev}$$

Exg4. The inlet to a hydraulic pump is 0.6 m below the top surface of an oil reservoir. If the specific gravity of the oil used is 0.86, determine the static pressure at the pump inlet. **Solution:** We know that

$$\text{Pressure} = \rho g h$$

The density of water is 1 g/cm$^3$ or 1000 kg/m$^3$.
Therefore, the density of oil is $0.86\times1$ g/cm$^3$ or 860 kg/m$^3$.
Pressure at the pump inlet is

$$P = 860\times0.6\,\mathrm{kg/m^2} = 516\,\mathrm{kg/m^2} = 0.0516\,\mathrm{kg/cm^2} = 0.0516\times0.981\,\mathrm{bar}$$
$$= 0.0506\,\mathrm{bar}$$

(Note: $1\,\mathrm{kg/cm^2} = 0.981\,\mathrm{bar}$.)

Eg5. A hydraulic pump delivers 12 L of fluid per minute against a pressure of 200 bar. (a) Calculate the hydraulic power. (b) If the overall pump efficiency is 60%, what size of electric motor would be needed to drive the pump?

**Solution:**
(a) Hydraulic power is given by

$$\text{Hydraulic power (kW)} = 12\ \mathrm{L/min}\times\frac{200\ \mathrm{(bar)}}{600} = 4\ \mathrm{kW}$$

(b) We have

$$\text{Electric motor power (power input)} = \frac{\text{Hydraulic power}}{\text{Overall efficiency}}$$

Substituting we get

$$\text{Electric motor power (power input)} = \frac{4}{0.6} = 6.67kW \quad \text{Electric motor power} = \frac{4}{0.6} = 6.67\,\text{kW}$$

## 2. VANE PUMPS

There are two types of vane pumps:

**a. Unbalanced vane pump:** Unbalanced vane pumps are of two varieties:

- Unbalanced vane pump with fixed delivery.
- Unbalanced vane pump with pressure-compensated variable delivery

**b. Balanced vane pump**

### ❖ UNBALANCED VANE PUMP

The main components of the unbalanced vane pump are the cam surface and the rotor. The rotor contains radial slots splined to drive shaft. The rotor rotates inside the cam ring. Each radial slot contains a vane, which is free to slide in or out of the slots due to centrifugal force. The vane is designed to mate with surface of the cam ring as the rotor turns. The camring axis is offset to the drive shaft axis.

When the rotor rotates, the centrifugal force pushes the vanes out against the surface of the cam ring. The vanes divide the space between the rotor and the cam ring into a series of small chambers. During the first half of the rotor rotation, the volume of these chambers increases, thereby causing a reduction of pressure. This is the suction process, which causes the fluid to flow through the inlet port. During the second half of rotor rotation, the cam ring pushes the vanes back into the slots and the trapped volume is reduced. This positively ejects the trapped fluid through the outlet port. In this pump, all pump action takes place in the chambers located on one side of the rotor and shaft, and so the pump is of an unbalanced design. The delivery rate of the pump depends on the eccentricity of the rotor with respect to the cam ring.

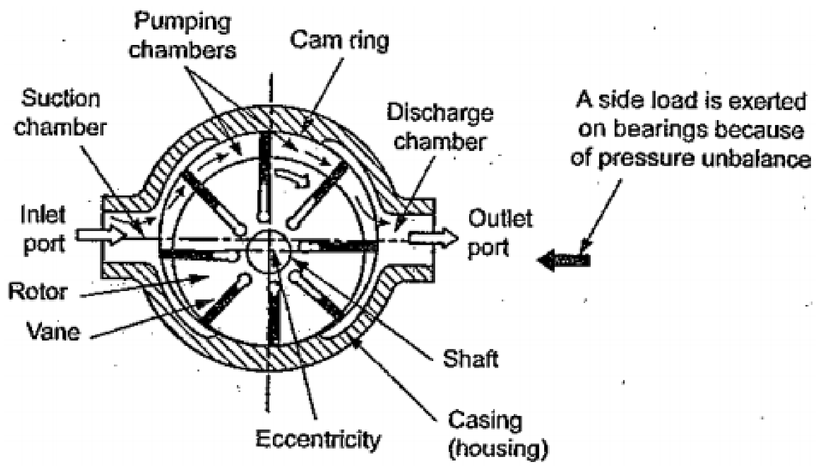



**Figure:** Unbalanced vane pump

**Pressure-Compensated Variable Displacement Vane Pump (an Unbalanced Vane Pump with Pressure-Compensated Variable Delivery)**

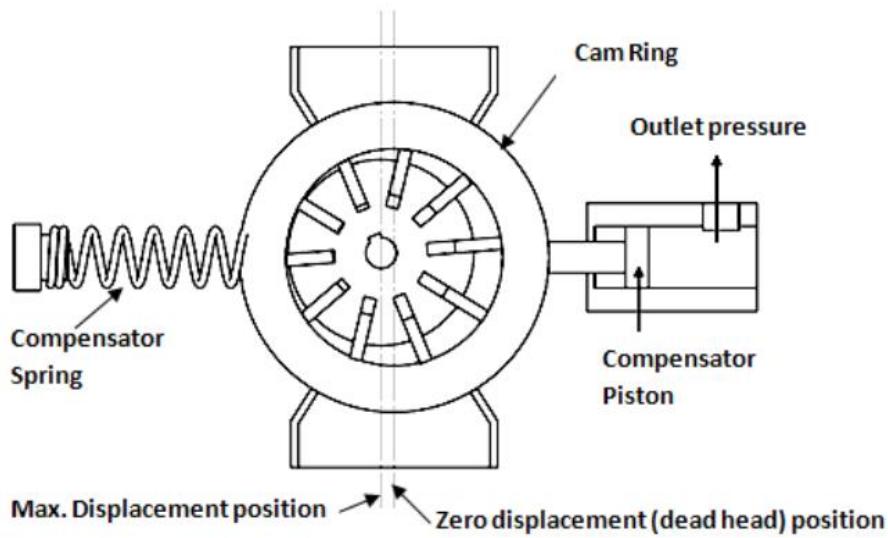



**Figure:** Operation of a variable displacement vane pump

Schematic diagram of variable displacement vane pump is shown in Fig**:** Operation of a variable displacement vane pump Variable displacement feature can be brought into vane pumps by varying eccentricity between the rotor and the cam ring. Here in this pump, the stator ring is held against a spring loaded piston.

The system pressure acts directly through a hydraulic piston on the right side. This forces the cam ring against a spring-loaded piston on the left side. If the discharge pressure is large enough, it overcomes the compensated spring force and shifts the cam ring to the left. This reduces the eccentricity and decreases the flow. If the pressure continues to increase, there is no eccentricity and pump flow becomes zero.

❖ BALANCED VANE PUMP

**Advantages and disadvantages of Vane Pumps**

The advantages of vane pumps are as follows:

1. Vane pumps are self-priming, robust and supply constant delivery at a given speed.
2. They provide uniform discharge with negligible pulsations.
3. Their vanes are self-compensating for wear and vanes can be replaced easily.
4. These pumps do not require check valves.
5. They are light in weight and compact.
6. They can handle liquids containing vapors and gases.
7. Volumetric and overall efficiencies are high.
8. Discharge is less sensitive to changes in viscosity and pressure variations.

The disadvantages of vane pumps are as follows:

1. Relief valves are required to protect the pump in case of sudden closure of delivery.
2. They are not suitable for abrasive liquids.
3. They require good seals.
4. They require good filtration systems and foreign particle can severely damage pump.

***Advantages and disadvantages of balanced vane pumps***

The advantages of balanced vane pumps are as follows:

1. The balanced pump eliminates the bearing side loads and therefore high operating pressure can be used.

2.The service life is high compared to unbalanced type due to less wear and tear.

**The disadvantages of balanced vane pumps are as follows:**

1. They are fixed displacement pumps.
2. Design is more complicated.
3. Manufacturing cost is high compared to unbalanced type.

**i. ANALYSIS OF VOLUMETRIC DISPLACEMET OF VANE PUMPS**

The volumetric displacement of the vane pump can be determined by using the following relation:

$$\text{Volumetric displacement, } V_D = \frac{\pi}{2}(D_C + D_R)\, e\, L$$

Let *D*C be the diameter of a cam ring in m, *D*R the diameter of rotor in m, *L* the width of rotor in m, *e* the eccentricity in m, and *V*D the pump volume displacement in m3/rev

$$e = \text{Eccentricity in m} = \frac{(D_C - D_R)}{2}$$

If N = Rotor speed in rev/min RPM, then the theoretical flow rate (discharge) can be given by:

$$Q_T = v_D \times N \quad ; \quad Q_T = \frac{\pi}{2}(D_C + D_R)e\,L \ \ \text{m}^3/\text{min}$$

Eg1: A vane pump has a rotor diameter of 63.5 mm, a cam ring diameter of 88.9 mm and a vane width of 50.8 mm. What must be eccentricity for it to have a volumetric displacement of 115cm$^3$?

**Solution:** Volumetric displacement is

$$V_D = \pi\left(\frac{D_C + D_R}{2}\right)Le$$

Where *D*c is the diameter of the cam ring, *D*R is the diameter of the rotor, *e* is the eccentricity and *L* is the width of the vane pump.

So we have:

$$115\times10^{-6} = \pi\times\frac{0.0889+0.0635}{2}\times e\times0.0508$$

Therefore eccentricity

$$e = 9.456\times10^{-3}\text{ m} = 9.456\text{ mm}$$

### 3. Piston pumps

- ✓ In piston pumps, the pumping action is affected by a piston that moves in a reciprocating cycle through a cylinder. The basic operation of piston pumps are very similar to that of the reciprocating engines.
- ✓ ***Classification :*** Piston pumps can be classified by the motion of the piston relative to their drive shaft as :
  1. Axial piston pumps, and
     (*a*) Bent axis type, and (*b*) Swash plate type.
  2. Radial piston pumps.
- ✓ In axial piston pumps, a number of pistons and cylinders are located in a parallel position with respect to the drive shaft, while in the radial type they are arranged radially around the rotor hub.

#### a. AXIAL PISTON PUMP

In the axial piston pump, rotary shaft motion is converted to axial reciprocating motion which drives the piston. Most axial-piston pumps are multi-piston designs and utilize check valves or port plates to direct liquid flow from inlet to discharge. Output can be controlled by manual, mechanical, or pressure compensated controls.

- **In-Line Axial Piston Pump**

An axial piston pump, in which the pistons are in line with the axis of the drive shaft, is illustrated in figure below

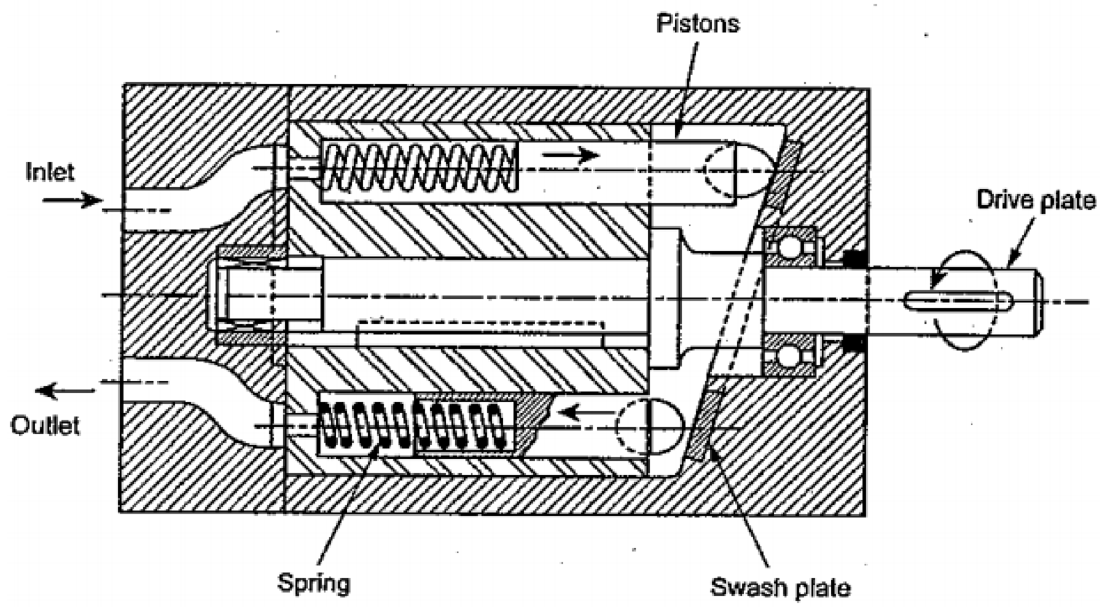



**Figure: In-line axial piston pump**

As shown in figure: in-line axial piston pump, the rotary drive motion is covered to reciprocating, axial piston motion by means of the swash plate (also known as thrust cam or wobble plate ), mounted on the drive shaft. Thus the rotation of the swash plate produces in- and –out motion of the pistons in their cylinders and hence the fluid is discharged.

- **Fixed – Displacement In-Line Axial Pump**

The axial pump illustrated on Figure: In-line axial piston pump is a constant-displacement piston pump. That means constant volume of oil is discharged for a set rotor speed. In these, pistons are stroked by a fixed angle plate.

- **Variable- Displacement in- Line Axial Pump (Swash Plate Design)**

This type of pump can also be designed to have variable displacement capability. This can be achieved by altering the angle of the swash plate. Because in the swash plate axial pump , the angle of tilt of the swash plate determines the piston stroke and hence the pump displacement. This is schematically illustrate in figure below

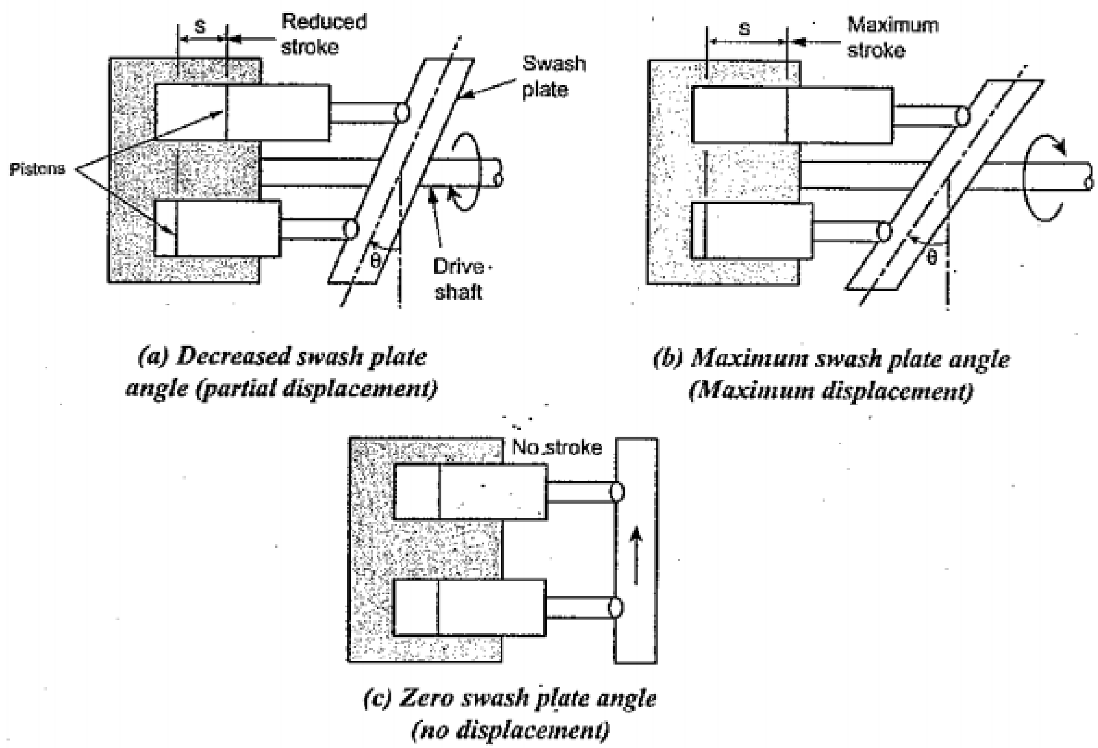



Figure: variation in pump displacement with swash plate angle

As could be seen from the Figure : variation in pump displacement with swash plate angle. The increase in the swash plate angle (θ) will increase the piston stroke and hence the fluid displacement. When the swash plate is vertical (i.e., angle is zero), then the displacement will be zero. Even one can reverse the flow direction by changing the angle of swash plate. However, the maximum swash plate angle is generally limited to $17^{1/2}$, due to various design considerations.

- **Bent axis type axial piston pump**

A typical 3D bent axis type axial piston pump is illustrated in Figure below. This type of pump contains a cylinder block rotating with the drive shaft. The centerline of the cylinder block is set at an offset angle relative to the centerline of the drive shaft. The cylinder block has a number of pistons and cylinders arranged along a circle. The ball and socket joints connect the piston rods with the drive shaft flange. When the distance between the drive shaft flange and cylinder block changes, the pistons move in and out of the cylinder. In order to provide alignment and positive drive, a universal link is used to connect the block to the drive shaft.

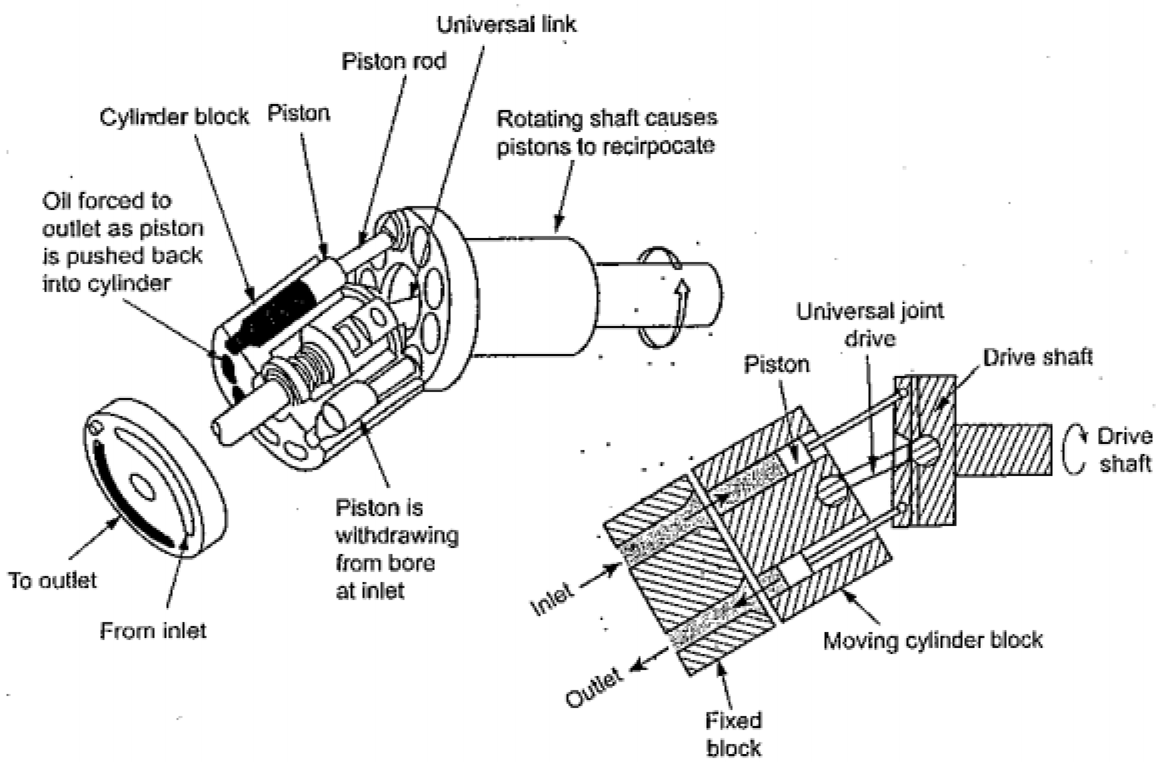



Figure: Bent axis type axial piston pump and bent axis pump

- Operation

When the piston carrying body turns, the exit passages in the cylinder bores move along the control slots of a firmly positioned control plate and are thus connected alternatively to the suction or discharge pipelines.

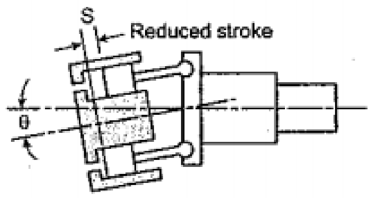
**Fixed –Displacement Bent axis type axial piston**

In fixed displacement pumps, the pumps are mounted in a fixed casing so that swing (or offset) angle cannot be adjusted. So the fixed displacement of the piston and hence the constant discharge of fluid are achieved.

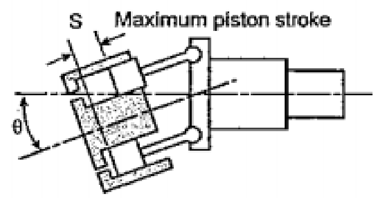
**Variable –Displacement Bent Axis Piston Pump**

In variable-displacement pumps, the swing (or offset) angle can be varied. Because the volumetric displacement of the pump varies with the offset angle. The variation in pump displacement with respect to offset angle is schematically illustrated in Fig. below

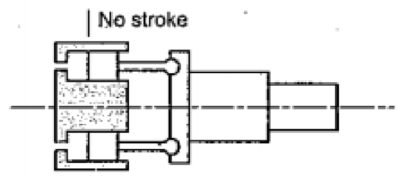
As could be seen from Fig below the increase in the offset angle (θ) will increase the piston stroke and hence the fluid displacement. When the offset angle is zero, then the displacement will be zero. However, for practical reasons, θ is to be varied from 0° to a maximum of about 30°.




*(a) Lesser offset angle (partial displacement)*




*(b) Maximum offset angle (maximum displacement)*




*(c) Zero offset angle (no displacement)*

Figure: Variation in pump displacement with offset angle

**VOLUMETRIC DISPLACEMT AND THEORETICAL FLOW RATE OF AN AXIAL PISTON PUMP**

For any axial piston pump, the volumetric displacement and theoretical flow rate can be determined as follows :

Let $\theta$ = Offset angle in degrees,

$S$ = Piston stroke in m,

$D$ = Piston circle diameter in m,

$d$ = Diameter of piston in m,

$A$ = Cross-sectional area of the piston in $m^2 = \frac{\pi}{4} d^2$,

$Y$ = Number of pistons, and

$N$ = Rotor speed in rpm.

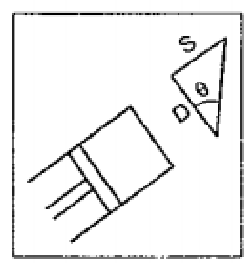



**Fig a**

From the geometry of a piston ( **Fig a** ), we get

$$\tan\theta = \frac{S}{D}$$

or $$S = D\tan\theta \quad \ldots (1)$$

We also know that,

Total displacement volume = (Displacement volume/Piston) × Number of pistons

$$\therefore \quad V_D = (\text{Area} \times \text{Stroke}) \times Y = ASY \quad \ldots (2)$$

Substituting equation (1) in (2), we get

$$\boxed{V_D = YAD\tan\theta} \quad \ldots (3)$$

Then the theoretical flow rate is given by,

$$\boxed{Q_T = YAND\tan\theta} \quad \ldots (4)$$

Eg : What is the theoretical flow rate from a fixed-displacement axial piston pump with a nine bore cylinder operating at 2000 RPM? Each bore has a diameter of 15 mm and stroke is 20 mm.

**Solution:** Theoretical flow rate is given by

$$Q_T = \text{Volume} \times \text{RPM} \times \text{Number of pistons}$$

$$= \frac{\pi}{4} \times D^2 \times L \times N \times n$$

$$= \frac{\pi}{4} \times 0.015^2 \times 0.02 \times \frac{2000}{60} \times 9$$

$$= 10.6 \times 10^{-3}\,\text{m}^3/\text{s}$$

**= 1 .06 LPS= 63.6 LPM**

**b. Radial piston pumps**

- **Construction and operation**

The radial piston pump has a number of radial pistons (in similar fashion to the spokes of a wheel) in a cylinder block which revolves around a stationary eccentric cam. In these pumps, the pistons move perpendicularly to the shaft centerline. As the cylinder block rotates, the eccentricity of the cam causes an in-and-out or pumping motion of the pistons.

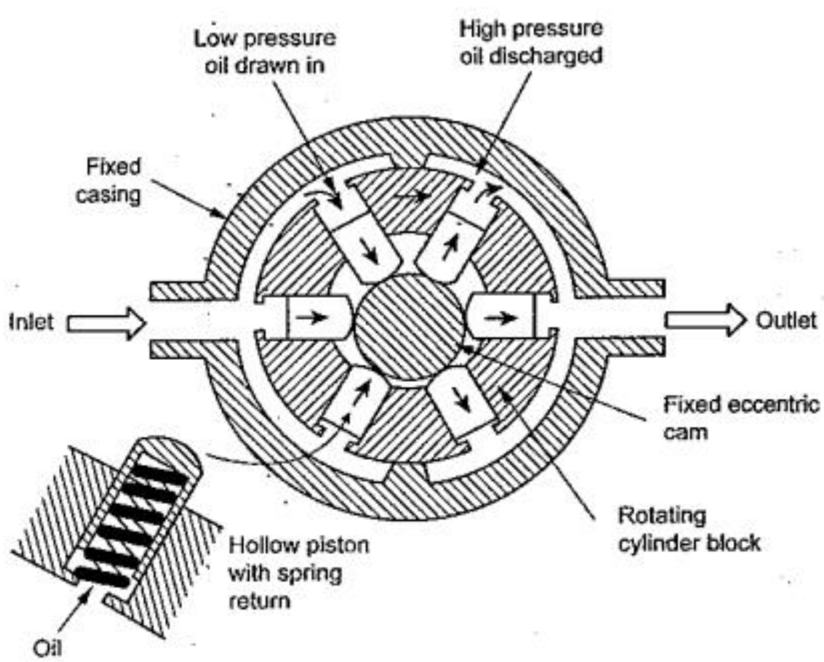



**Figure:** Radial piston pump

As could be seen from the figure of piston pump, the fluid in flow and outflow at each piston is controlled through revolving ports. During the down stroke, each piston is connected to the fluid inlet and hence the fluid is drawn inside the cylinders. During the upward stroke, each piston is connected to the fluid outlet and hence fluid is discharged outside the pump.

- **Theoretical flow rate of a radial piston pump**

  The theoretical discharge of a radial piston pump can be calculated by using the following relation:

$$\boxed{Q_T = 0.5\, e\, Y\, \pi\, d^2 N \quad m^3/min}$$

where $e$ = Eccentricity in m,
$Y$ = Number of pistons,
$d$ = Diameter of piston in m, and
$N$ = Rotor speed in rpm.

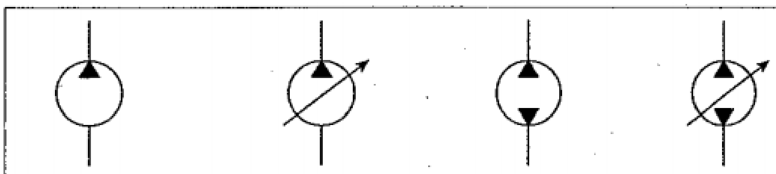
- **Advantages and disadvantages of piston pumps**

  Table: Advantages and Disadvantages of piston pumps

| Advantages | Disadvantages |
|---|---|
| ✓ Piston pumps are capable of delivering high operating pressures.<br>✓ They can handle oils in a wide viscosity range.<br>✓ They can handle liquids containing vapours and gases.<br>✓ They can provide a variable delivery of liquid.<br>✓ They are self-priming.<br>✓ They are quite in operation.<br>✓ They have exceptionally long life. | ✓ They tend to be heavy and bulky.<br>✓ They have a pulsating discharge.<br>✓ Power pumps cannot be operated against a closed discharge. Hence relief valves are required.<br>✓ Most types requ're inlet and discharge valves. |

❖ **GRAPHIC SYMBOLS FOR PUMPS**

The four different standard symbols used for hydraulic pumps are given below:



*(a) Fixed displacement, unidirectional pump* *(b) Variable displacement unidirectional pump* *(c) Fixed displacement, bidirectional pump* *(d) Variable displacement bidirectional pump*

❖ **Pump Performance**

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

**1. Volumetric efficiency ($\eta v$ ):** It is the ratio of actual flow rate of the pump to the theoretical flow rate of the pump. This is expressed as follows:

$$\text{Volumetric efficiency} = \frac{\text{Actual flow rate produced by the pump}}{\text{Theoretical flow rate that the pump should produce}} \times 100$$

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

Significant: Volumetric efficiency ($\eta v$) indicates the amount of leakage that takes place within the pump. This is due to manufacture tolerances and flexing of the pump casing under designed pressure operating conditions.

- For gear pumps, $\eta v$ = 80%–90%.
- For vane pumps, $\eta v$ = 92%.
- For piston pumps, $\eta v$ = 90%–98%.

**2. Mechanical efficiency ($\eta m$ ):** It is the ratio of the pump output power assuming no leakage to actual power delivered to the pump:

$$\text{Mechanical efficiency } (\eta_m) = \frac{\text{Pump output power assuming no leakages}}{\text{Actual power delivered to the pump}}$$

Mechanical efficiency (**$\eta m$** ) indicates the amount of energy losses that occur for reasons other than leakage. This includes friction in bearings and between mating parts. This includes the energy losses due to fluid turbulence. Mechanical efficiencies are about 90%–95%. We also have the relation

$$\eta_m = \frac{pQ_T}{T_A N}$$

Where $p$ is the pump discharge pressure in Pa or N/m$^2$, $Q_T$ is the theoretical flow rate of the pump in m$^3$/s, $T_A$ is the actual torque delivered to the pump in Nm and $N$ is the speed of the pump in rad/s. It (**$\eta m$**) can also be computed in terms of torque as follows:

$$\eta_m = \frac{\text{Theoretical torque required to operate the pump}}{\text{Actual torque delivered to the pump}} = \frac{T_T}{T_A}$$

The theoretical torque ($T_T$) required to operate the pump is the torque that would be required if there were no leakage.The theoretical torque ($T_T$) is determined as follows

$$T_T(\text{N m}) = \frac{VD_N}{2\pi}\left(\text{m}^3 \times \frac{N}{\text{m}^2}\right) = \text{N m}$$

The actual torque (*TA* ) is determined as follows

$$\text{Actual torque } T_A \text{ (N m)} = \frac{P}{\omega}\left(\frac{\text{N m/s}}{\text{rad/s}}\right) = \text{N m}$$

where $\omega = 2\pi N/60$. Here $N$ is the speed in RPM.

**3. Overall efficiency (ηo):** It is defined as the ratio of actual power delivered by the pump to actual power delivered to the pump

$$\text{Overall efficiency } (\eta_o) = \frac{\text{Actual power delivered by the pump}}{\text{Actual power delivered to the pump}}$$

Overall efficiency ($\eta_o$) considers all energy losses and can be represented mathematically as follows:

$$\text{Overall efficiency } (\eta_o) = \eta_v \eta_m$$

$$\Rightarrow \eta_o = \frac{Q_A}{Q_T} \times \frac{pQ_T}{T_A N}$$

Eg1. A gear pump has an outside diameter of 82.6 mm, inside diameter of 57.2 mm and a width of 25.4 mm. If the actual pump flow is 1800 RPM and the rated pressure is 0.00183 $m^3$ /s, what is the volumetric efficiency?

**Solution:** We have

Outside diameter $D_o = 82.6$ mm

Inside diameter $D_i = 57.2$ mm

Width $d = 25.4$ mm

Speed of pump $N = 1800$ RPM

Actual flow rate $= 0.00183\ \text{m}^3/\text{s}$

Theoretical flow rate

$$Q_T = \frac{\pi}{4} \times (D_o^2 - D_i^2) \times d \times \frac{N}{60}$$

$$= \frac{\pi}{4} \times (0.0826^2 - 0.0572^2) \times 0.0254 \times \frac{1800}{60}$$

$$= 2.125 \times 10^{-3}$$

Volumetric efficiency is

$$\eta_v = \frac{0.00183}{2.125 \times 10^{-3}} \times 100 = 86.11\%$$

Eg 2. A pump having a volumetric efficiency of 96% delivers 29 LPM of oil at 1000 RPM. What is the volumetric displacement of the pump?

**Solution:**

Volumetric efficiency of the pump $\eta v$ = 96%

Discharge of the pump = 29 LPM

Speed of pump $N = 1\,000$ rpm

Now

$$\eta_v = \frac{\text{Actual flow rate of the pump}}{\text{Theoritical flow rate of the pump}} = \frac{Q_A}{Q_T}$$

$$\Rightarrow 0.96 = \frac{29}{Q_T}$$

$$\Rightarrow Q_T = 30.208 \text{ LPM}$$

Volumetric displacement

$$V_D = \frac{Q_T}{N} = \frac{30.208 \times 10^{-3} \times 60}{60 \times 1000}$$

$$= 30.208 \times 10^{-6} \text{ m}^3/\text{rev} = 0.0302 \text{ L}/\text{rev}$$

Eg3. A positive displacement pump has an overall efficiency of 88% and a volumetric efficiency of 92%. What is the mechanical efficiency?

**Solution:** The overall efficiency is

$$\eta_o = \eta_m \times \eta_v$$

$$\Rightarrow \eta_m = \frac{\eta_o}{\eta_v} = \frac{88}{92} \times 100 = 95.7\%$$

Eg4. Determine the overall efficiency of a pump driven by a 10 HP prime mover if the pump delivers fluid at 40 LPM at a pressure of 10 MPa.

**Solution:**

$$\text{Output power} = pQ$$

$$= 10 \times 10^6 \text{ N/m}^2 \times 40 \text{ L/min} \times \frac{\text{m}^3/\text{s}}{1000 \text{ L/s}} \times \frac{1 \text{ min}}{60 \text{ s}}$$

$$= 6670 \text{ W}$$

$$\text{Input power} = 10 \text{HP} \times \frac{746 \text{ W}}{1 \text{ HP}} = 7460 \text{ W}$$

Now

$$\eta_o = \frac{\text{Pump output power}}{\text{Pump input power}}$$

$$= \frac{6670}{7460} = 0.894 = 89.4\%$$

Eg5. How much hydraulic power would a pump produce when operating at 140 bar and delivering 0.001 $m^3/s$ of oil? What power rated electric motor would be selected to drive this pump if its overall efficiency is 85%?

**Solution:**

Operating pressure of the pump = 140 bar

Flow rate $Q = 0.001 \text{m}^3/\text{s}$. Now

$$\text{Power of pump} = \text{Pressure} \times \text{Flow rate}$$

$$= 140 \times 10^5 \times 0.001$$

$$= 14 \text{ kW}$$

Overall efficiency of pump $\eta_o = 85\%$

Power to be supplied is

$$\frac{\text{Power of pump}}{\eta_o} = \frac{14 \text{kW}}{0.85} = 16.47 \text{kW}$$

Eg6. A pump has a displacement volume of 98.4 $cm^3$. It delivers 0.0152 $m^3/s$ of oil at 1000 RPM and 70 bar. If the prime mover input torque is 124.3 Nm. What is the overall efficiency of pump? What is the theoretical torque required to operate the pump?

**Solution:**

Volumetric discharge = 98.4 $cm^3$

Theoretical discharge is

$$Q_T = V_D \times \frac{N}{60} = 98.4 \times \frac{1000}{60} = 1.64 \times 10^{-3} \text{ m}^3/\text{s}$$

Volumetric efficiency is

$$\eta_v = \frac{1.52 \times 10^{-3}}{1.64 \times 10^{-3}} \times 100 = 92.68\ \%$$

Overall efficiency is

$$\eta_o = \frac{Q_A \times \text{pressure}}{T \times \omega} = \frac{1.52 \times 10^{-3} \times 70 \times 10^5 \times 60}{124.3 \times 2 \times 1000 \times \pi} \times 100 = 81.74\%$$

The mechanical efficiency is

$$\eta_{\text{mechanical}} = \frac{\eta_{\text{overall}}}{\eta_{\text{volumetric}}} = \frac{81.74}{92.78} = 88.2$$

Now

Theoretical torque = Actual torque × $\eta_{\text{mechanical}}$ = 124.3 × 0.882 = 109.6 Nm

Note: Mechanical efficiency can also be calculated as

$$\eta_m = \frac{pQ_T}{T\omega}$$

$$= \frac{70 \times 10^5 \text{ N/m}^2 \times 0.00164 \text{ m}^3/\text{s}}{124.3\ (\text{N m}) \times \frac{1000}{60} \times 2\pi \text{ rad/s}}$$

$$= 0.882 = 88.2\%$$

❖ **What is cavitation?. Name four popular methods to reduce cavitation**

- During the working of positive displacement pump a vacuum is created at the inlet of the pump. This allows atmospheric pressure to push the fluid in. In some situations the vacuum may become excessive, and a phenomenon known as Cavitation occurs.
- 

**The four popular methods to reduce cavitation are:**

1) Keep the suction line velocities below 1.5 m/s
2) Keep the pump inlet as short as possible
3) Minimize the number of fittings in the inlet line
4) Mount the pump as close as possible to the reservoir.

❖ **Name the three ways by which noise of pump can be reduced**

- Noise is a significant factor used to determine the performance of pumps
- Any increase in noise level normally indicates wear and danger of failure of pump
- Noise is measured in units of decibels (dB)

- Table presents the approximate noise levels for various pump designs. Generally speaking external gear and the piston pumps are the noisiest while screw pumps are very quiet; vane and internal gear pumps have noise levels somewhere in between a piston and screw pumps.
- Table : noise levels for various pump designs

| Pump type | Noise level (dB) |
|---|---|
| Gear | 80 - 100 |
| Vane | 65 - 85 |
| Piston | 60 - 80 |
| Screw | 50 - 70 |

o By proper design of pump

o By proper clamping of hydraulic distribution like pipes , fittings etc.

o By using sound absorption material in the design of fluid power systems.

❖ **The important considerations in the selection of a pump for any given application are:**

1) Flow rate requirement
2) Operating speed of pump
3) Pressure rating
4) Performance/application
5) Reliability
6) Maintenance
7) Cost
8) Noise level of the pump
9) Oil compatibility
10) Type of pump control
11) Pump contamination tolerance
12) Availability of pump and spars

❖ **Slip**

- Slip is the leakage occurs between the discharge and suction sides of a pump through the pump clearances
- The extent of this leakage depends on the width, length and shape of the clearances, the viscosity of the pumped liquid, and the pressure difference between the discharge and suction sides of the pump.
- Pump speed does not influence slip. But slip increases with increasing liquid viscosity.

✓ **TOPIC 5 : OIL TREATMENT SYSTEM**

**a. Reservoir**

A properly constructed reservoir is more than just a tank to hold oil until the system demands fluid (*Figure below*). It should also be capable of the following:

- Dissipating heat from the fluid.
- Separating air from the oil.
- Settling out contamination in the oil.

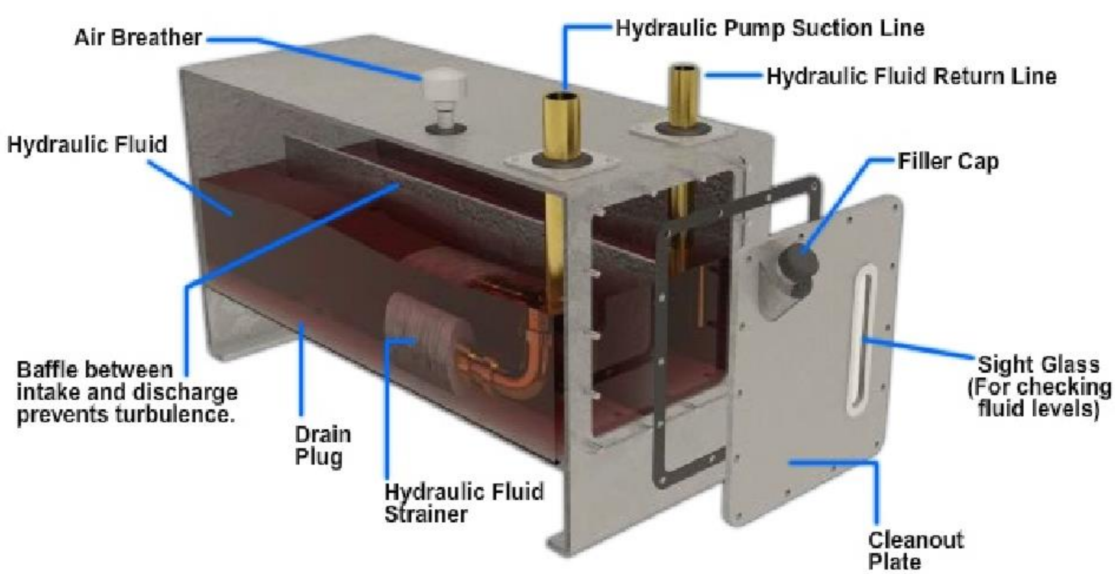



**Figure:** Typical hydraulic reservoir

Ideally, the reservoir should be high and narrow rather than shallow and broad. The oil level should be as high as possible above the opening to the pump suction line. This condition prevents the vacuum at the line opening from causing a vortex or whirlpool effect. Anytime you see a whirlpool at the suction line opening, the system is taking in air. As a rule of thumb, the reservoir level should be two to three times the pump output per minute.

By this rule which works well for stationary machinery, a 20-gallon per minute (gpm) system would require a 40- or 60-gpm reservoir. However, this is not possible for mobile equipment. You are more likely to find a 20- or 30-gallon tank to support a 100-gpm system. This is possible because mobile systems operate intermittently rather than all the time. The largest reservoirs are on mobile equipment. These reservoirs may have a 40- or 50- gallon capacity, capable of handling more than 200-gpm output. The reservoir must be sized to ensure there is a reserve of oil with all the cylinders in the system fully extended. The reserve must be high enough to prevent a whirlpool at the suction line opening. Also, there must be enough space to hold all the oil when the cylinders retract with some space to spare for expansion of hot oil.

An air vent allows the air to be drawn in and pushed out of the reservoir by the ever changing fluid level. An air filter is attached to the air vent to prevent drawing atmospheric dust into the system by the ever changing fluid level. A firmly secured filling strainer of fine mesh wire is always placed below the filler cap .The sight gauge is provided so the normal fluid level can always be seen, as it is essential that the fluid in the reservoir be at the correct level. The baffle plate segregates the outlet fluid from the inlet fluid. Although not a total segregation, it does allow time to dissipate the air bubbles, lessen the fluid turbulence (contaminants settle out of non-turbulent fluid), and cool the return fluid somewhat before it is picked up by the pump.

## LEARNING OUTCOME 2.2: IDENTIFY THE MAIN COMPONENTS

- One of the most important considerations in any fluid power system is control. If control components are not properly selected, the entire system does not function as required. In fluid power, controlling elements are called valves.
- A valve is a device that receives an external signal (mechanical, fluid pilot signal, electrical or electronics) to release, stop or redirect the fluid that flows through it.
- Valves are devices used to control pressure, flow direction, or flow rate in hydraulic circuits
- The control valves utilize mechanical motion to control the distribution of hydraulic energy within the system.

### 1. Types of valves:

Control valves are classified into three basic types, based on their function in the hydraulic system, as:

**a. Directional control valves (DCVs)**
They determine the path through which a fluid transverses a given circuit.

**b. Pressure control valves**
They protect the system against overpressure, which may occur due to a sudden surge as valves open or close or due to an increase in fluid demand.

c. **Flow control (or volume control) valves**

Shock absorbers are hydraulic devices designed to smooth out pressure surges and to dampen hydraulic shock. In addition, the fluid flow rate must be controlled in various lines of a hydraulic circuit. For example, the control of actuator speeds can be accomplished through use of flow control valves. Non-compensated flow control valves are used where precise speed control is not required because the flow rate varies with pressure drop across a flow control valve.

**Note**: *Valve can be hydraulic and pneumatic*

- **Topic 1: Directional control valves types**

**PNEUMATIC AND HYDRAULIC VALVES**

✓ **Pneumatic valves**

1. Air control valves

- **The main functions of Air control valves are:**
  i. To start and stop pneumatic energy
  ii. To control the directional flow of compressed air
  iii. To control the flow rate of the compressed air
  iv. To control the pressure rating of the compressed air
- **Types of Air control valves**

Pneumatic valves can be classified in many ways

2. **Classification of DCVs Based on the main function**

1. DCVs can be classified as follows:
   - Check valves.
   - Shuttle valves.
   - Two -way valves.
   - Three-way valves.
   - Four-way valves.
2. Pressure control valves
3. Flow control valves

3. **Classification based on their construction**

- Poppet (or seat ) type valve
- Sliding spool type valves
- Rotary spool type valves

Now we shall see some important air control valves in the following sections

a. **Check valves**

- Check valves are the most commonly used and the simplest type of directional control valves
- **Functions**: The check valves are used :
  - **i.** To allow free flow of compressed air in only one direction.
  - **ii.** To prevent any flow of compressed air in the opposite direction
- Since check valves block the reverse flow of the fluid, they are also known as **non-return valves.**

**Construction and operation**

The sectional view and ANSI symbol of pneumatic check valves are shown in figure below:

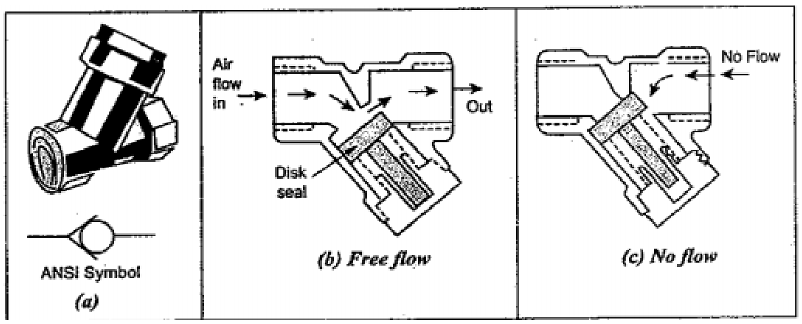



Figure: Pneumatic check valve

As shown in fig (b), when flow is in the forward direction, the compressed air pressure pushes the disk seal and thus the valve allows free flow. Instead, if flow is attempted in the opposite direction as shown in fig(C), the compressed air pushes the disk seal in the closed position. Hence no flow is permitted in opposite direction.

**1. Directional control valves**

- As the name suggests, the function of a directional control valve (DCV) is to control the direction of flow in a pneumatic circuit.
- The DCVs are used to start, stop and regulate the direction of air flow and to help in the distribution of air in the desired line.
- DCVs can be classified in many different ways

**1. Based on the construction**

- Poppet (or seat ) type valve
- Sliding spool type valves
- Rotary spool type valves

**2. Based on the number of ports present:**

- Two -way valves.
- Three-way valves.
- Four-way valves

2. **Two – way valves**

Basically two-way valve is an **on-off** type valve. This 2/2 way has two ports (a supply port and exhaust port) and two position (open and closed). As shown in fig below, 2/2 way valve is available to operate either normally open or normally closed conditions.

A normally open two-way valve (fig (a)) permits flow in its normal or in its rest position and blocks flow when actuated. The normally closed valve (fig (b)) block flow in its normal position and permits flow when actuated. These valves have long life and can be used to handle dry and lubricated air.

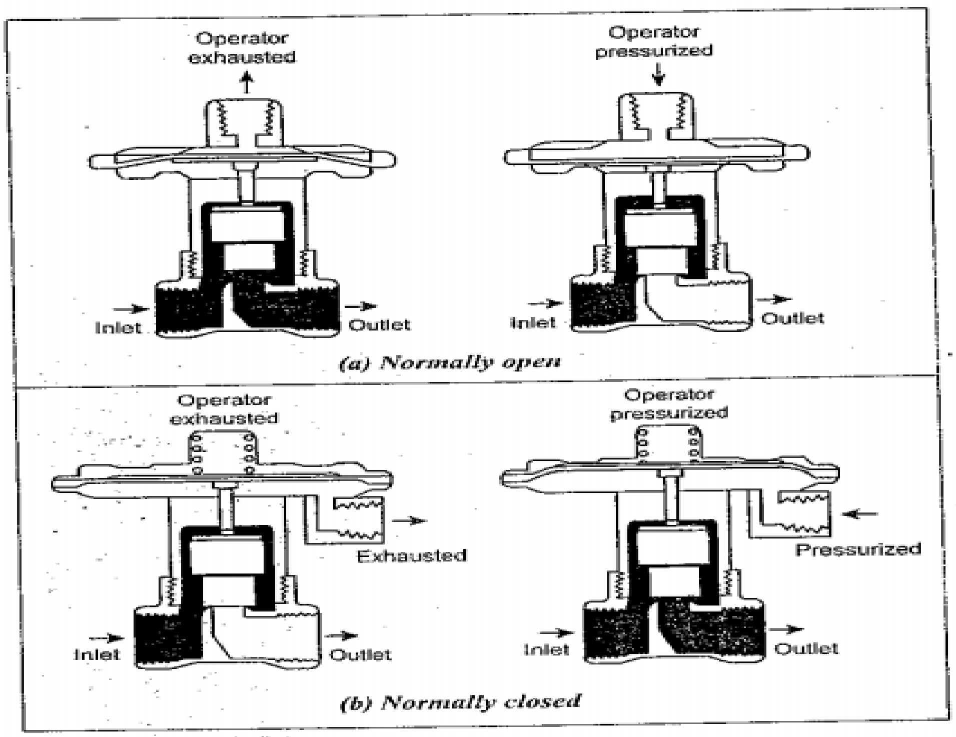



Figure: Two-way valves

### 3. Three - way valve

The three- way type valves have three ports: An inlet, an exhaust and a cylinder port

As could seen from fig (a) below one flow port is connected to either of the other two ports .This valve may also be used to pressurize one port and exhaust the other port. Thus these valves can be used as a pilot relay to operate the other valves.

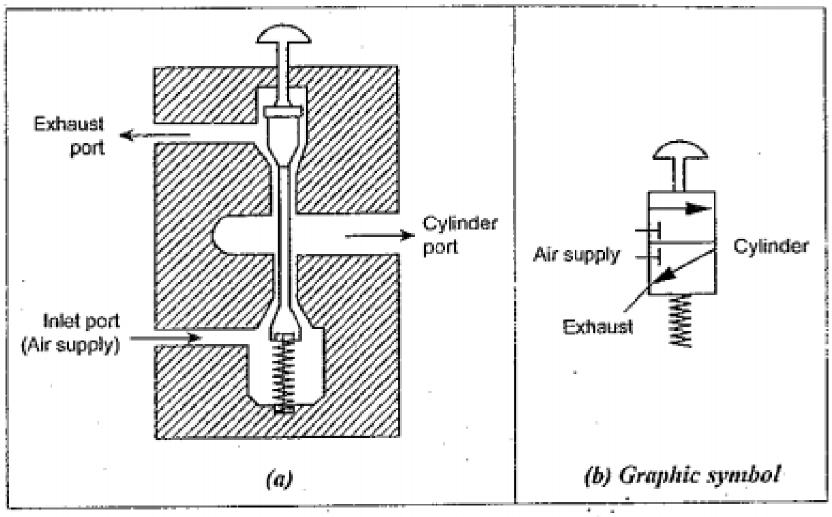



Figure: 3/2 way DC valve

### 4. Four – way valves

The four way type valves have four ports: An inlet; an exhaust, and two cylinder ports.

The construction and operation of a typical valve- seat type four-way two- position (i.e, 4/2)

Pneumatic valve is illustrated in fig (a), fig (b) below shows the graphic symbol of the 4/2 way valve.

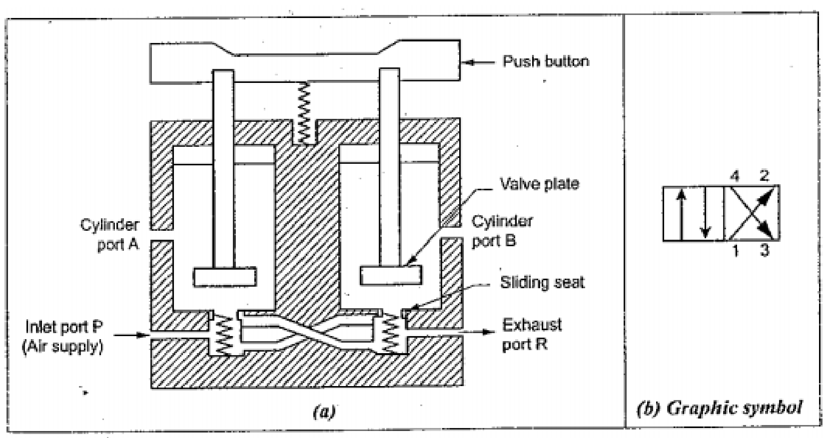



*Fig. 4/2 way DC valve*

As shown in figure, the inlet port P connects to cylinder ports A and B to exhaust port R .

When the valve elements are actuated by means of the push button, they are unseated and port P connects to cylinder ports B and A to exhaust port R.

**Notes:** Generally two way DC valves are used as an-off type valves; Three way DC valves are used to control single-acting linear actuators and Four way DC valves are used to control double-acting actuators.

### 5. Shuttle valves

- Shuttle valves also known as **double check valves**, are used when control is required from more than one power source.
- In other words, shuttle valves are used to select the higher of the two input pressures automatically and connect to output port. This valve is also known as '**ORGATE'**

The construction and operation of a typical three port spool-type shuttle valve is illustrated in fig(a) below. The alternative ball-type shuttle valve for the same purpose is shown in fig (b) below.

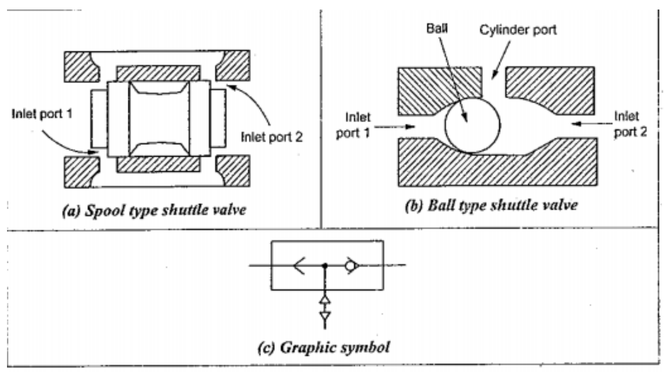



*Fig. Shuttle valve*

As shown in fig (a) and (b), this valve consists of two inlet ports and one outlet port. As long as pressure in the right inlet port is greater than the left, the spool (or ball) closes the left port. When pressure at the left port becomes greater than at the right , the spool (or ball) moves to the right , closing the right port and opening the left.

### 6. Quick exhaust valve

- A quick exhaust valve is a typical shuttle valve. The quick (or fast) exhaust valve is used to exhaust the cylinder air to the atmosphere quickly.
- It is basically used with spring return single – acting pneumatic cylinders to increase the piston speed of cylinders
- The construction and operation of a typical quick exhaust valve is shown in fig below. It consists of a movable disc and three ports- an inlet port (P), and exhaust port(R), and a cylinder port (A). Its working principle is very much similar to that of a shuttle valve.

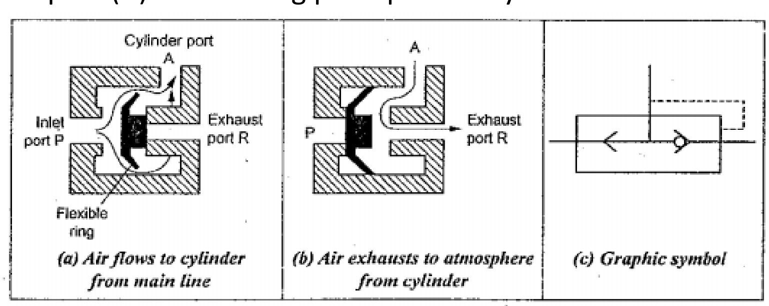



*Fig. Quick exhaust valve*

When the air flowing to the cylinder from the DC valve is applied at port P, then the flexible ring covers the exhaust port R , whereby the compressed air passes from port P to the cylinder through port A (fig a).

But the return air from the cylinder pushes the flexible ring to cover the inlet port p, whereby the exhaust air immediately expelled to the atmosphere (fig b). Thus the resistance to piston movement is reduced considerably and the speed of the piston in the cylinder is accelerated proportionately.

4. **Pressure regulating valves**

- ✓ As the name suggests, *the pneumatic pressure regulator is used to supply a prescribed reduced outlet pressure in a pneumatic circuit and to maintain it at a constant value.*
- ✓ Usually these pneumatic pressure regulators are installed at the inlet of the each separate pneumatic circuit. Sometimes they are installed within a circuit to provide two or more different pressure levels for separate portions of the circuit.

5. **Flow control valve**

- *Flow control valves also known as* ***volume – control valves,*** *are used to regulate the volumetric flow of the compressed air to different parts of the pneumatic system.*
- The construction and operation of a typical spring –loaded disk flow control valve is illustrated in figure below:

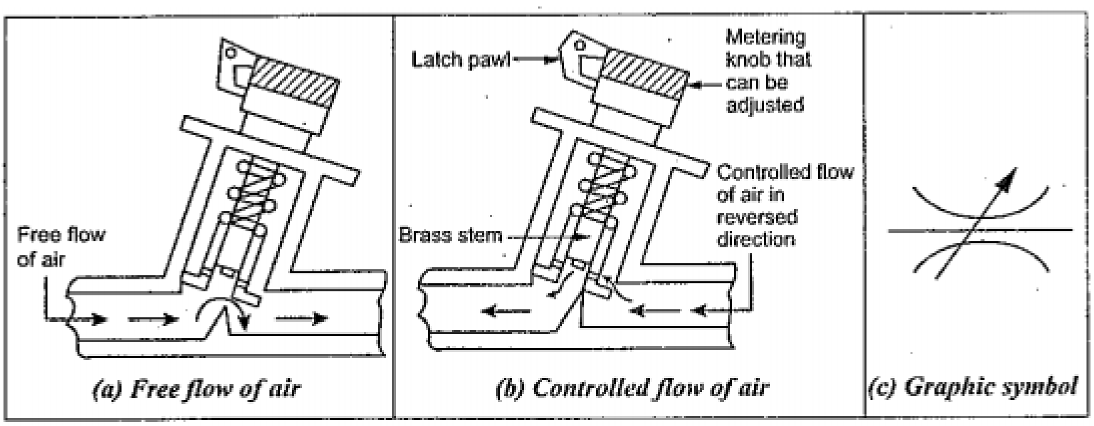



*Figure: Flow control valve*

As shown in figure (a) and (b), the spring loaded disk allows free flow in one direction and an adjustable or controlled flow in the opposite direction. A tapered brass stem controls the adjustment by controlling the flow through the cross hole in the disk.

### 2.2. Hydraulic valves

**What are hydraulic valves?**

- Hydraulic valves are devices used to control pressure, flow direction ,or flow rate in hydraulic circuits

- These control valves utilize mechanical motion to control the distribution of hydraulic energy within the system.

### 2.2.1. Types of control valves

Control valves are classified into three basic types, based on their function in the hydraulic system. They are:

1. Directional control valves
2. Pressure control valves
3. Flow control(or volume control) valves

### 2.2.2. Valves configuration

There are essential types of control valves based on their configuration or modes of operation .They are:

- Poppet (or seat ) valves
- Sliding spool valves, and
- Rotary spool valves

Let see a brief understanding before discussing the construction and operation of different types of control valves

### 2.2.3. Poppet (or seat ) valves

- **Construction and operation**

The most common form of poppet valve is shown on the figure below. Normally this valve is in the closed condition and hence there is no connection between port 1 and port 2. In the poppet valves, balls, discs or cones are used to control the flow.

When the push button is depressed, the ball is pushed out of its seat and hence the flow is permitted from port 1 to port2. When the push button is released, spring and fluid pressure force the ball back up against its seat and so closes off the flow.

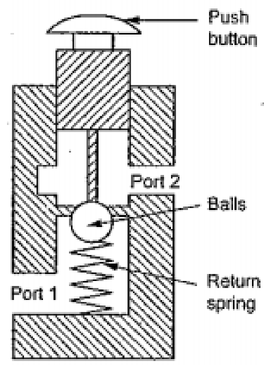



Figure: Poppet seat

- **Advantages of poppet seat**

Poppet valves exhibit the following advantages:

i. Simple design
ii. Less expensive
iii. Very robust
iv. Less sensitive to fluid contamination

- **Disadvantages of poppet valves**

  The force required to operate the poppet valves are more. Therefore they are suitable mostly for low pressure applications.

- Application **of poppet valves**

Poppet valves are essentially two-way valves. Therefore they are limited to :

i. Applications in which flow reversal is not required .e.g: check valves and relief valves ,and
ii. Low- power applications because of their relatively high leakage rate

### 2.2.4. Sliding spool valves

The sliding- spool valves are the most frequently used type in hydraulic systems

- Construction and operation

A spool moves horizontally within the valve body to control the flow. The raised areas called 'land' block or open port to give the required operation.

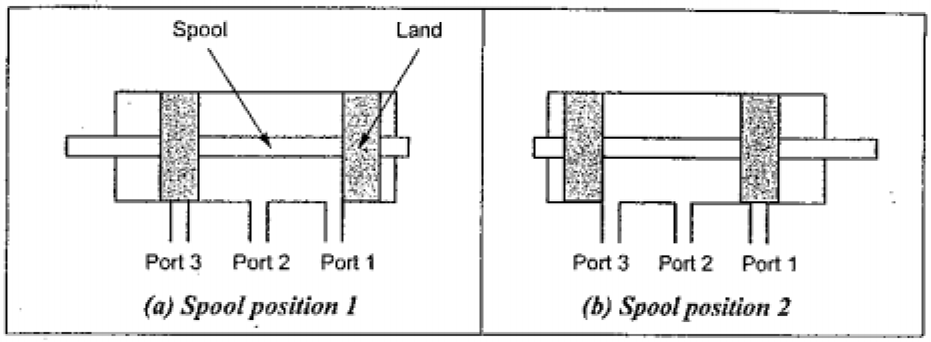



Figure: construction and operation of sliding –spool valve

In fig(a),the fluid supply is connected to port 1 and now port 3 is in closed position. Thus the flow is permitted from port 1 to port 2. In fig (b) , when the spool is moved to the left, the fluid supply is cut off and port 2 is connected to port 3. Thus the flow is permitted from port2 to port 3.

- **Advantages of sliding –spool valves**

**i.** Different operations can be achieved with a common body and different spool.
**ii.** Reduced manufacturing cost
**iii.** Reduced fluid leakage rate
**iv.** All types of actuation are easily adaptable
**v.** They are used for high pressure applications

### 2.2.5. Rotary spool valves

Rotary spool valves have a rotating spool which aligns with holes in the valve casing to give the required operation.

- Construction and operation

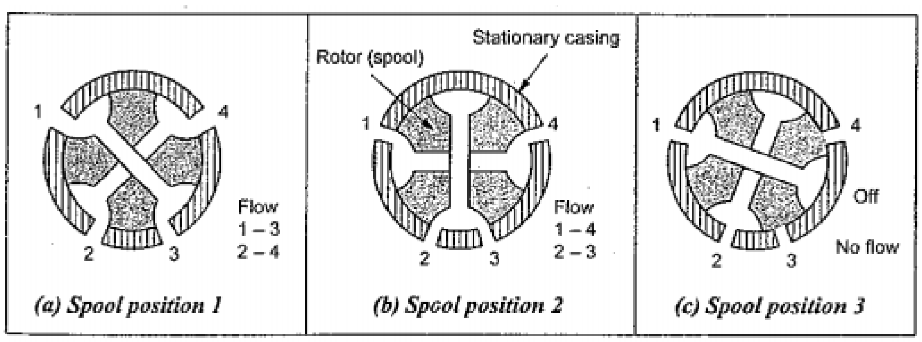



Figure: Construction and operation of a rotary-spool valve

The figure above illustrates the construction and operation of a typical rotary spool valve, with centre off action. When the spool rotates, it opens and closes port and subsequently allows and prevents the fluid flow through those ports.

The figure has four ports 1, 2, 3, and 4. For the position of spool as in fig (a), the flow is permitted from port 1 to port 3, and from port 2to port 4.

When the spool rotates to a position as shown in fig (b), the flow is permitted from port 1 to port 4, and from port 3 to port 3. For the spool position shown in fig(c), there is no fluid flow as all the four ports are blocked.

- **Advantages of rotating spool valves**
  i. They are simple and compact in design and operation
  ii. They have low operating forces
  iii. They are widely used for low pressure applications

### 2.2.6. Directional control valves

- As the name suggests, the function of a directional control valve (DCV) is to control the direction of flow in a hydraulic circuit.
- The DCVs are used regulate the direction in which the fluid flows in a hydraulic circuit.

The function of a DCV is to control the direction of fluid flow in any hydraulic system. A DCV does this by changing the position of internal movable parts. To be more specific, a DCV is mainly required for the following purposes:

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

Any valve contains ports that are external openings through which a fluid can enter and exit via connecting pipelines. The number of ports on a DCV is identified using the term "way." Thus, a valve
with four ports is a four-way valve A DCV consists of a valve body or valve housing and a valve mechanism usually mounted on a sub-plate.

The ports of a sub-plate are threaded to hold the tube fittings which connect the valve to the fluid conductor lines. The valve mechanism directs the fluid to selected output ports or stops the fluid from passing through the valve.

- **Classification of Directional control Valves**

The directional control valves can be classified in many different ways

I. The directional control valves are basically classified, according to the construction DCVs are classified into three groups, as:
   - Poppet (or seat ) valves
   - Sliding spool valves, and
   - Rotary spool valves

II. Based on the number of ports present, DCVs may be classified as:
   - Two way valves
   - Three way valves, and
   - Four way valves

III. Based on mode of actuation, the directional control valves can be classified as:
   - Manually operated DCVs
   - Mechanically operated DCVs
   - Solenoid operated DCVs
   - Pilot operated DCVs

IV. However for our study we can classify the directional control valves into three:
   - Check valves
   - Position valves, and
   - Shuttle valves

Now, we shall discuss the construction and operation of some of the important directional control valves in the following sections.

2.2.6.1. Check valves (or two way valves)

a. Introduction

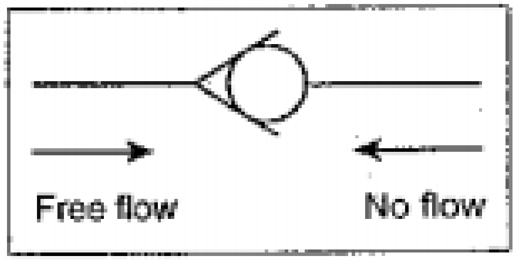
- Check valves are the most commonly used and the simplest type of directional control valves
- The check valve is a **two- way valve** because it contains two ports. Also a check valve is analogous to a diode in electric circuits
- **Functions :** The check valves are used:
   i. To allow free flow in only one direction , and
   ii. To prevent any flow in the other direction
- Since check valves block the reverse flow of fluid, they are also known as **non-return valves**
- The symbolic representation of a check valve, is shown on the figure below and illustrates its function clearly.

b. Types of check valves

Check valves are of several types. But the two important types of check valves are:

1. Poppet-type check valves, and

2. Pilot-operated type check valves




*Symbolic representation of a check valve*

c. Poppet-Type (or Simple) check valves

- **Construction and operation**

The construction and operation of a typical poppet type check valve is illustrated in figure below. Normally a spring holds the poppet in the closed position.

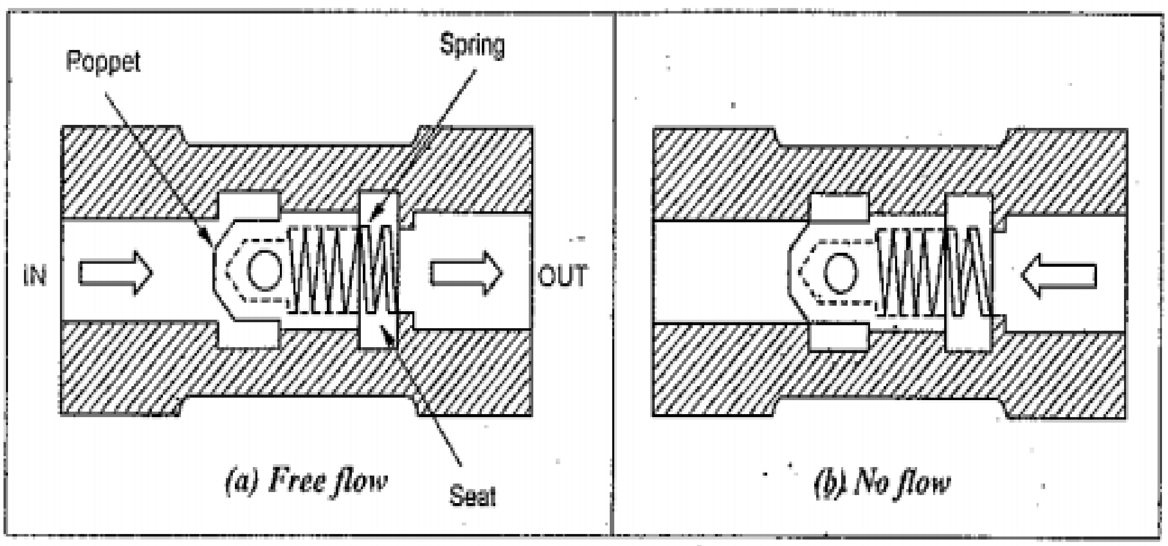



Figure: construction and operation of a poppet-type check valve

When flow is in the normal direction, the liquid pressure acts against the spring tension to hold the poppet offset the seat. When the liquid pressure overcomes the spring force, as shown in fig (a), the valve allows the free flow. When flow stops, the spring seats the poppet and liquid cannot pass in the reverse direction.

Instead, if flow is attempted in the opposite direction as shown in fig (b), the liquid pressure along with the spring force pushes the poppet in the closed position. Hence no flow is permitted in opposite direction.

- **Applications of simple check valves**

Usually poppet type check valves are used to provide the pilot pressure to operate larger valves.

### 2.2.6.2. Pilot – Operated check valves

The piloted operated check valve allows free fluid flow in one direction, but reversed flow depends upon the pilot actuation. That means, this type check valve also allows the reverse flow, provided pilot pressure is applied at the pilot pressure port of the valve to overcome the spring force of the poppet.

a. Construction and operation

   First the free flow in the normal direction from port A to port B is achieved in the usual manner. But the reverse flow is blocked as the fluid pressure pushes the poppet into the closed position.

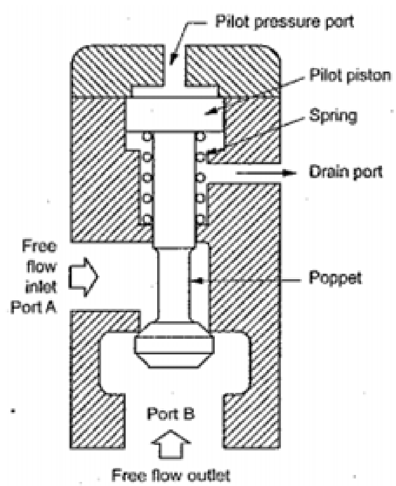



Figure: Pilot-Operated check valve

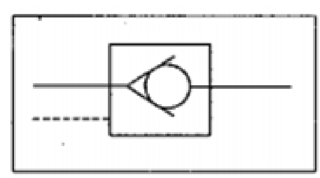


Fig: Symbol of a pilot-operated check valve

In order to permit the fluid flow in the reverse direction i.e. from port B to port A, a pilot pressure is applied through the pilot pressure port. The pilot pressure pushes the pilot piston and the poppet down. Thus the fluid flow in the reverse direction is also obtained. The purpose of the drain port in the circuit is to prevent oil from creating a pressure build up on the bottom of the pilot piston.

**Note:** *The dashed line presents the pilot pressure line*

b. Applications of pilot-Operated check valves

The pilot – operated check valves are widely used to hydraulically lock the cylinders such as in a hydraulic jack.

2.2.6.3. Position valves

a. Introduction

- The function of the position valve is to control the introduction of fluid to the lines of the system. When the valve is operated, the liquid lines within it are shifted
- The position valves are usually described by the following relation:
  (Number of ports/Number of positions) valve

For example a 4/2 valve has 4 ports and 2 positions

The ports of a directional control valve are designed by letter, as listed in table below

| Ports | Designation |
|---|---|
| Working lines | A, B, C, and so on. |
| Pressure (power) supply | P |
| Return/Exhaust lines | R, S, T and so on. (Normally T for hydraulic systems, R and S for pneumatic systems.) |
| Control (pilot) lines | Z, Y, X, and so on. |

Table: Ports' designations

b. Valve position

✓ A direct control valve has two or three working positions generally. They are :

1. Normal or zero position or neutral position.
2. Working positions (such as retract and extend positions).

✓ It is necessary to differentiate between neutral and operating positions. In directional control valves with spring return, the neutral position is defined as the position to which the valve returns after the actuating force has been withdrawn.

✓ In all fluid control systems, the valve positions can be represented by letters $a$, $b$, $c$, and so on, with '0' being used for central neutral position.

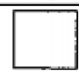
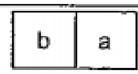
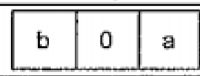
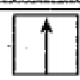
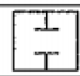
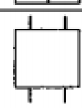
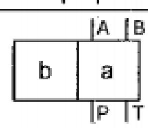
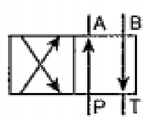
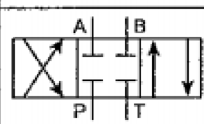
✓ The starting (or initial) position is the position taken up by the valve (due to spring in case of spring actuated directional control valve) after installation. The valve attains the working positions when actuated.

c. Valve symbols

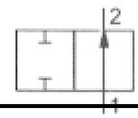
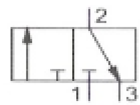
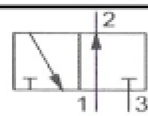
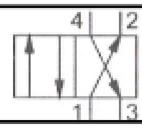
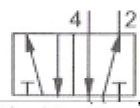
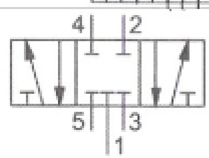
For representing valves in circuit diagrams, symbols are used. Generally a valve is represented by a square for each of its switching positions. Two positions are represented by two adjacent squares. It should be noted that symbols show only the functional aspect of the valve and not its principle of design or constructional details.

The basic valve symbols and their description are presented in Table

***Table Basic valve symbols and their description***

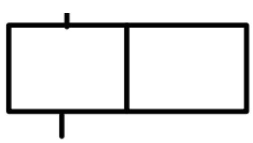
| | Valve symbol | Description |
|---|---|---|
| Valve position |  | A valve position is represented by a square. |
| Two position valve |  | A number of squares is equal to the number of distinct positions that the valve can take up. Therefore the figure shows the two position valve. |
| Three position valve. |  | Three adjacent squares indicate the three position valve. |
| Flow path |  | Inside a square, the line indicates the flow and the arrow the direction of flow. |
| Flow shut off |  | Cut-offs of fluid flow are shown by short transverse lines inside the square. |
| Initial convections |  | The ports of a valve are added on the outside of the square box. The connections to inlet and outlet ports are drawn only to a initial (or neutral) position. |
| 4/2 valve . |  | Figure shows the 4 ports (A, B, P and T) and 2 positions (*a* and *b*) valve. |
| 4/2 valve |  | In position '*a*', the fluid is delivered from port P to port A and returned from port B to port T.<br>In position '*b*', flow is reversed, *i.e.*, the fluid is delivered from port P to port B and returned from port A to port T. [*Note :* Here ports are drawn only to the initial position. For the other position, readers should mentally identify the ports.] |
| 4/3 valve |  | Figure shows a 4 ports and 3 positions valve.<br>In position '*a*', the fluid is delivered from port P to port A and returned from port B to port T.<br>In position '0', the load is in the off (or neutral) position. Since all A, B, P and T ports are blocked, therefore no fluid flow.<br>In position '*b*', the flow is reversed.<br>[*Note :* Here ports are shown only to the neutral position; for other two positions, readers should mentally identify the ports.] |

***Note*** The above valve symbols are to be used in hydraulic circuits. The corresponding symbols having unfilled arrow heads can be used in pneumatic circuits.

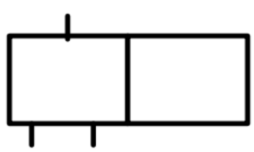
| SYMBOL | EXPLANATION |
|---|---|
|  | 2/2 - way directional control valve, normally open |
|  | 3/2 – way directional control valve normally closed |
|  | 3/2 – way directional control valve, normally open |
|  | 4/2 – way directional control valve Flow from 1 to 2 and from 4 to 3 |
|  | 5/2 – way directional control valve Flow from 1 to 2 and 4 to 5 |
|  | 5/3 – way directional control valve Mid position closed |

**d. Valve Ports**

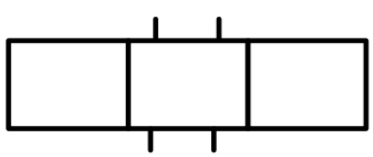
Every valve port, which appears on the outside of the valve, is supposed to be shown on the symbol. But the ports are shown on only one of the boxes, the box that represents the flow paths that exist at the start of the machine cycle. Some examples are:



A 2-position 2-port valve



A 2-position 3-port valve



A 3-position 4-port valve

**e. Classification of position valves**

Position valves are classified in terms of the number of fluid ports and the number of valve positions, as:

- Two way, two position valves (2/2 valves)
- Three way, two position valve(3/2valve)
- Four way, two position valves (4/2 valves)
- Four way , three position valves (4/3 valves), and so on

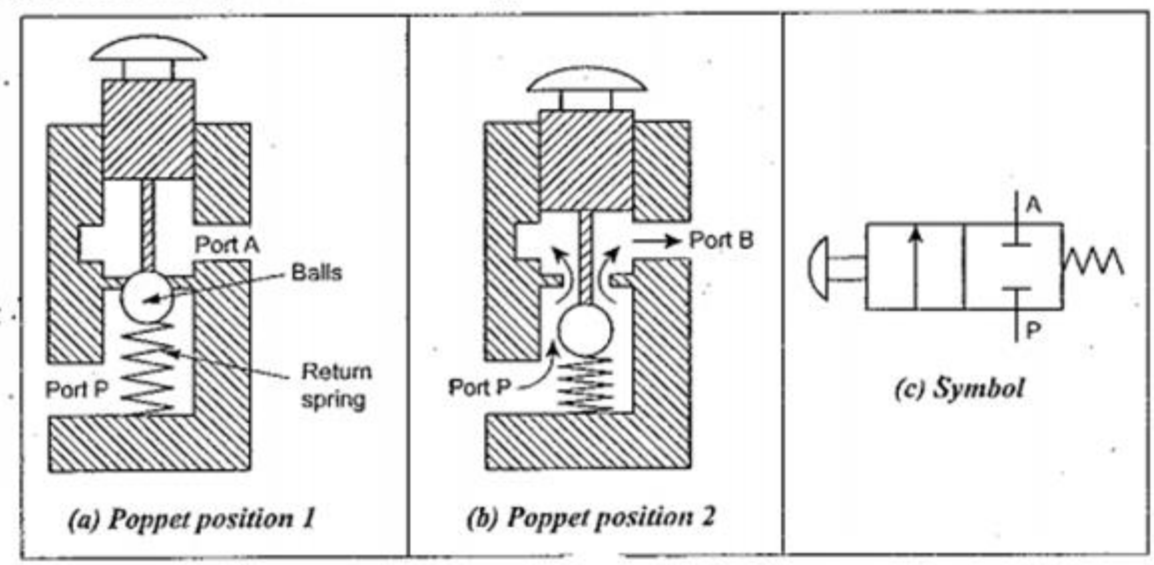
➢ **Two position valves**

**2/2 Directional Control Valves**

The 2/2 valves have 2 ports and 2 positions.

**Construction and Operation**

The poppet-type check valve illustrated in Fig is a typical 2/2 valve. However, the construction and operation of a similar type 2/2 DC valve




*Operation of a 2/2 DC valve*

***Position 1 :*** When the push-button is in normal position, spring and fluid pressure force the ball up, therefore the flow is blocked, as shown in fig(a)

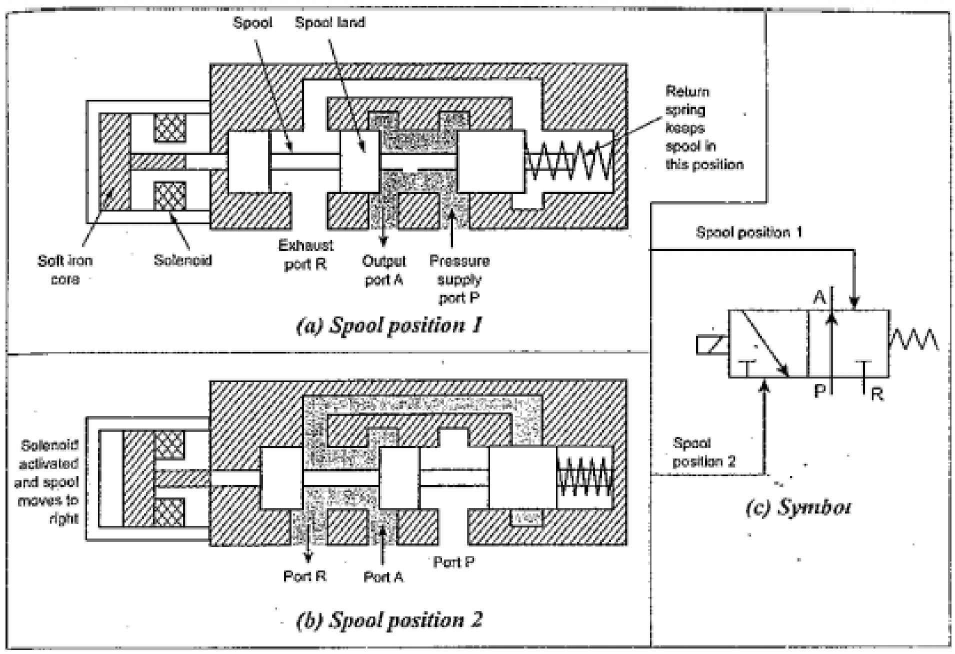
***Position 2 :*** When the pressure of the push-button pushes the ball off its seat, then the flow is permitted from port P to port A. as shown in fig(b)

## ➢ 3/2 DCVS

The 3/2 valves have 3 port and 2 positions

### Construction and Operation

The construction and operation of a typical sliding-spool type, solenoid-actuated 3/2 DC valve is illustrated in Fig ure . It has three ports or openings : pressure supply port (P), output port (A), and exhaust port (R).




*Construction and operation of a solenoid-actuated 3/2 valve*

As shown in Figure :(*a*) and (*b*), the valve is actuated by a current passing through a solenoid and, returned to its original position by a spring. The spool slides over the finely finished valve bore inside the valve housing.

***Spool position 1 :*** In the original or neutral position of the spool, (Figure :(*a*)), the pressurized fluid flows from port P to port A to move the actuator, the exhaust port (R) remaining closed.

***Spool position 2 :*** When the solenoid is activated (Figure t(*b*)), the spool moves to the extreme left. In the extreme spool position, the fluid from port P gets closed and hence the fluid is permitted to flow from port A to port R.

Thus the valve alternately connects and disconnects fluid supply to the cylinder by the sliding spool.

### -Graphic Symbol

Figure :(*c*) shows a graphic symbol of a solenoid actuated, spring return 3/2 valve, illustrating the above operation.

### ➢ 4/2 DCVs

The 4/2 valves have 4 ports and 2 distinct positions

The construction and operation of a typical sliding-spool type 4/2 DC valve is illustrated in Figure : It has four ports or openings, P, A, B, and T.

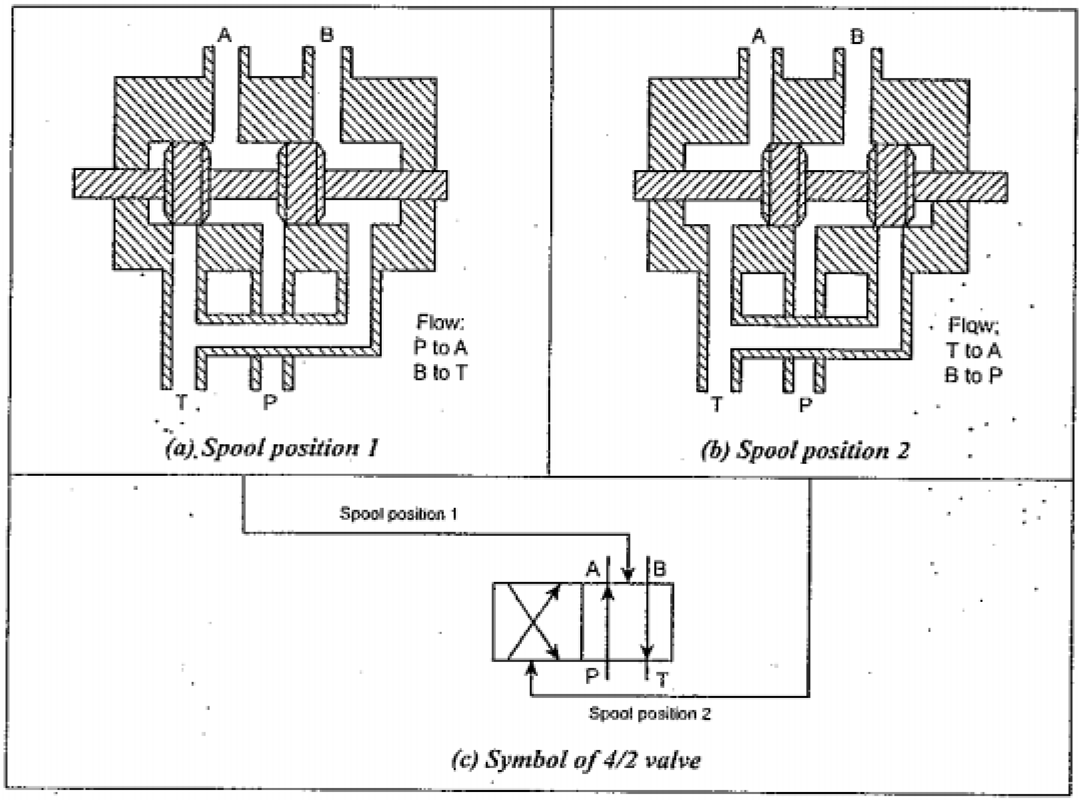



*Figure : Operation of a 4/2 DC valve*

***Spool position 1 :*** When the spool is in position as shown in Figure :(*a*), the fluid can flow from port P to port A and return from port B to port T.

***Spool position 2 :*** When the spool is in the position as shown in Figure :(*b*), the fluid can flow from port T to port A and return from port B to port P.

The graphical symbol is represented on fig(c)

### ➢ Three position valves

The 4/3 directional control valves have 4 ports and 3distinct positions. This valve also has four ports P, A, B and T.

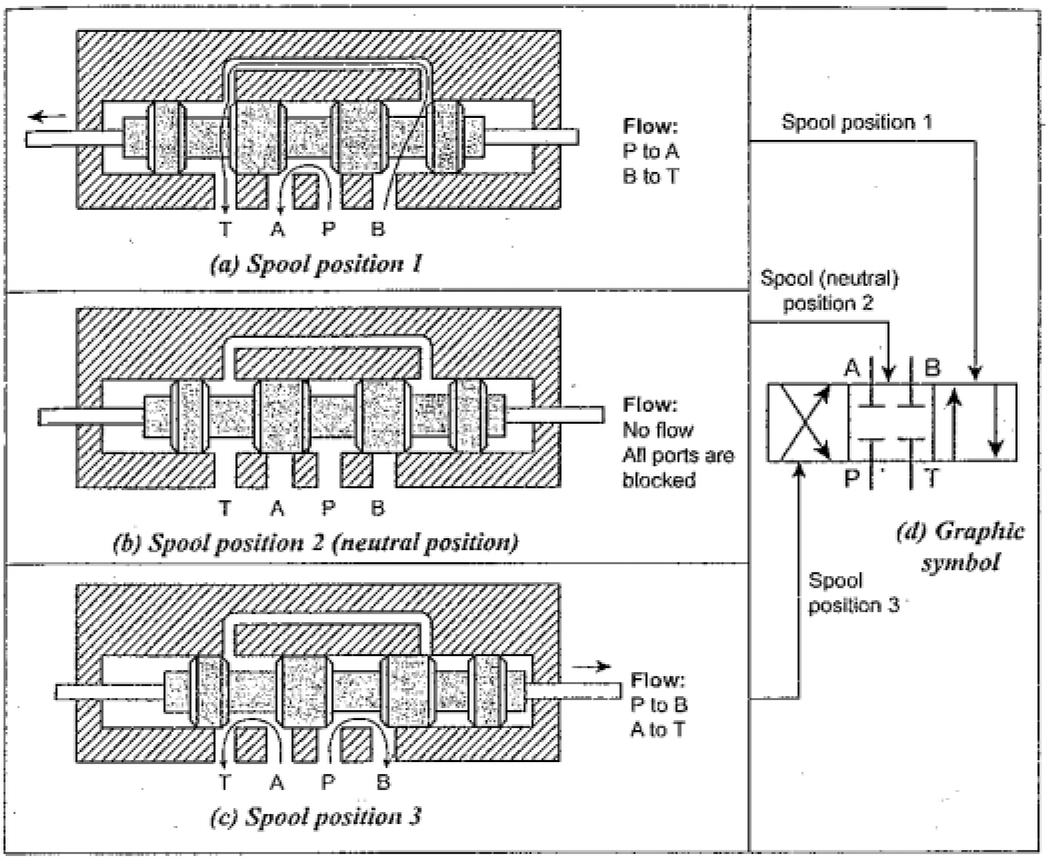



Figure: operation of a 4/3 DC valve

***Spool position 1 :*** For the spool position shown in Figure : (*a*), the fluid can flow from port P to port A and return from port B to port T.

***Spool position 2 :*** During the neutral position shown in Figure : (*b*), all the ports are blocked.

***Spool position 3 :*** For the spool position shown in Figure :(*c*), the reverse flow is permitted. *i.e.*, fluid can flow from port P to port B and return from port A to port T.

- **Graphic Symbol**

Figure : (*d*) represents the graphic symbol for the above 4/3 DC valve.

- **Centre Flow Configurations for Three-Position, Four-Way Valves**

As we discussed, the two extreme positions of a 4/2 control valve controls the two extreme direction of motion of fluid. In 4/3 valves, the third position usually is an intermediate or a centre position. Varieties of centre positions are possible in 4/3 DC valves by suitably designing the spool. Figure : illustrates some of the widely used centre flow path configurations for 4/3 valves.

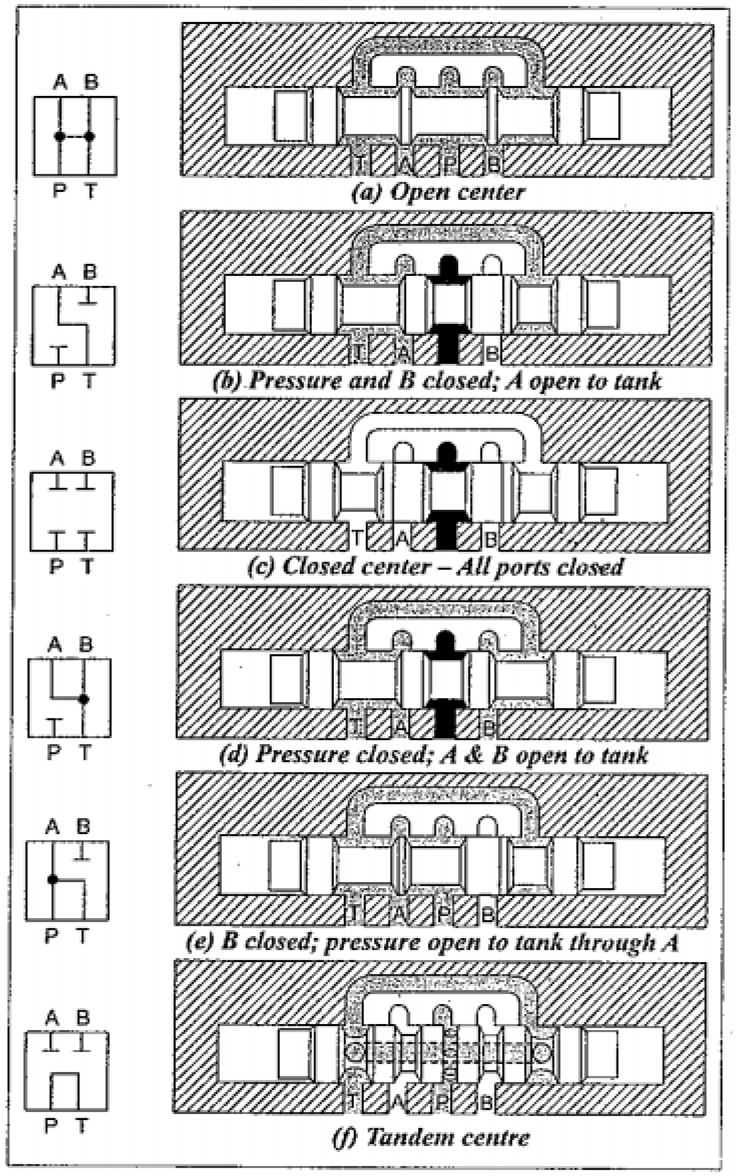



Figure: Various center flow paths for the three- position, four-way valves

These centre positions are briefed below :

**1. Open Centre :** ✓ In open centre type, all ports of the valve P, A, B, and T are open to each other, as shown in Fig(a)

- ✓ ***Advantage :*** As soon as the cylinder completes its cycle, the open centre DC valve allows the pump flow to return to back the tank (reservoir) at a minimum pressure. This prevents unnecessary heat build-up in the system.
- ✓ ***Disadvantage :*** When the valve is centred, no other cylinder can operate. Therefore, open-centre type valve is used mostly for a single cylinder or single motor circuit.

**2. Closed Centre :** ✓ In closed centre type, all the ports P, A, B, and T are blocked to each other, as shown in Figure : ($c$).

- ✓ ***Advantage :*** The closed centre type valve can use the pump flow for other parts of the circuit. Therefore closed typed valves are used when multiple functions are to be accomplished from one source.
- ✓ ***Disadvantage :*** When the valve is in closed centre position, the pump flow cannot be unloaded to the tank. So the hydraulic cylinder or fluid motor cannot be moved.

**3. Tandem Centre :** ✓ The tandem centre type valve, as shown in Figure : ($f$), directs the pump flow out of the reservoir port T with the other two working ports A and B closed when in the centre position.

- ✓ ***Advantage :*** Like open centre valve, this type valve also unloads the pump at essentially atmospheric pressure. The application of this design is to permit the flow to be connected to a series of valves for multiple circuits.
- ✓ ***Disadvantage :*** When a number of cylinders are operated from a single source, the pressure differential for each tandem centre valve will be 3 to 4 bar each while the valve is in its centre position.

**4. Floated Centre :** ✓ The floated centre type valves allow independent operation of cylinders connected to the same power source, as shown in Figure : ($b$), ($d$), and ($e$).

- ✓ ***Advantage :*** This type does not build up any pressure in the cylinder lines. Therefore, there will not be any drifting of cylinders during this condition.
- ✓ ***Disadvantage :*** The load cannot be locked in this position during the neutral position.

### - Applications of Position Valves

- ✓ ***Two way directional valves*** are generally used as shut off valves. Unlike a check valve, the two-way valve can block flow in both directions.
- ✓ Generally ***three way directional control valves*** are used to control single-acting linear actuators.
- ✓ The ***four way directional control valves*** are used to control double-acting actuators.
- ✓ A ***three-position valve*** can be used : ($i$) to isolate an actuator from the circuit, ($ii$) to provide a bypass to the reservoir around the actuator, or ($iii$) to hold an actuator in an intermediate position.

### - Specification of Directional Control Valves

The DC valves are usually specified by the following parameters :

1. Rated flow,
2. Rated pressure,
3. Outlet and inlet port size,
4. 3 way or 4 way spool,
5. Open or closed centre application,
6. Spring centred or not,
7. Solenoid type and power, *etc.*

## 2.2.7. Pressure control valves

✓ As the name suggests, *pressure control valves are the devices used to control the fluid pressure in a system.*

✓ ***Functions :*** The pressure control valves perform one or more of the following functions :

(*i*) To limit the maximum pressure in various circuit components as a safety measure.

(*ii*) To maintain the desired pressure levels in various parts of the circuits.

(*iii*) To unload system pressure, *i.e.*, to change the direction of all or part of the flow when the pressure at a certain point reaches a specified level.

(*iv*) To assist sequential operation of actuators in a circuit with pressure control.

## Types of Pressure control valves

The important types of pressure control valves and their functions are presented in table

Table: Types of pressure control valves and their functions

| Sl.No. | Type | Function/Description |
|---|---|---|
| 1. | Pressure limiting valve (relief valve) | Relief valve limits the maximum pressure that can be applied to the part of the system to which it is connected. |
| 2. | Pressure reducing valve (pressure-regulator valve) | Pressure reducing valve maintains a prescribed reduced pressure at its outlet regardless of the valve inlet pressure. |
| 3. | Sequence valve | Sequence valve directs flow to more than one portion of a fluid circuit in sequence. |
| 4. | Counterbalance valve (Back-pressure valve) | Counterbalance valve permits free flow in one direction and restricted flow in the opposite direction. |
| 5. | Unloading valve | Unloading valve allows pressure to build up to an adjustable setting, then bypasses the flow as long as a remote source maintains the preset pressure on the pilot port. |
| 6. | Pressure switch | Pressure switch is used when a pressure-actuated electric signal is required for system control. |
| 7. | Hydraulic fuse | ✓ Hydraulic fuse employs a frangible diaphragm, which establishes the maximum pressure in a hydraulic circuit by rupturing at a preset pressure valve.<br>✓ Hydraulic fuse, analogous to an electric fuse, is used to prevent the system pressure from exceeding beyond the allowable limit in order to protect the system components from damage. |

Now we shall discuss the construction and operation of the pressure-limiting, pressure-reducing and sequence valves in details in the following sections.

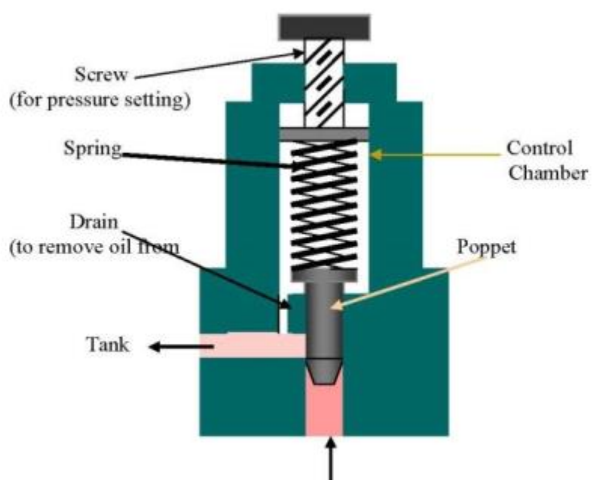
**Note**: It may be noted that relief, sequence, counterbalance, and unloading valves are normally closed valves whereas the pressure-reducing valves are open valves

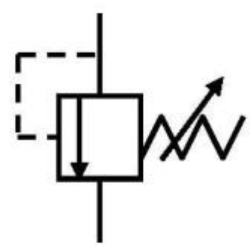
1. **Pressure limiting valve( Relief Valves)**

The pressure relief valve is used to protect the hydraulic components from excessive pressure.

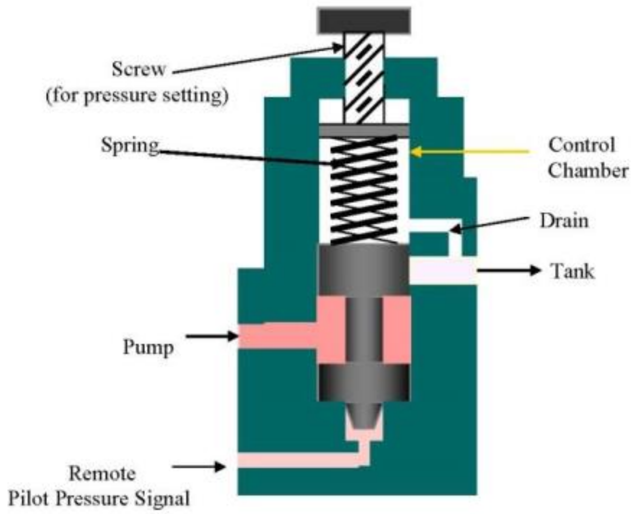
It is one of the most important components of a hydraulic system and is essentially required for safe operation of the system. Its primary function is to limit the system pressure within a specified range. It is normally a closed type and it opens when the pressure exceeds a specified maximum value by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

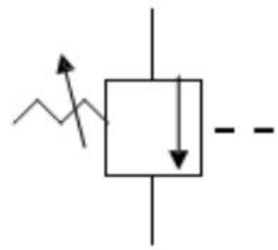
**Pressure Relief Valve:** When the system pressure exceeds a set value, the poppet raises up and allows fluid to flow rank.



2. **Unloading Valve**: An unloading valve is used to permit a pump to operate at minimum load. The unloading valve is normally closed valve with the spool closing the tank port. When a pilot pressure is enough to overcome the spring force, spool moves up and flow is diverted to tank. When the pilot pressure is relaxed, spool moves down and lets the flow to the circuit for operation.



The unloading valve is used in system having one or more fixed delivery pump to control the amount of flow at any given time. A well designed hydraulic circuit uses the correct amount of fluid for each phase of a given cycle of machine operations. When pressure builds up during the feed phase of the cycle, the pilot pressure opens the unloading valve, causing the large discharge pump to bypass its flow back to the tank.

3. **Sequence valve:** A sequence valve's primary function is to divert flow in a predetermined sequence. It is a pressure-actuated valve similar in construction to a relief valve and normally a closed valve. When the main system pressure overcomes the spring  setting, the valve spool moves up allowing flow from the secondary port.

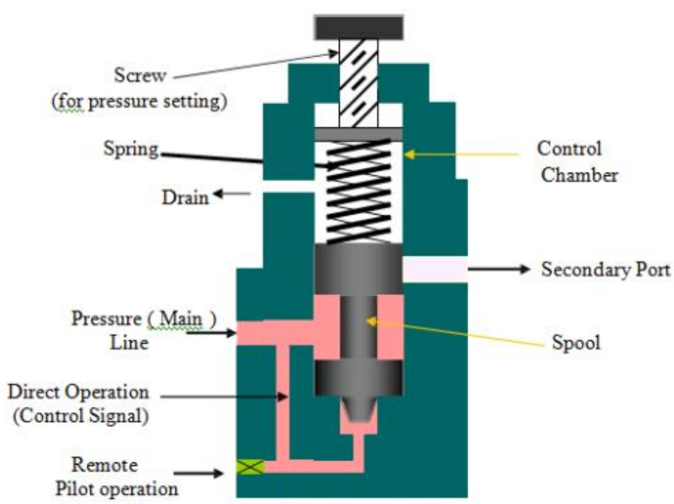
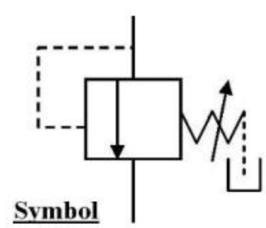
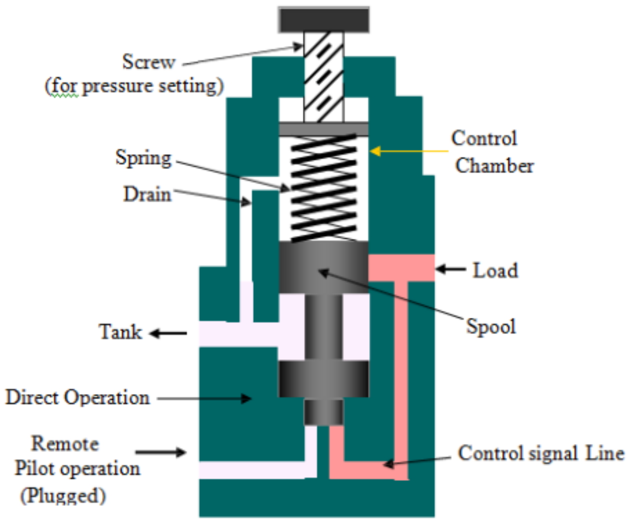


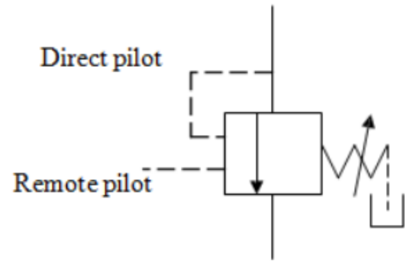

Fig.4.29b. **Sequence valve**



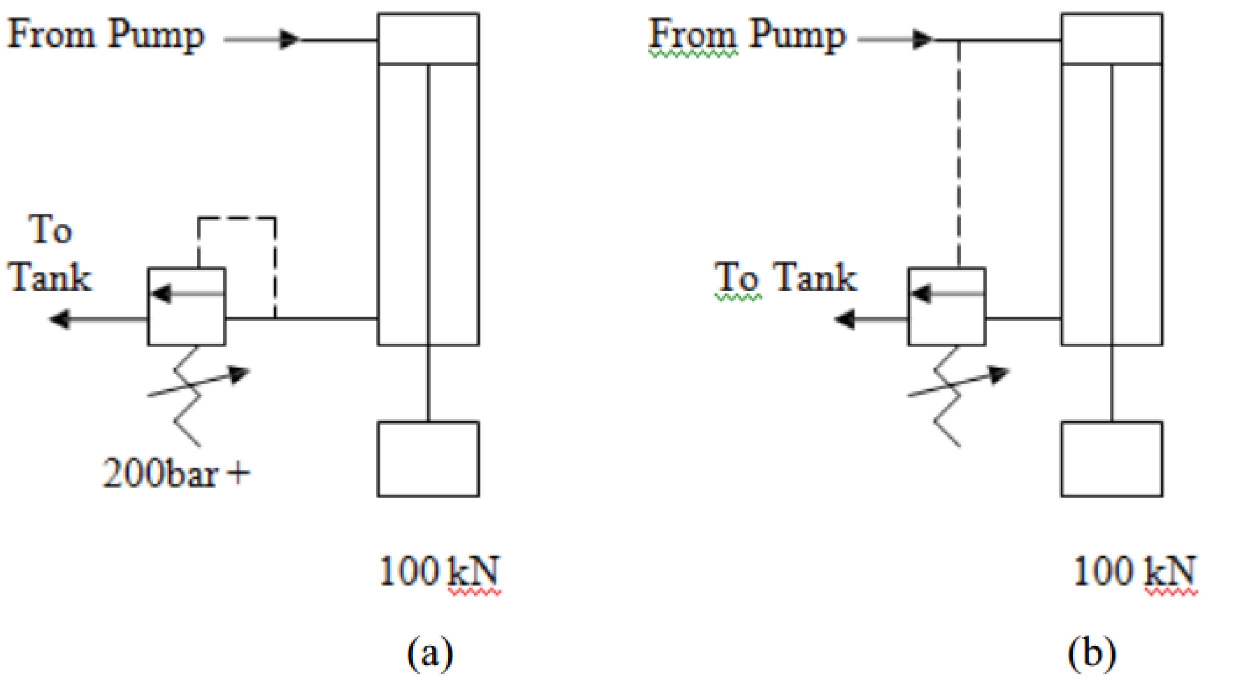

**4.Counter balance Valve**: A C o u n t e r balance valve is used to maintain back pressure to prevent a load from failing. One can find application in vertical presses, lift trucks, loaders and other machine tool that must position or hold suspended loads.



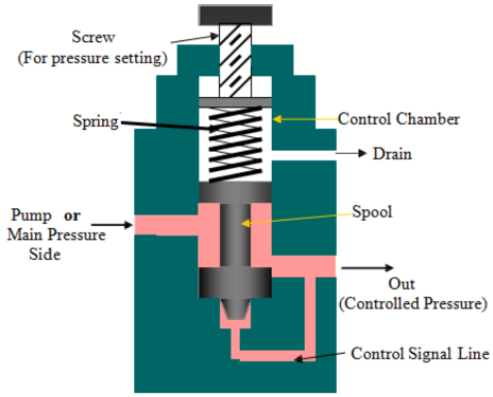

Counter Balance Valve



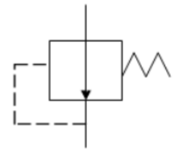

When a counterbalance valve is used on large vertical presses, it may important to analyze the source of pilot pressure. Figures (a) and (b) illustrate the comparison between direct and remote pilot signal.




**5.Pressure Reducing Valve**: Pressure reducing valve is used to limit its outlet pressure. Reducing valves are used for the operation of branch circuits, where pressure may be less than the main system pressure. The pressure reducing valve is normally an open type valve. When the secondary pressure is high, it lifts the spool against the spring force and throttles the flow till such extent that the secondary pressure reaches the value as set by spring.



Pressure Reducing Valve



**Note:**

➢ **Pressure control valves**

Pressure control valves :

❖ Pressure regulating valves- controls the pressure in a control circuit and keeps the pressure constant irrespective of any pressure fluctuations in the system.

❖ Pressure limiting valves are utilised on the up-stream side of the compressor to ensure the receiver pressure is limited, for safety, and that the supply pressure to the system is set to the correct pressure.

❖ Pressure sequence valve senses the pressure of any external line and compares the pressure of the line against a pre-set adjustable value, creating a signal when the pre-set limit is reached.

## FLOW CONTROL VALVES

### What are Flow Control Valves ?

✓ *Flow control valves, also known as **volume-control valves,** are used to regulate the rate of fluid flow to different parts of a hydraulic system.*

✓ Since control of flow rate is a means by which the speed of hydraulic machine elements is governed, therefore flow control valves are also known as ***speed-control valves.***

✓ The flow rate to a particular system component is varied by throttling or by diverting the flow.

### Types of Flow Control Valves

The two basic types of flow control valves are :

1. Non-pressure compensated flow control valves, and
   (*i*) Globe valve, and (*ii*) Needle valve.
2. Pressure compensated flow control valves.

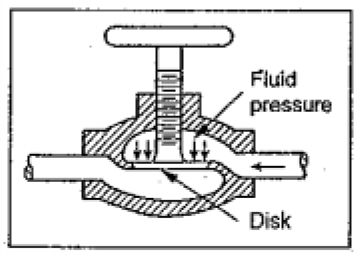
1. **Non-pressure compensated flow control valves**

**1. What are Non-Pressure Compensated Flow Control Valves ?**

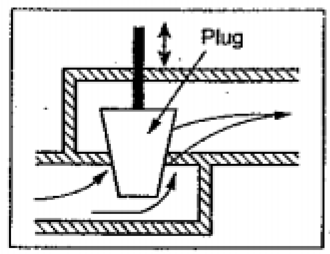
- ✓ The non-pressure compensated type flow control valves are used where system pressures vary considerably and precise flow-rate controls are not required.
- ✓ These valves operate based on the principle that the flow through an orifice will be constant, if the pressure drop remains constant.
- ✓ All the simple valves such as globe, needle, butterfly, gate, and ball valves are non-pressure compensated valves.

- **Globe valve**

In a globe valve , flow rate can be changed by means of disk, plug ,or ball which nests against a seat as shown on figure below




***Disk-type globe valve***




***Plug-type globe valve***

*1. Disk-type globe valve :* Disk-type globe valve, also known as a ***butterfly valve,*** consists of a large disc which is rotated inside the pipe, the angle determining the flow rate, as shown in Fig

*2. Plug-type globe valve :* Plug-type globe valve has a tapered plug that can control the flow rate by varying the vertical plug position, as shown in Fig.

*3. Ball-type globe valve :* Ball-type globe valve has a ball with a through-hole which is rotated inside a machined seat, as shown in Fig.

✓ The needle valve has a pointed stem that can be adjusted manually to control the flow rate of fluid through the valve, as shown in Fig.

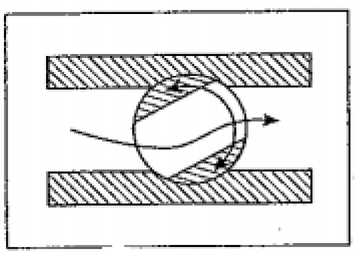
✓ Needle valves have a smaller flow area and higher pressure drop than the globe valve.

### Applications of Non-Pressure Compensated Flow Control Valves

1. The globe valves are used to throttle only in lines where the liquid velocity is relatively low.
2. In comparison to globe valves, needle valves are more suitable in throttling the flow for any velocity.

### Limitations of Non-Pressure Compensated Flow Control Valves

In both globe and needle valves, changes in the pressure drop produce variations in the flow rate. Therefore precise accuracy in flow-rate control and hence the speed control cannot be achieved by using non-pressure compensated flow control valves.



*Ball-type globe valve*

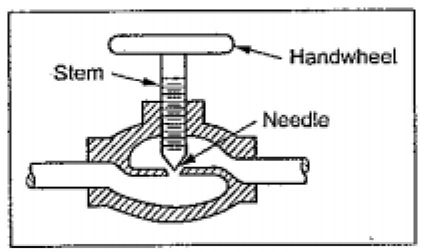
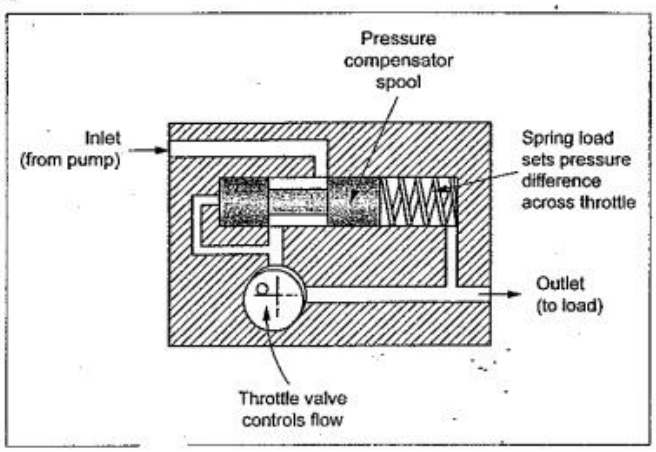



*Fig. 7.23.*

### Construction and Operation

The construction and operation of a typical pressure-compensated flow control valve is illustrated in Fig.




*Pressure-compensated flow control valve*

The valve actually has two main parts arranged in series. They are :

*1. Throttle valves :* Similar to a needle valve, the throttle valve has an orifice whose area can be adjusted by an external knob setting. This throttle valve setting determines the flow rate is to be controlled.

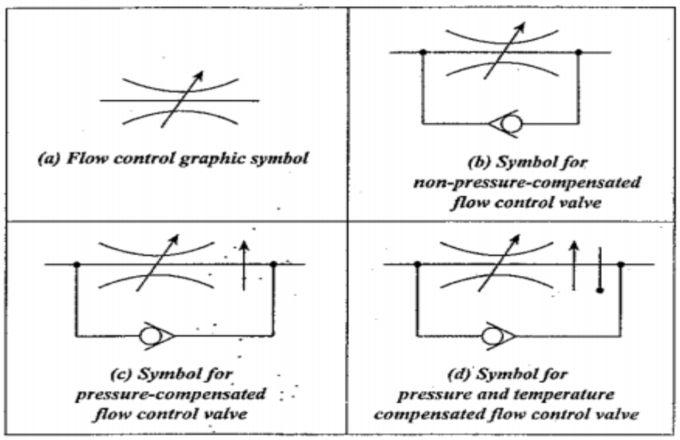
**2. *Pressure compensator :*** The pressure compensator spool controls the size of the inlet orifice and maintains a constant pressure drop across the throttle valve.

As inlet pressure increases and overcomes the spring force, the pressure compensator spool closes the inlet passage. It blocks off all flow in excess of the throttle setting. As a result, the valve permits the fluid flow only to the amount for which the throttle is already set.

When the fluid passes through the throttle valve, the pressure builds up in the spring side of the compensator. This pressure drop produces a rapid compensation in the form of spool motion. This spool adjustment causes the pressure drop to return quickly to its original valve, thus maintaining constant flow.

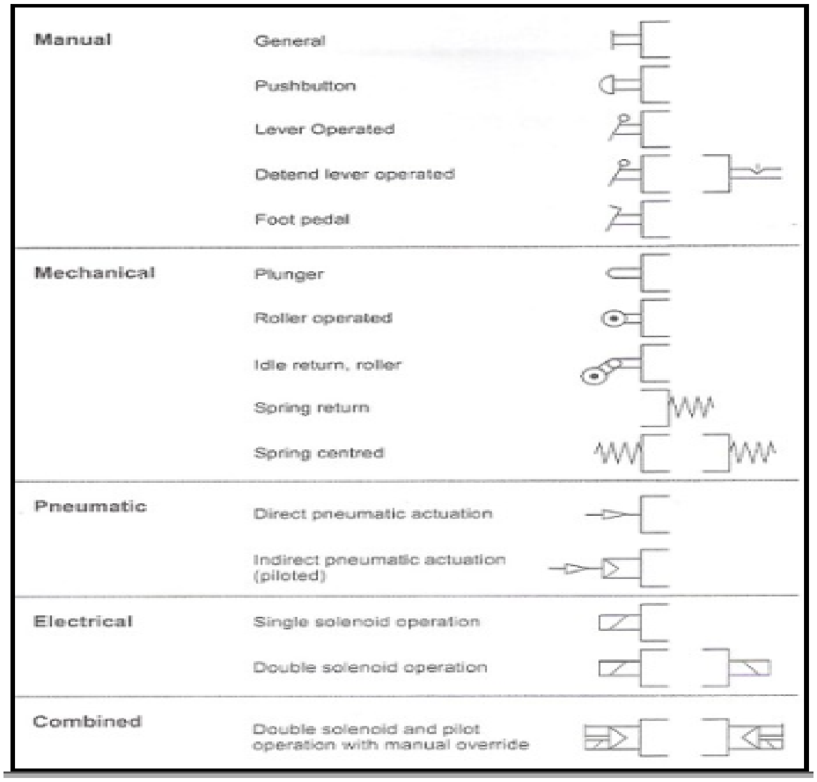
*Note* Flow control valves can also be affected badly by temperature changes which change the viscosity of the fluid. Therefore often flow control valves have temperature compensation.

**Flow control valves symbols**



- Topic 2: Actuation methods of valves

The symbols for the methods of actuation are detailed in ISO 1219. The types of actuation may vary e.g. manually actuated, mechanically actuated, pneumatically actuated, electrical, combined actuation.




- Directional control valves can be actuated by different methods.

The four actuation methods normally used are:

- Manually actuation
- Mechanical actuation
- Electrical actuation , and
- Fluid actuation

1. **Manually – actuated Valve**:

A manually actuated DCV uses muscle power to actuate the spool. Manual actuators are hand lever, push button, pedals. The following symbols show the DCV actuated manually


(a) (b)

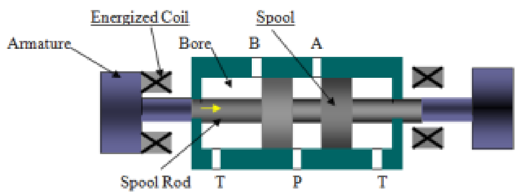
Fig a & b shows the symbol of 2 / 4 DCV manually operated by hand lever to 1 and spring return to 2. In the above two symbols the DCV spool is returned by springs which push the spool back to its initial position once the operating force has stopped.

### 2. Mechanical Actuation

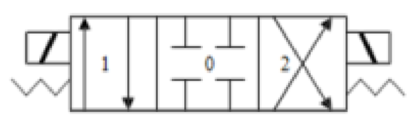
The DCV spool can be actuated mechanically, by roller and cam, roller and plunger. The spool end contains the roller and the plunger or cam can be attached to the actuator (cylinder).. When the cylinder reaches a specific position the DCV is actuated. The roller tappet connected to the spool is pushed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

### 3. Solenoid Actuated DCV or electrical actuation

A very common way to actuate a spool valve is by using a solenoid is illustrated in the figure. When the electric coil (solenoid) is energized, it creates a magnetic force that pulls the armature into the coil. This caused the armature to push on the spool rod to move the spool of the valve.. The advantage of a solenoid valve is that the switching time is less.

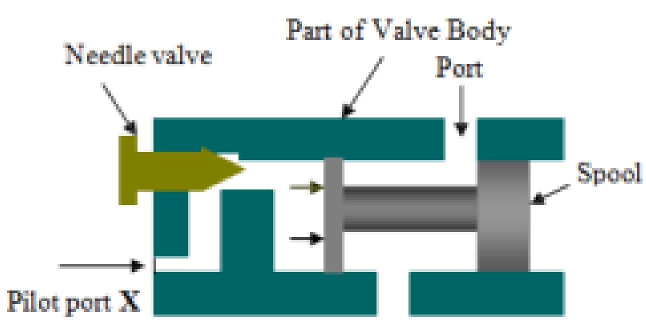


Working of solenoid to shift spool of valve

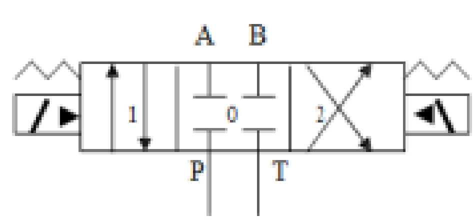



### 4. Hydraulic actuation:

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



Pilot actuated DCV

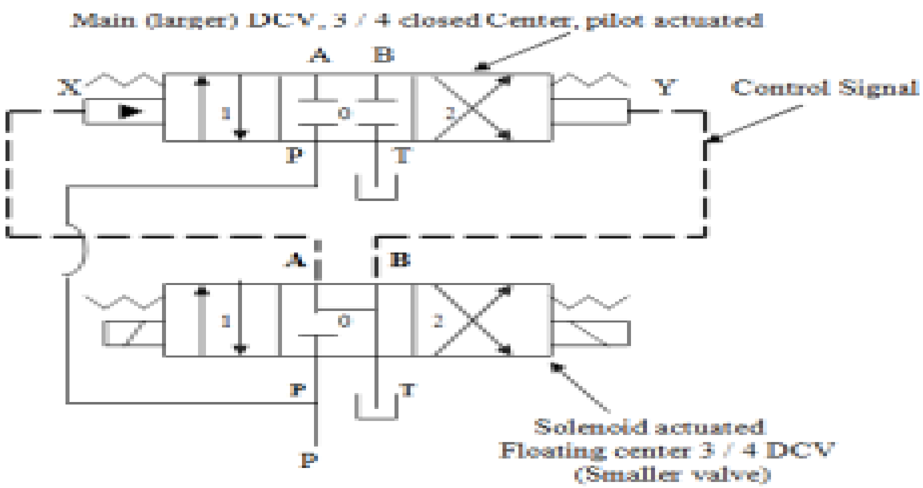


5. **Pneumatic actuation**

DCV can also be operated by applying compressed air against a piston at either end of the valve spool. The construction of the system is similar to the hydraulic actuation as shown in Figure above The only difference would be the actuation medium. The actuation medium is the compressed air in pneumatic actuation system.

6. **Indirect actuation of directional control valve**

The direction control valve can be operated by manual, mechanical, solenoidal (electrical), hydraulic (pilot) and pneumatic actuations. The mode of actuation does not have any influence on the basic operation of the hydraulic circuits. Mostly, the direct actuation is restricted to use with smaller valves only because usually lot of force is not available. The availability of limited force is the greatest disadvantage of the direct actuation systems. In practice, the force required to shift the spool is quiet higher. Therefore, the larger valves are often indirectly actuated in sequence. First, the smaller valve is actuated directly and the flow from the smaller valve is directed to either side of the larger valve. The control fluid can be supplied by the same circuit or by a separate circuit. The pilot valve pressure is usually supplied internally. These two valves are often incorporated as a single unit. These valves are also called as Electro-hydraulic operated
DCV.




Indirect actuation of directional control valve

- **TOPIC 3: PNEUMATIC/HYDRAULIC ACTUATORS**

- Actuators are the devices used for converting pressure energy of pressurized fluid into the mechanical energy to perform useful work.

- In other words, Actuators are used to perform the task of exerting the required force at the end of the stroke or used to create displacement by the movement of the piston.
- Actuators can be pneumatic and Hydraulic now we can discuss on them in the following sections.

## HYDRAULIC ACTUATORS

- ✓ Actuators are the devices used for converting hydraulic energy of pressurized fluid into the mechanical energy.
- ✓ In other words, actuators perform a function just opposite to that of the pumps
- ✓ The pressurized hydraulic fluid delivered by the hydraulic pump is supplied to the actuators, which converts the energy of the fluid into mechanical energy. This mechanical energy is used to get the work done.
- ✓ The hydraulic actuators produce linear, rotary, or oscillating motion.
- ✓ They can be used for lifting , tilting , clamping , opening , closing , metering , mixing, turning , swinging , counterbalancing , bending and for many other operations.
- ✓ Special applications are on roll-over devices, conveyors, valve operators, printing presses, rock drills, dies, clamps, machine tools, etc.

### 1. Types of hydraulic Actuators

Based on the type of motion actuators produce, they are categorized into two:

1. Linear actuators ( also called ‘ hydraulic cylinders’), and
2. Rotary actuators (also called ‘ hydraulic motors’)
   a. Continuous rotary actuators(or Simply hydraulic motors), and
   b. Limited rotation rotary actuators( also called ‘Oscillation fluid motors’)

The linear actuators generate motion in a straight line to perform the work .The rotary actuators generate rotary output motion to perform the work.

### 1. Linear actuators (or Hydraulic cylinders)

- ✓ A linear actuator or hydraulic cylinder is a fluid motor that generates linear motion. In other words, hydraulic cylinder is a device which converts fluid power into linear mechanical force and motion.

- ✓ 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

#### a. Types of hydraulic cylinders

The linear hydraulic cylinders can be classified into many types based on various criteria. Some of them are given below:

I. **Based on the cylinder action:**
   - ✓ Single acting cylinder
   - ✓ Double acting cylinder

II. **Based on the cylinder's design:**
   - ✓ Plunger or ram cylinder
   - ✓ Tandem cylinders
   - ✓ Double rod cylinders
   - ✓ Telescopic cylinders
   - ✓ Cable cylinders
   - ✓ Diaphragm cylinders
   - ✓ Bellow cylinders
   - ✓ Duplex cylinders, etc

III. **Based on the cushioning feature :**
- ✓ Cushioned type hydraulic cylinders, and
- ✓ Non-cushioned type cylinders
- ✓

**IV. Based on the piston or plunger used:**
   - ✓ Piston type cylinders, and
   - ✓ Plunger type cylinders

V. **Based on cylinder's movement:**
   - ✓ Rotating type air cylinder
   - ✓ Non rotating type air cylinder
   - ✓

Now we shall present only few important basic hydraulic cylinders in the following sections

➢ **SINGLE ACTING CYLINDER**

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

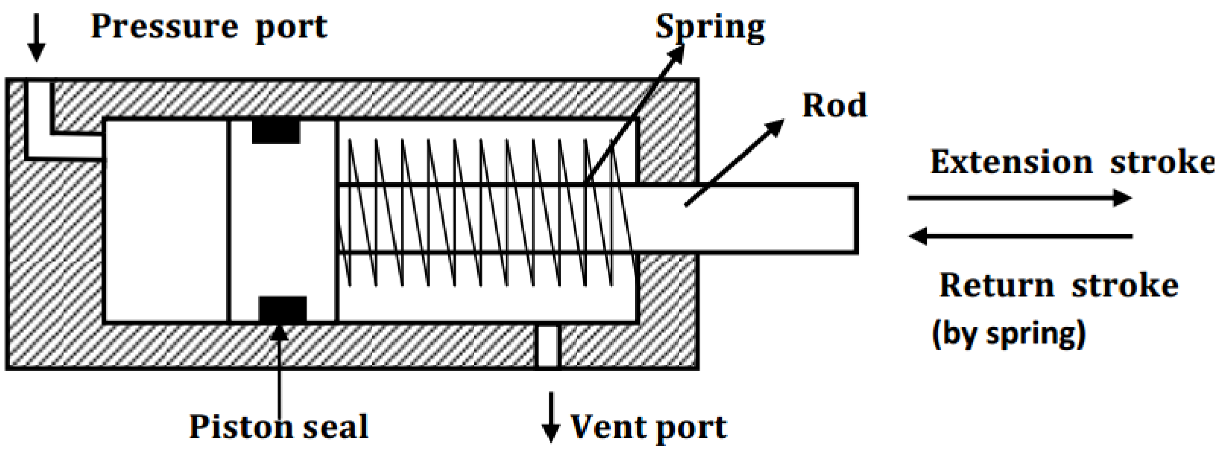



**Figure 1.1** Single-acting cylinders

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

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

**Gravity-Return Single-Acting Cylinder**

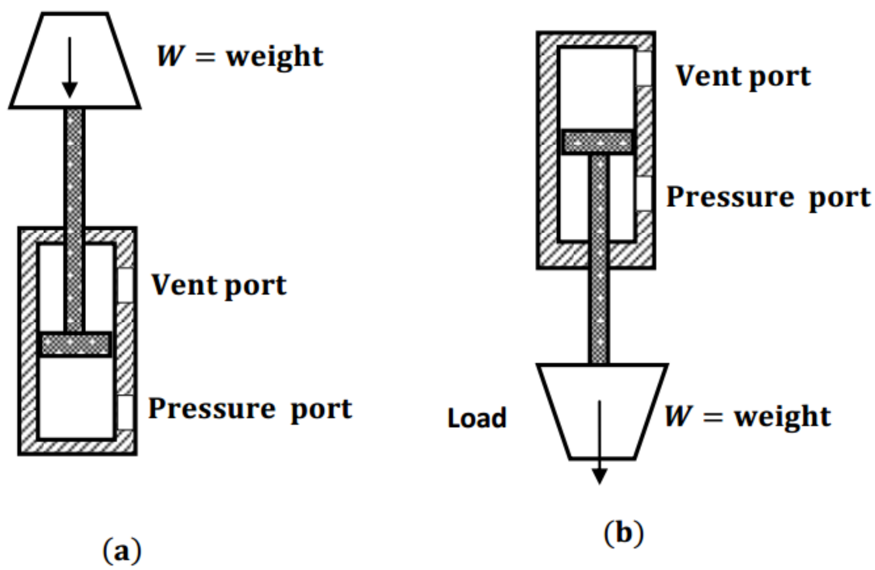



**Figure 1.2** Gravity-return single-acting cylinder: (a) Push type; (b) pull type

Figure1.2 shows gravity-return-type single-acting cylinders. In the push type [Fig. 1.2(a)], the cylinder extends to lift a weight against the force of gravity by applying oil pressure at the blank end. The oil is passed through the blank-end port or pressure port. The rod-end port or vent port is open to atmosphere so that air can flow freely in and out of the rod end of the cylinder. To retract the cylinder, the pressure is simply removed from the piston by connecting the pressure port to the tank. This allows the weight of the load to push the fluid out of the cylinder back to the tank. In pull-type gravity-return-type single-acting cylinder, the cylinder [Fig. 1.2(b)] lifts the weight by retracting. The blank-end port is the pressure port and blind-end port is now the vent port. This cylinder automatically extends whenever the pressure port is connected to the tank.

**Operation**

During the extending action, the force is applied by the pressurized fluid. The force applied to a piston depends on both the area of the piston and the pressure of the fluid.

Mathematically, the force applied is given by: $\boldsymbol{F} = \boldsymbol{P} \times \boldsymbol{A}$

Where **p =**Pressure of the fluid**; A =** Area of the piston = $\frac{\pi}{4}D^2$ **;** and

**D =** Diameter of the piston.

- **Spring-Return Single-Acting Cylinder**

A spring-return single-acting cylinder is shown in Fig.1.3.In push type [Fig. 1.3(a)], the pressure is sent through the pressure port situated at the blank end of the cylinder. When the pressure is released, the spring automatically returns the cylinder to the fully retracted position. The vent port is open to atmosphere so that air can flow freely in and out of the rod end of the cylinder. Figure 1.3(b) shows a spring-return single-acting cylinder. In this design, the cylinder retracts when the pressure port is connected to the pump flow and extends whenever the pressure port is connected to the tank. Here the pressure port is situated at the rod end of the cylinder.

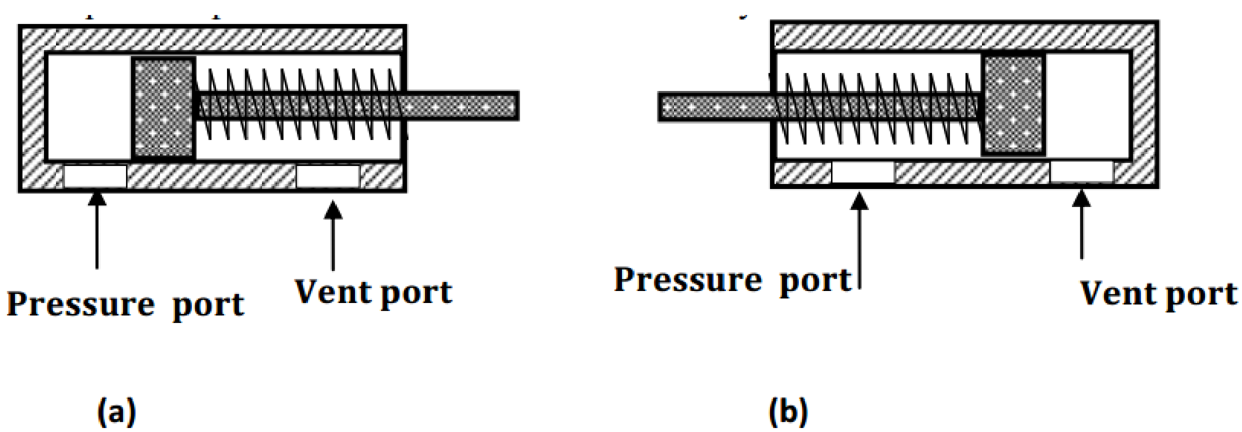



**Figure 1.3** (a) Push- and (b) pull-type single-acting cylinders

- **Double-Acting Cylinder**

There are two types of double-acting cylinders:

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

**_1_ Double-Acting Cylinder with a Piston Rod on One Side**

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

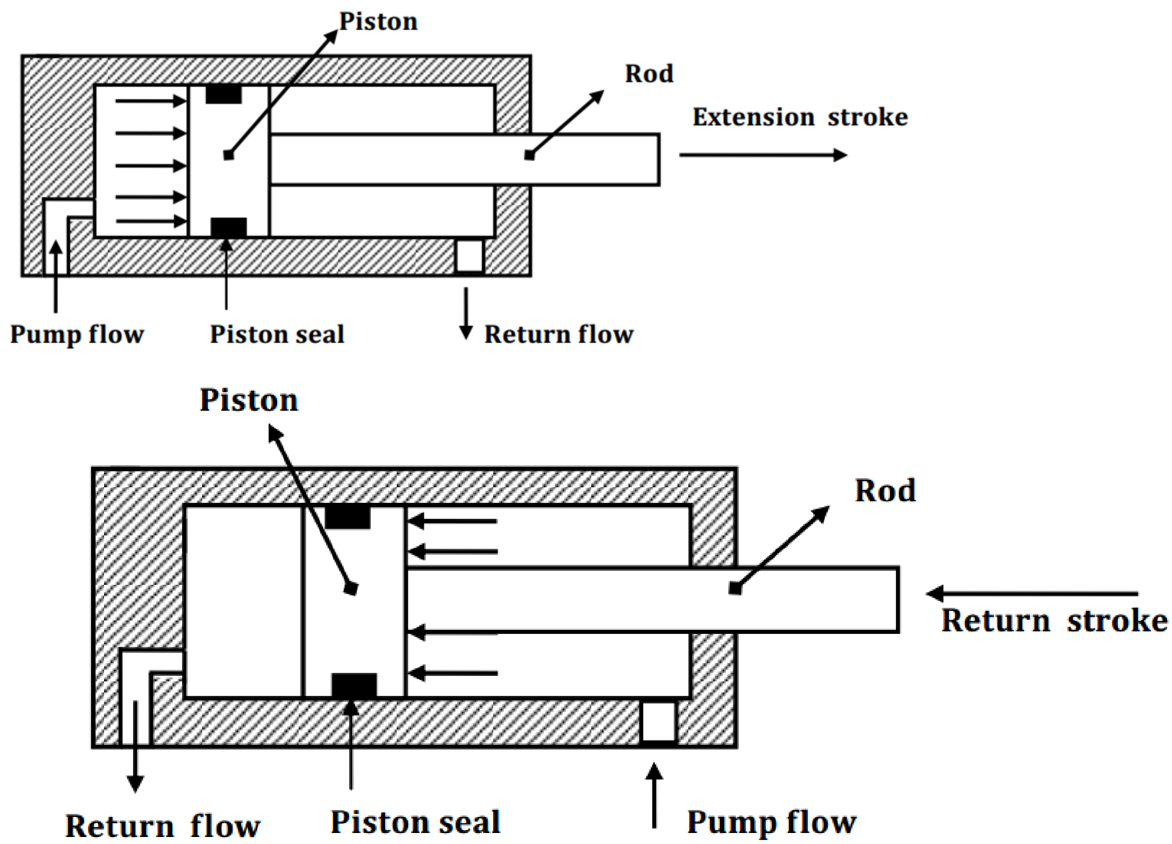
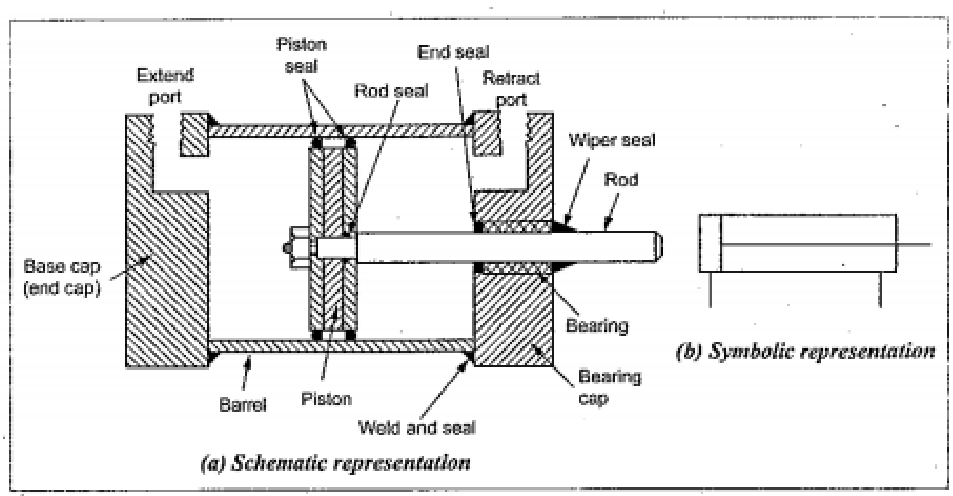



**Figure 1.4** Double-acting cylinder with a piston rod on one side




***Double-acting hydraulic cylinder***

2. **Double-Acting Cylinder with a Piston Rod on Both Sides**

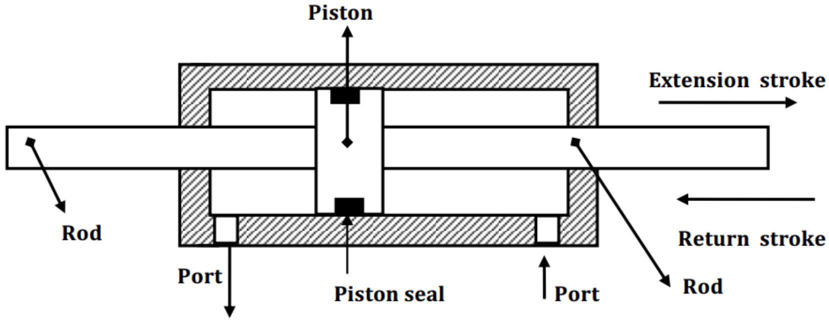



**Figure 1.5**Double-acting cylinder with a piston rod on one side

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

- **Analysis of cylinder Force, Velocity, and Power of a Double- Acting Cylinder**

The force, velocity, and power of a double-acting cylinder can be calculated as below :

Let $D$ and $d$ = Diameters of the piston and piston rod respectively,

$A_p$ and $A_r$ = Cross-sectional area of the piston and the piston rod respectively,

$F_{ext}$ and $F_{ret}$ = Hydraulic force acting on piston during the extension and retraction strokes respectively,

$v_{ext}$ and $v_{ret}$ = Velocity of the piston during the extension and retraction strokes respectively,

$Q_{in}$ = Cylinder input volume flow rate in $m^3/s$, and

$P$ = Hydraulic pressure in $N/m^2$.

*For extension stroke :*

$$F_{ext}\,(N) = P_{ext}\,(N/m^2) \times A_p\,(m^2)$$

$$v_{ext}\,(m/s) = \frac{Q_{in}\,(m^3/s)}{A_p\,(m^2)}$$

$$\text{Power (kW)} = v_{ext}\,(m/s) \times F_{ext}\,(kN) = Q_{in}\,(m^3/s) \times P\,(kN/m^2)$$

*For retraction stroke :*

$$F_{ret}\,(N) = P_{ret}\,(N/m^2) \times (A_p - A_r)\ m^2$$

$$V_{ret}\,(m/s) = \frac{Q_{in}\,(m^3/s)}{(A_p - A_r)\,m^2}$$

$$\text{Power (kW)} = v_{ret}\,(m/s) \times F_{ret}\,(kN)$$

$$= Q_{in}\,(m^3/s) \times P_{ret}\,(kN/m^2)$$

### 3. Telescopic Cylinder

A telescopic cylinder (shown in Fig. 1.6) is used when a long stroke length and a short retracted length are required. The telescopic cylinder extends in stages, each stage consisting of a sleeve that fits inside the previous stage. One application for this type of cylinder is raising a dump truck bed. Telescopic cylinders are available in both single-acting and double-acting models. They are more expensive than standard cylinders due to their more complex construction. They generally consist of a nest of tubes and operate on the displacement principle. The tubes are
supported by bearing rings, the innermost (rear) set of which have grooves or channels to allow fluid flow. The front bearing assembly on each section includes seals and wiper rings. Stop rings limit the movement of each section, thus preventing separation. When the cylinder extends, all the sections move together until the outer section is prevented from further extension by its stop ring. The remaining sections continue out-stroking until the second outermost section reaches the limit of its stroke; this process continues until all sections are extended, the innermost one being the last of all.

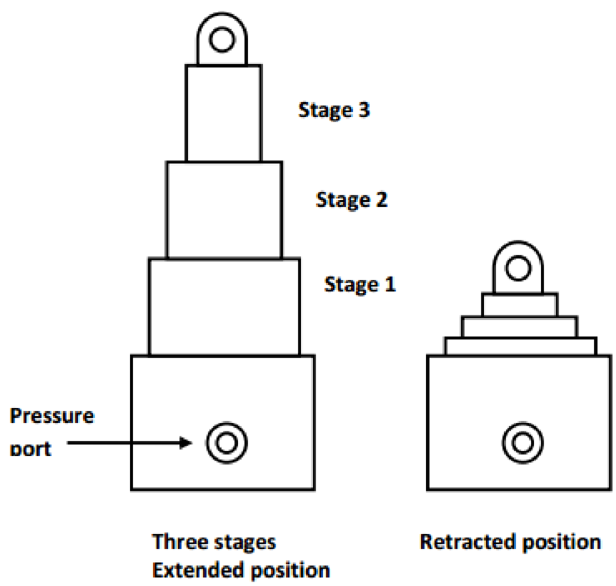



**Figure 1.6** Telescopic cylinder

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

4. Tandem cylinder

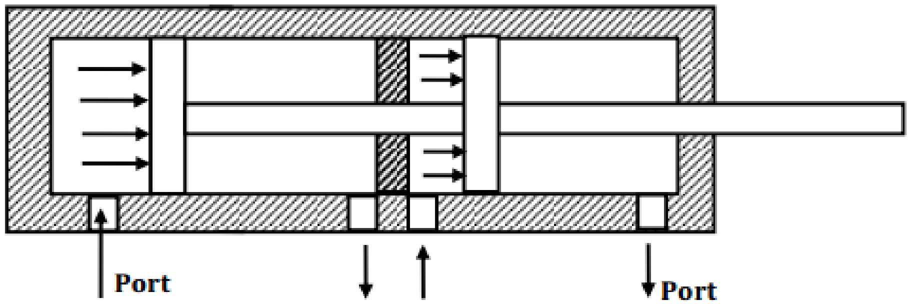



**Figure 1.7**Tandem cylinder

A tandem cylinder, shown in Fig. 1.7, is used in applications where a large amount of force is required from a small-diameter cylinder. Pressure is applied to both pistons, resulting in increased force because of the larger area. The drawback is that these cylinders must be longer than a standard cylinder to achieve an equal speed because flow must go to both pistons.

**5. Cylinder cushioning**

- **What is meant by Cylinder Cushion?**

When the pressurized fluid is allowed to enter inside the cylinder, the piston accelerates and travels in the cylinder barrel. If the piston is allowed to travel at the same speed till the end of the stroke, it will hit the end cap with a great impact. To avoid this impact, the piston needs to decelerate at the end of the travel. The arrangement made at the end caps to achieve the same is called '**cylinder cushion'.**

- Construction and operation

A typical cylinder cushioning arrangement is illustrate in figure (a) and (b) show the position of the position of the piston of the start and of the cushioning action, respectively.

As the piston approaches the end of its stroke, the plunger enters the end cap port and thus blocks the free flow. Now the fluid is trapped between the piston and the end cap. This fluid can escape only by passing through the adjustable restrictor, as shown in figure (b). This fluid flow through the restricted flow path causes the piston to decelerate. The rate of deceleration of the piston can be controlled by the adjustable needle valve. A non-return or check valve is provided to allow free flow of fluid to the cylinder quickly during the return stroke.

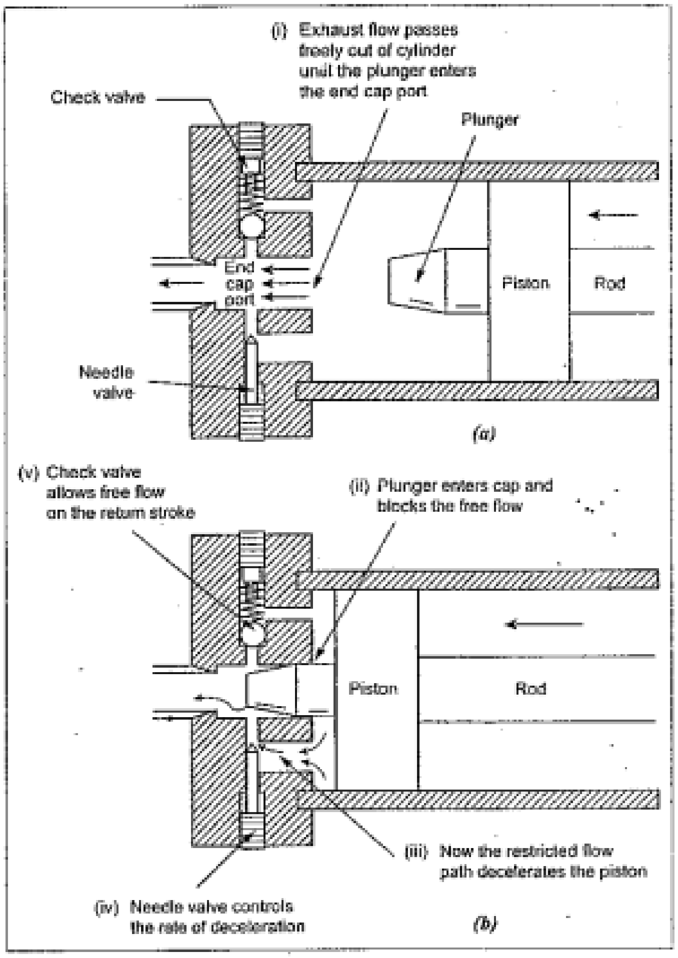



Figure: Operation of Cylinder Cushions

## ROTARY ACTUATORS (OR HYDRAULIC MOTORS)

- ✓ *The function of a rotary actuator is to convert hydraulic energy into rotary mechanical energy.*
- ✓ Rotary actuators are the hydraulic equivalents of electric motors. Hence rotary actuators are also called as ***hydraulic motors.***
- ✓ The hydraulic motors are very much identical in construction and size to rotary type pumps. They work on exactly the reverse principle to that of rotary pumps.
- ✓ Instead of pushing the fluid as pumps do, in a hydraulic motor the rotating elements (*i.e.*, vanes, gears, pistons, *etc.*) are pushed by the pressurized fluid. This enables the hydraulic motor to develop the necessary output torque and rotating motion.
- ✓ The hydraulic motors are usually rated/specified in terms of the torque developing capacity or differential pressure.

## Classification of Hydraulic Motors

The hydraulic motors can be classified based on their degree of angular movement as :

1. Continuous rotary hydraulic motors, and

   (*i*) Gear motors, (*ii*) Vane motors, and (*iii*) Piston motors.

2. Limited rotation hydraulic motors†

   (*i*) Vane type, and (*ii*) Piston type.

Now we shall discuss the construction and operation of gear, vane, and piston motors, in the following sections.

### ➢ CONTINUOUS ROTARY HYDRAULIC MOTORS

1. Gear motors

   Like gear pumps, gear motors are fixed displacement devices. Also, gear motors can be classified as external or internal gear units. External gear motors include the gear-on gear units such as the spur gear motor. Internal gear motors include the crescent seal types and the gerotor type unit.

   - Construction and operation

The figure below illustrates the operation of a gear motor. In this type, both the gear wheels are driven and one of the gear wheels has an extended shaft to provide output torque.

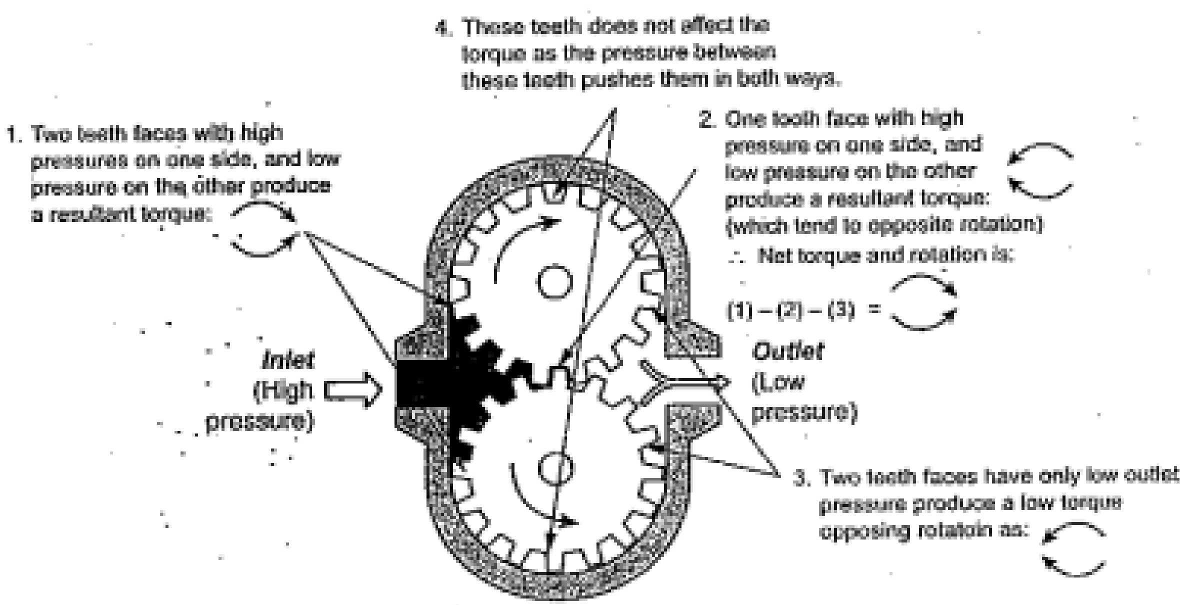



Figure: torque development by a gear motor

In the gear motor, rotary motion is produced by the unbalanced hydraulic forces on the gear teeth. The hydraulic imbalance in a gear motor is caused by gear teeth unmeshing. As gear teeth unmesh, all teeth subjected to system pressure are hydraulically balanced, except for one side of one tooth on one gear. This imbalance of force on gears, as shown in Fig.6.9, develops the torque. It should be noted that the larger the gear tooth or higher the pressure, more is the torque produced.

### Advantages of Gear Motors

The gear motors are simple in design, and very cheap in cost.

### Disadvantages of Gear Motors

✓ Gear motors are subjected to relatively high internal leakage. Therefore, they are not suitable for high torque, low speed applications.

✓ The high pressure at the inlet, coupled with the low pressure at the outlet, generates very high bearing loads.

### Ranges

✓ The gear motors are available for peak operating pressures upto about 125 bars, with rated capacities upto 10 Lps, and maximum speeds of about 3000 rpm.

- **VANE MOTORS**

Vane motors work on the same principle as vane pumps in reverse. In these motors, the pressurised fluid acting on the vanes cause them to rotate and thus developing the torque output. They are suitable for low speed applications than gear motors.

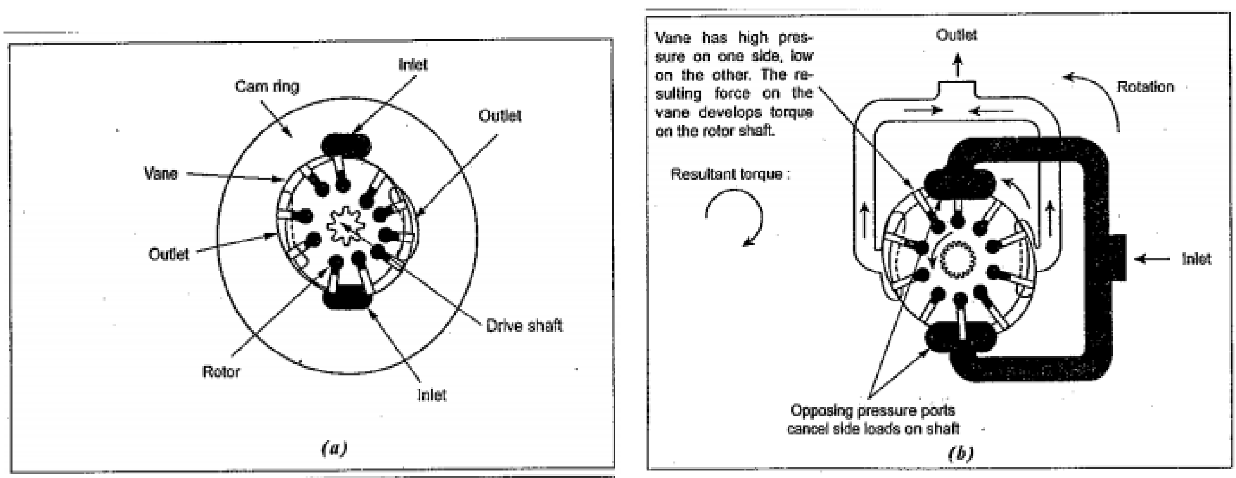



Figure : Operation of a balanced vane motor

Like vane pumps, vane motors can be classified as unbalanced or balanced vane motors. But most vane motors used universally are of the balanced-rotor type. Because hydraulic unbalance causes large radial bearing loads which limit the use of unbalanced vane motors to low pressure operation. Therefore most vane motors have a mechanical configuration similar to that of the balanced vane pump. Also balanced vane motors are fixed-displacement units.

**Figure:** illustrates the construction and operation of a balanced-type vane motor.

The vane motor produces torque by the hydraulic pressure that acts on the exposed surfaces of the vanes, which slide in and out of the rotor connected to the driver shaft. To accommodate starting and low-speed operation, it is usually necessary to provide a force, in addition to the centrifugal force, to move the vane radially outward. Springs are commonly used for this purpose. The larger the exposed area of the vane, or higher the pressure, more is the torque developed. Also, as the inlet connects to two opposing pressure passages, the side loads on the rotor are balanced with each other (**Figure**($b$)).

PISTON MOTORS

- ✓ Piston motors are positive displacement motors which can develop an output torque at the shaft by allowing pressurised fluid to act on the pistons.
- ✓ The piston motors can be either fixed or variable-displacement devices.
- ✓ They are suitable for low speed, high torque traction applications such as earth-moving machinery, agricultural tractors, railway locomotive and other industrial applications.
- ✓ The piston motors are the most efficient and can operate at the highest speeds and pressures, when compared to gear and vane type motors.
- ✓ *Types :* Piston motors can be classified in terms of the piston motion as :
  1. Axial-piston motors, and
  2. Radial-piston motors.

### Axial Type Piston Motors

***Construction and Operation :*** The operation of an axial type piston motor is essentially the same as that of an axial piston pump except for the direction of flow

The pressurised liquid introduced through the motor inlet forces the piston assembly against the thrust cam or swash/wobble plate. The angular application of this force causes the plate to rotate and this rotation is transmitted by the shaft. The displacement can be varied by changing the angle of the thrust cam.

### Radial Type Piston Motors

***Construction and Operation :*** The operation of a radial type piston is also essentially the same as that of an radial piston pump except for the direction of flow

Fluid enters the piston chamber through a central eccentric cam. The piston is forced radially outward against the thrust ring, thereby producing a force tangent to the piston chamber. The resulting torque causes the shaft to rotate.

LIMITED ROTARY HYDRAULIC ACTUATORS

- ✓ The limited-rotation motors provide an oscillating power output. In other words, limited-rotation motors provide rotary output motion over a finite angle. Usually the rotation of the shaft of these motors is 90°, 180°, or 270°.

- ✓ *Types :* The two types of limited-rotation motors used to obtain an oscillatory output are :
  1. Vane type limited rotation motors, and
  2. Piston type limited rotation motors.

### Vane Type Limited Rotation Motors

There are two types of limited rotation vane motors, the single-vane and the double-vane. Fig. **(a)** and **(b)** illustrate the operation of a typical single-vane and double-vane rotation motors respectively. In both the single- and the double-vane units, seals are maintained between the rotor and the barriers, and between the vanes and the housing.

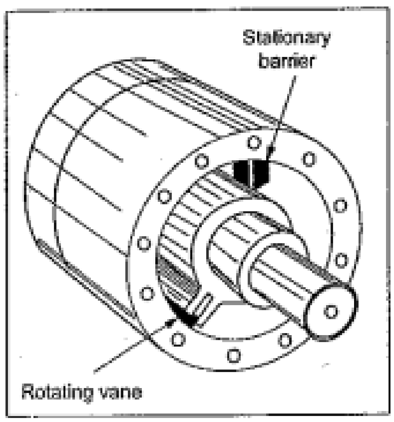



*Fig.* **(a)** *Single-vane rotation motor*

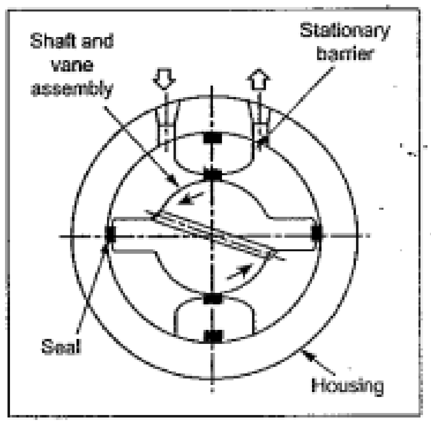



*Fig.* **(b)** *Double-vane rotation motor*

### Single-Vane Rotation Motor

As shown in Fig **(a)** , the single-vane unit consists of a cylindrical housing, a shaft with a single vane, a barrier which limits the vane rotation, and end pieces which support the shaft. Pressurised liquid enters on the side of the vane, forcing the vane to rotate to the barrier. The single-vane unit produce the rotation of approximately 280°.

### Double-Vane Rotation Motor

In the double-vane unit, the pressurised fluid enters on one side of a vane and is ported through the shaft to the corresponding side of the other vane, as shown in Fig **(b)** . A rotation of about 100° can be obtained with the double-vane unit.

### Analysis of Torque Capacity in a Single-Vane Type Limited Rotation Motor

The torque producing capacity of a single-vane type limited rotation motion can be determined as below.

Let $T$ = Torque developing capacity in N-m,

$F$ = Hydraulic force acting on vane in N,

$P$ = Hydraulic pressure in $N/m^2$,

$A$ = Surface area of vane in contact with liquid in $m^2$,

$R_R$ = Outer radius of rotor in m,

$R_V$ = Outer radius of vane in m, and

$L$ = Width of vane in m.

Area of vane surface, $A = (R_V - R_R)\,L$

The hydraulic force acting on the vane, $F = \begin{Bmatrix} \text{Hydraulic} \\ \text{pressure} \end{Bmatrix} \times \begin{Bmatrix} \text{Vane} \\ \text{surface area} \end{Bmatrix}$

$$= P \times A = P\,(R_V - R_R)\,L$$

We know that the torque developing capacity,

$$T = \text{Vane force} \times \text{Mean radius of the vane}$$

$$= [P\,(R_V - R_R)\,L]\left(\frac{R_V + R_R}{2}\right)$$

or

$$\boxed{T = \frac{P\,L}{2}\,(R_V^2 - R_R^2)\,L}$$

We also know that,

Volumetric displacement, $\boxed{V_D = \pi\,(R_V^2 - R_R^2)\,L}$

Combining equations (6.8) and (6.9), we get

$$\boxed{T = \frac{P \cdot V_D}{2\pi}}$$

- **HYDRAULIC MOTOR PERFORMANCE**

Like in hydraulic pumps, the performance of hydraulic motor is also evaluated by using volumetric, mechanical, and overall efficiencies

a. Volumetric Efficiency($\eta_{vol}$)

The volumetric efficiency of a hydraulic motor is the inverse of that for a pump. Mathematically,

$$\boxed{\eta_{vol} = \frac{\text{Theoretical flow rate motor should consume}}{\text{Actual flow rate consumed by motor}} \times 100 = \frac{Q_T}{Q_A} \times 100}$$

b. Mechanical Efficiency($\eta_{\text{mech}}$)

The mechanical efficiency of a hydraulic motor is the inverse of that for a pump. Mathematically,

$$\boxed{\eta_{mech} = \frac{\text{Actual torque delivered by motor}}{\text{Torque motor should theoretically deliver}} \times 100 = \frac{T_A}{T_T} \times 100}$$

where $T_A = \dfrac{\text{Actual power delivered by motor (watts)}}{\text{Angular speed of motor shaft (rad/s)}} = \dfrac{P}{\omega}$, and

$$T_T = \frac{V_D\,(\text{m}^3/\text{rev}) \times P\,(\text{N/m}^2)}{2\pi}$$

c. Overall Efficiency($\eta_o$)

The overall efficiency of the hydraulic motor is the product of the volumetric and mechanical efficiencies, mathematically.

$$\boxed{\eta_0 = \eta_{vol} \times \eta_{mech}}$$

Combining equations (6.11), (6.12), (6.13), and (6.14), we get

$$\boxed{\eta_0 = \frac{T_A\,(\text{N-m}) \times \omega\,(\text{rad/s})}{P\,(\text{N/m}^2) \times Q_A\,(\text{m}^3/\text{s})} \times 100}$$

**Note** The actual power delivered to a motor by the fluid is called by the term *'hydraulic power'*. Similarly, the actual power delivered to a load by a motor via a rotating shaft is called *'brake power'*.

## PNEUMATIC ACTUATORS

1. What are pneumatic actuators?

- Pneumatic actuators are the devices used for converting the pressure energy of air (also called pneumatic energy) into mechanical energy to perform useful work.
- The pressurized air delivered by the air compressor is supplied to the pneumatic actuators, which converts the pressure energy of the air into mechanical energy. This mechanical energy is used to perform some useful work.
- Like hydraulic actuators, the pneumatic actuators also produce linear, rotary, or oscillating motion.

2. Types of pneumatic actuators

Based on the types of motion actuators produce, the pneumatic actuators are categorized into two:

i. Linear actuators (also called 'pneumatic cylinders'), and

ii. Rotary actuators (also called 'air motor'.

The pneumatic cylinders generate motion in a straight line to perform the work. The air motors generate rotary output motion to perform the work.

**Note:** *At the outset, the construction, working and functions of pneumatic actuators are very much similar. But generally pneumatic actuators are of lighter construction and of lesser weight; this is because the fluid medium- air-can be used mostly for low or medium pressure applications only.*

- Pneumatic linear actuators(Pneumatic cylinders)

1. What are pneumatic cylinders?
   - Pneumatic cylinders are the devices for converting the air pressure into linear mechanical force and motion.
   - The pneumatic cylinders are basically used for single-purpose applications such as clamping, stamping, transferring , allocating , ejecting , metering , tilting, bending, turning and many other applications.

2. Types of pneumatic Cylinders

The different classification schemes of the pneumatic cylinders are given below

VI. **Based on application for which air cylinders are used:**

- ✓ Light duty air cylinders
- ✓ Medium duty air cylinders
- ✓ Heavy duty air cylinders

VII. **Based on the cylinder action:**

- ✓ Single acting cylinder
- ✓ Double acting cylinder
- ✓ Single rod type double acting cylinder
- ✓ Double rod type double acting cylinder
- ✓

VIII. **Based on cylinder's movement:**

- ✓ Rotating type air cylinder
- ✓ Non rotating type air cylinder
- ✓

IX. **Based on the cylinder's design:**

- ✓ Through rod cylinders

- ✓ Cushion end cylinders
- ✓ Tandem cylinders
- ✓ Double rod cylinders
- ✓ Telescopic cylinders ,etc

- **Single acting cylinders.**
  - ✓ As the name suggests, the single – acting air cylinders can deliver a force in only one direction. In these types, air only moves or pushes the piston in one direction and the piston is returned by means of an external spring or by gravity.
  - ✓ In **the double- acting air cylinders,** air pressure can be applied to either side of the piston, thereby providing a pneumatic force in both directions.
  - ✓ The construction, working principle, graphical symbol, merits and demerits of single and double – acting air cylinders are very much similar to that of the hydraulic cylinders.

**Some of the basic pneumatic cylinder types and their brief descriptions are presented in Table below:**

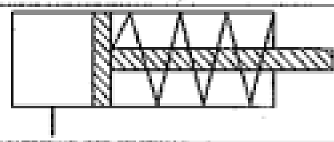
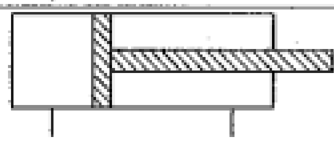
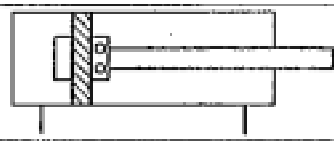
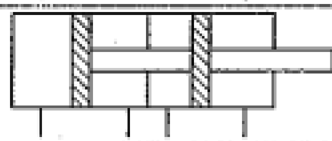
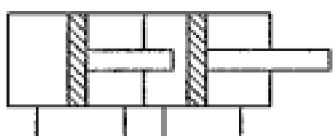
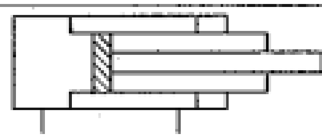
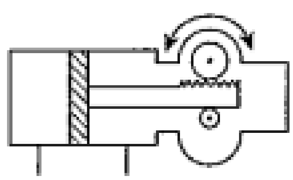
| Sl.No. | Cylinder Type | Diagram | Description |
|---|---|---|---|
| 1. | Single-acting cylinder |  | Air pushes the piston in one direction and the piston is returned by means of an external spring. |
| 2. | Double-acting cylinder |  | The force exerted by the compressed air moves the piston in both directions. |
| 3. | Cushion end cylinder |  | Cushioning is used in the end positions, to prevent sudden damaging impacts. |
| 4. | Tandem cylinder |  | Here two cylinders are arranged in series so that the force obtained from the cylinder is almost doubled. |
| 5. | Dual linear cylinder (Three position cylinder) |  | Similar to tandem cylinder, but the piston and rod assemblies of a dual actuator are not fastened together as in the tandem cylinder. |
| 6. | Double-rod cylinder (Through rod cylinder) |  | It has piston rods extending from both ends of the cylinder. It produces equal force and speed on both sides of the cylinder. |
| 7. | Telescoping cylinder |  | It is a two-stage, double-acting telescopic cylinder; for more details refer Section 6.6.2. |
| 8. | Turn cylinder (Rotary cylinder) |  | It has a piston rod having rack and pinion arrangement in such a manner that with linear movement of the piston rod, the worm wheel rotates at 45°, 90°, 180°, *etc.* |

**Table:** Some basic types of pneumatic cylinders

- Rotating and Non-rotating type Air Cylinders

Rotating – type air cylinders are used in applications requiring that the cylinder body can be connected to a rotating member while the air connections to the cylinder be in a stationary housing.

Such cylinders are used on lathes, grinders, spinning machines and other machines with rotating spindles.

Non- rotating type air cylinders are more widely used than rotating cylinders. Because the great majority of applications do not involve a rotating member

- **Pneumatic Rotary Actuators (Air Motors)**

**What are Air Motors?**

- ✓ The function of an air motor (or a pneumatic rotary actuator) is to convert the pressure energy of the compressed air into rotary mechanical energy.
- ✓ **Types :** like hydraulic motors, air motors can also be classified based on their degree of angular movement as:
  - **i.** Continuous rotary air motors, and
    - a. Gear motors,
    - b. Vane motors, and
    - c. Piston motors
  - **ii.** Limited rotation air motors
    - a. Vane type, and
    - b. Piston type
- Continuous Rotary Air Motors

These air motors with unlimited angle of rotation (even up to 10,000 revolutions per minute) are most widely used to provide very high rotational speeds. Their constructions are very much similar to that of hydraulic motors.

1. **Gear motors:** In the gear motors, rotary motion is produced by the unbalanced pneumatic forces on the gear teeth. Thus the torque is generated by the pressure of the air against the teeth profiles of the two meshed gear wheels.

2. **Vane motors:** In the vane motors, the pressurized air acting on the vanes cause them to rotate and thus developing the torque output. They are suitable for low speed applications than gear motors.

3. **Piston motors:** Piston motors are positive displacement motors which can develop an output torque at the shaft by allowing pressurized air to act on the pistons. The two types of piston motors are axial and radial piston motors

- Limited rotation air motors

The limited rotation air motors provide rotary output motion over a finite angle. The standard rotations of the shaft of these motors are $94^0$, $184^0$, and $364^0$. The construction and operation of limited ration air motors are very much similar to that of the hydraulic motors.

- **Cylinder Force, Velocity and Power**

The output force (*F*) and piston velocity (*v*) of double-acting cylinders are not the same for extension and retraction strokes.

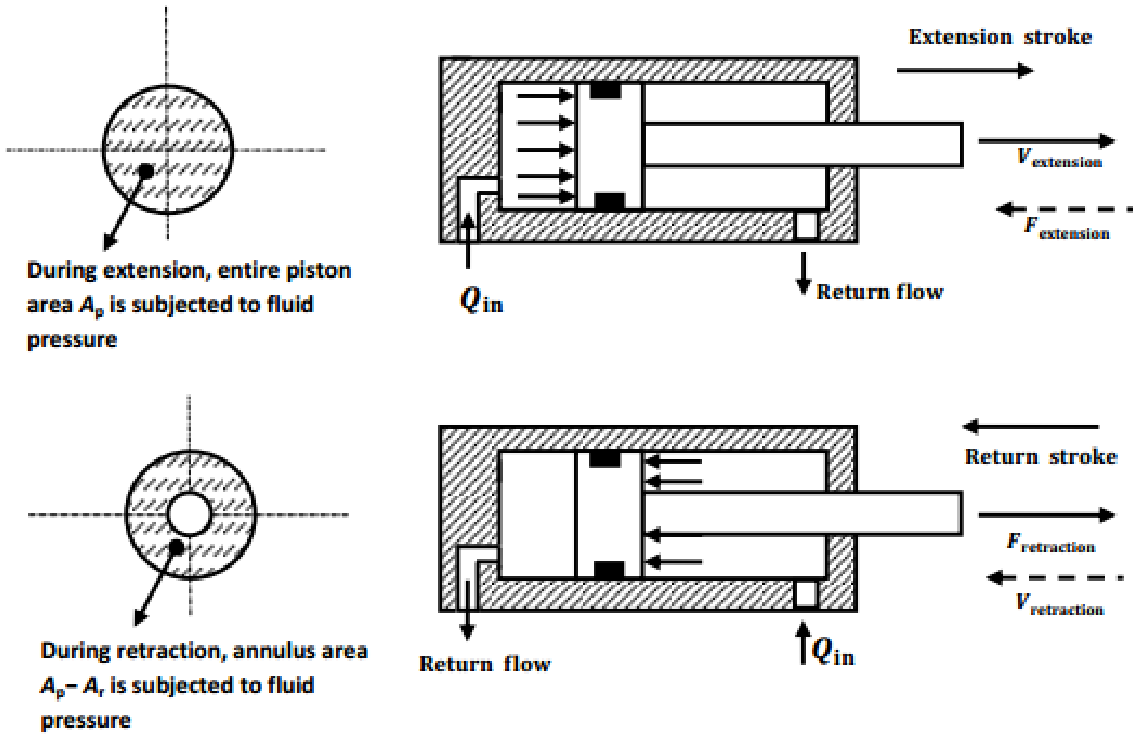


Figure: Effective area during (a) extension strokes and (b) retraction strokes

During the extension stroke shown in Fig(a),the fluid pressure acts on the entire circular piston area *A*p. During the retraction stroke, the fluid enters the rod-end side and the fluid pressure acts on the smaller annular area between the rod and cylinder bore (*A*p-*A*r) as shown by the shaded area in Fig.(b) (*A*r is the area of the piston rod).

Due to the difference in the cross-sectional area, the velocity of the piston changes . Because *A*p is greater than (*A*p - *A*r), the retraction velocity (*v*ret) is greater than the extension velocity (*v*ext) for the same flowrate.

During the extension stroke, the fluid pressure acts on the entire piston area (*A*r), while during the retraction stroke, the fluid pressure acts on the annular area (*A*p-*A*r). This difference in area accounts for the difference in output forces during extension and retraction strokes. Because *A*r is greater than *A*p-*A*r), the extension force is greater than the retraction force for the same operating pressure. Force and velocity during extension stroke

Velocity $$v_{\text{ext}} = \frac{Q_{\text{in}}}{A_{\text{p}}}$$

Force
$$F_{\text{ext}} = p \times A_{\text{p}}$$

Force and velocity during retraction stroke
Velocity

$$v_{\text{ext}} = \frac{Q_{\text{in}}}{A_{\text{p}} - A_{\text{r}}}$$

Force,

$$F_{\text{ext}} = p \times (A_{\text{p}} - A_{\text{r}})$$

Power developed by a hydraulic cylinder (both in extension and retraction) is

$$\text{Power} = \text{Force} \times \text{Velocity} = F \times V$$

In metric units, the kW power developed for either extension or retraction stroke is

$$\text{Power (kW)} = v_{\text{p}}\,(\text{m/s}) \times F\ (\text{kN})$$
$$= Q_{\text{in}}\,(\text{m}^3/\text{s}) \times p\ (\text{kPa})$$

Power during extension is

$$P_{\text{ext}} = F_{\text{ext}} \times v_{\text{ext}} = p \times A_{\text{p}} \times \frac{Q_{\text{in}}}{A_{\text{p}}} = p \times Q_{\text{in}} \qquad (1.1)$$

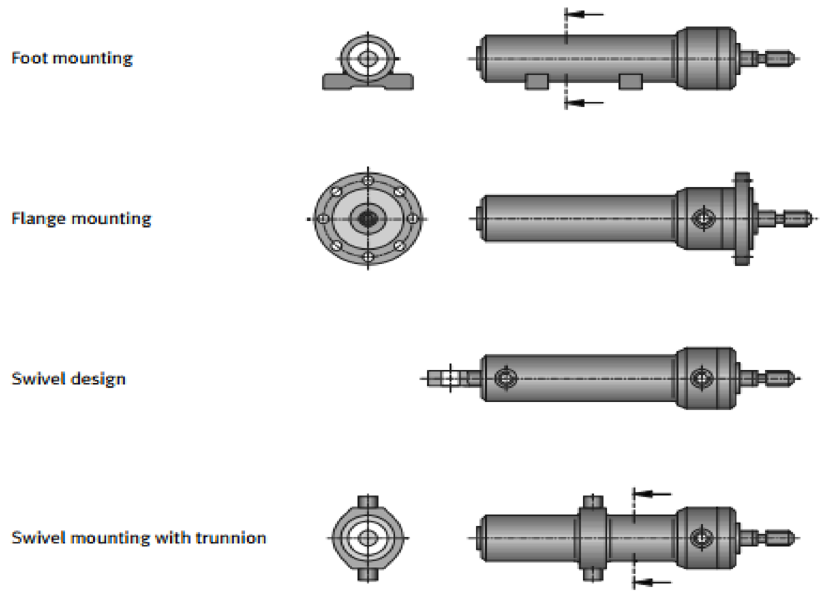
Power during retraction is

$$P_{\text{ret}} = F_{\text{ret}} \times v_{\text{ret}}$$
$$= p \times (A_{\text{p}} - A_{\text{r}}) \times \frac{Q_{\text{in}}}{A_{\text{p}} - A_{\text{r}}}$$
$$= p \times Q_{\text{in}} \qquad (1.2)$$

Comparing Equation. (1.1) and (1.2), we can conclude that the powers during extension and retraction strokes are the same.

**Types of mounting**

Cylinders are mounted in various ways according to usage. Some types of mounting are shown in the diagram.




## LEARNING OUTCOME 2.3: IDENTIFY ACCESSORIES

- **TOPIC 1: Non- return valves**

Non return valves can stop the flow completely in one direction. In the opposite direction the flow is free with a minimal pressure drop due to the resistance of the valve. The one-way blocking action can be effected by cones, balls, plates or diaphragms.

✓ Check valves

**Check Valve**: This valve allows flow from P to A., when pressure is enough to overcome the spring force acting on the ball, which is quite small. It does not allow flow in the other direction ie from A to P. The symbol for check valve is as shown. It is also called On-off or Non-return valve.

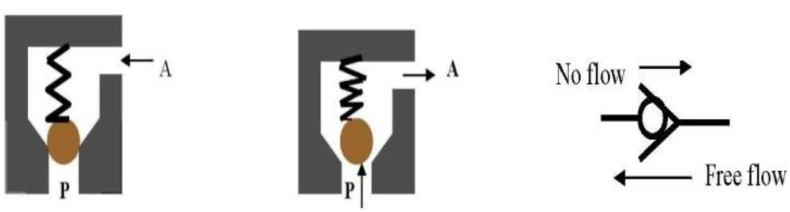
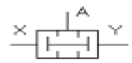


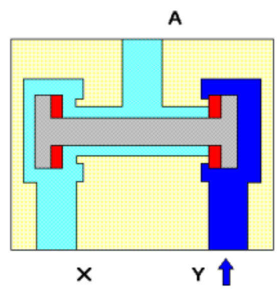
Figure: Check valve

The simplest type of directional control valve is a check valve which is a two way valve because it contains two ports. These valves are also called as on-off valves because they allow the fluid flow in only in one direction and the valve is normally closed. Two– way valves is usually the spool or poppet design with the poppet

- ✓ Dual pressure valves

The two pressure valve has the inlets X and Y and one outlet A. The two pressure valve is used mainly for interlocking controls, safety controls, check functions or logic operations. The application of a signal at Y produces no pressure at A.

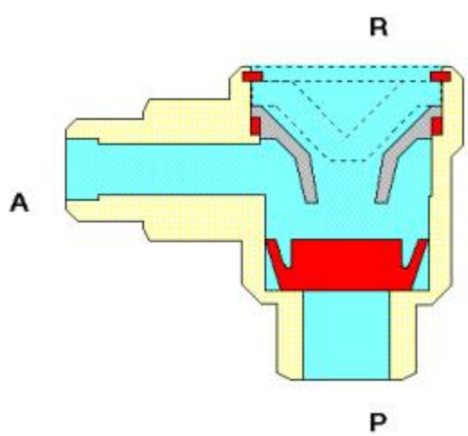


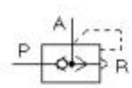




Two pressure valve

- ✓ Quick exhaust valves

Quick exhaust valves are used to increase the piston speed of cylinders. Lengthy return times can be avoided, particularly with single acting cylinders. To reduce resistance to flow, the air is expelled to atmosphere close to the cylinder and through a large orifice. Read more on the previous sections in pneumatic valves.




Quick exhaust valve

- **TOPIC 2: Pressure valves**

Pressure-control valves are found in virtually every hydraulic system, and they assist in a variety of functions, from keeping system pressures safely below a desired upper limit to maintaining a set pressure in part of a circuit.

Pressure-control valves are found in virtually every hydraulic system, and they assist in a variety of functions, from keeping system pressures safely below a desired upper limit to maintaining a set pressure in part of a circuit. Types include relief, reducing, sequence, counterbalance, and unloading. All of these are normally closed valves, except for reducing valves, which are normally open. For most of these valves, a restriction is necessary to produce the required pressure control. One exception is the externally piloted unloading valve, which depends on an external signal for its actuation.

- **TOPIC 3: Flow control valves**

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

- **Plug or glove valve**

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

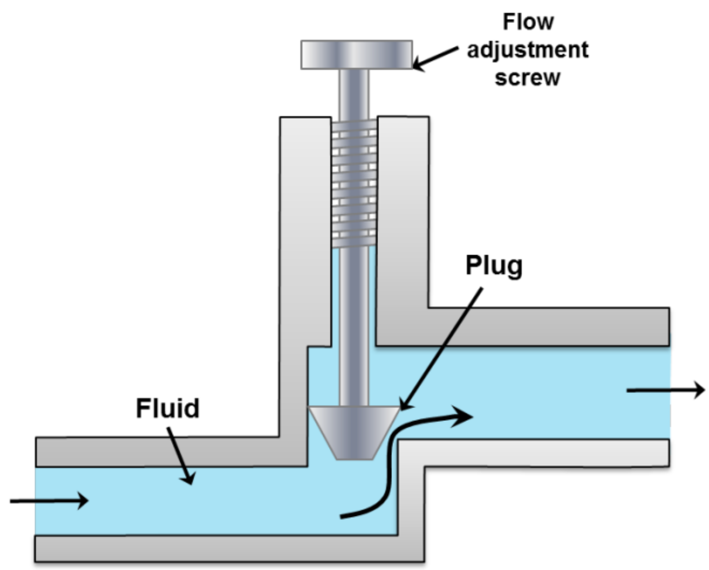



Figure: Plug or glove valve

**2.Butterfly valve**

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

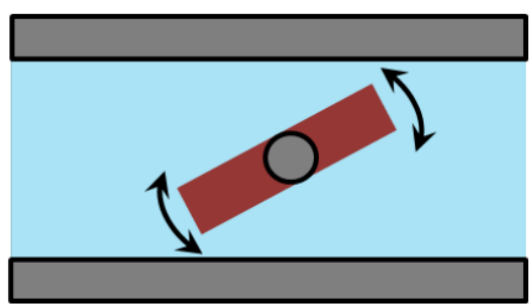


Figure : Butterfly valves

**3 Ball Valve**

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

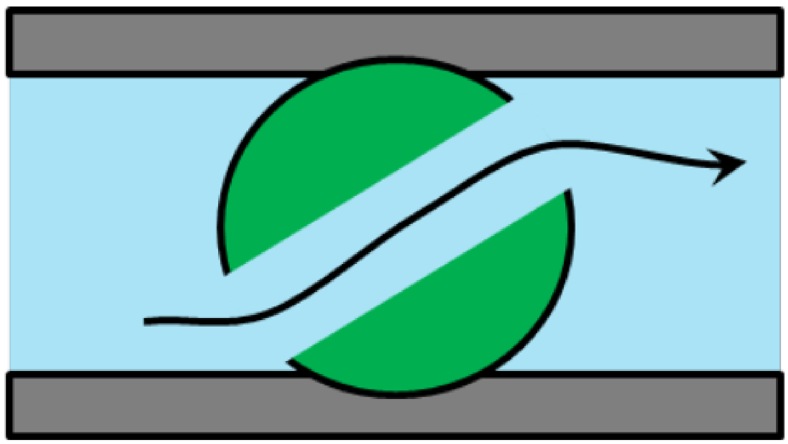


Figure: Ball valve

**4 Balanced valves**

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

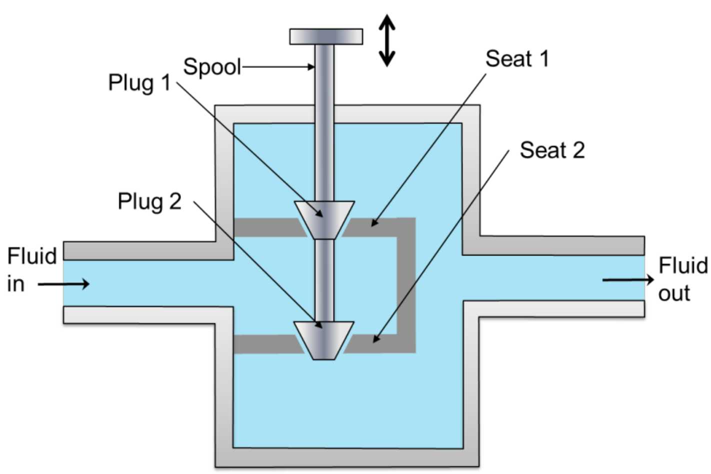
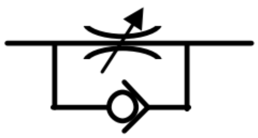



Figure: Balanced valves

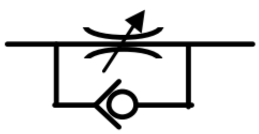
**Symbolic representation of flow control valve**

Fixed Restriction or orifice - Restricts flow in both directions.

Adjustable Restriction - Restricts flow in both directions.



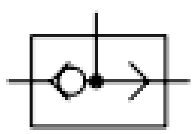
Flow Control Valve - (also called speed control valve) allows free flow in one direction but restricts flow in the other direction. In this example free flow is from right to left, restricted flow from left to right.



In this example, free flow is from left to right. Restricted flow is from right to left.

- **<u>TOPIC 4: Shut- off valves</u>**

Shuttle valves also known as **double check valves**, are used when control is required from more than one power source. In other words, shuttle valves are used to select the higher of the two input pressures automatically and connect to output port. This valve is also known as '**ORGATE'**



Shuttle valve

- **<u>TOPIC 5: Safety valves</u>**

Safety valve also known as safety valve which is used to protect the system against over pressure

Pressure relief valves are used as:

- Safety valves
  A pressure relief valve is termed a safety valve when it is attached to the pump, for example, to protect it from overload. The valve setting is fixed at the maximum pump pressure. It only opens in case of emergency.

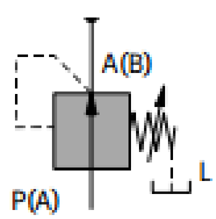



Figure: Safety valve

- **<u>TOPIC 6: Hydraulic and pneumatic accessories</u>**

- ✓ Accumulators

An accumulator is a pressure storage reservoir in which hydraulic fluid is stored under pressure from an external source. These are used to supply additional fluid when main line fluid pump is inadequate to perform the actuation. Usually gas filled bladders at high pressure act on the reservoir of fluid in the accumulator to make up for the required line flow.

**Use of Accumulator:**

**1. Energy Accumulation:**

Accumulators are widely used as a supplementary energy source. The system in which pressurized oil discharged from accumulators is used to operate cylinders enables pumps to be smaller, shortens their cycles, and conserves energy.

**2. Pulse Absorption:**

All pressurized fluid discharged from pumps has a pulse. Pulses produce noise or vibrations that can cause instability or damage devices. The use of an accumulator can attenuate pulses.

**3. Impact Absorption:**

The rapid closure of valves or sudden changes in load within a hydraulic circuit can result in impact pressure in pipes, which can then lead to noise or damage to those pipes or devices. The use of an accumulator can mitigate any such internal shock.

**4. Thermal Expansion Compensation:**

Changes in the volume of a liquid resulting from changes in the temperature within a closed circuit can increase or decrease the internal pressure. An accumulator can be used to mitigate any such fluctuations in the pressure.

**5. Gas Spring:**

The use of the accumulators as a gas spring rather than a metal spring enables larger load systems to be downsized.

**6. Equilibrium Action:**

The accumulators can be used as counter balances. The accumulators smoothly balance the weight or impact of products and machinery via gas pressure.

**7. Leak Compensation:**

The accumulators can compensate for any decreases in pressure due to internal leaks and thus retain the pressure of pressure control circuits or during any maintenance work.

**8. Transfer Barrier:**

The use of a transfer barrier type accumulator enables transfers to take place within the fluid circuit without the different types of fluids or gases mixing.

The major types of accumulators are as follows: pneumatic (gas-loaded), weight-loaded, and spring-loaded.

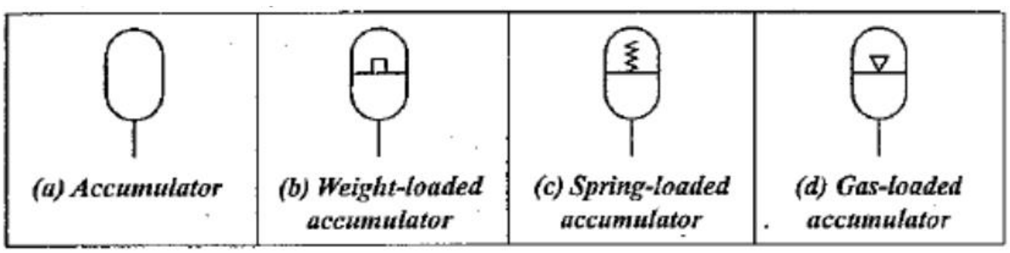



Figure: Various graphical symbol of accumulator

In the pneumatic (gas-loaded) accumulators, gas and oil occupy the same container. When the oil pressure rises, incoming oil compresses the gas. When oil pressure drops, the gas expands, forcing oil out. In most cases, the gas is separated from the oil by a piston (*Figure a*), a bladder (*Figure b*), or a diaphragm (*Figure c*). This prevents mixing of gas and oil, keeping gas out of the hydraulic system.

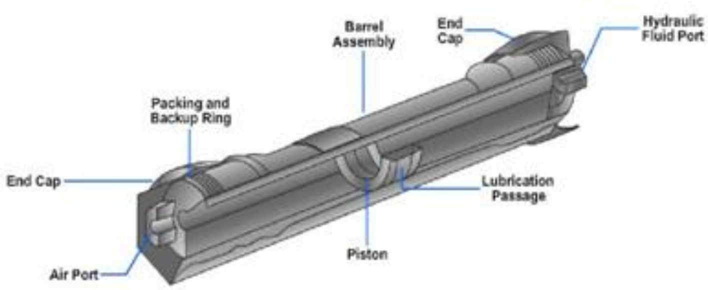



Figure: Floating piston –type accumulator Figure : Piston or Bladder type accumulator

The weight-loaded accumulator uses a piston and cylinder along with heavy weights on the piston for loading or charging the oil. It is loaded by gravity, and operation is very basic. The pressure oil in the hydraulic circuit is pushed into the lower section of the cylinder, raising the piston and weights. The accumulator is now charged and ready for work. The major disadvantages are its bulky size and heavy weight, which render it impractical for mobile equipment.

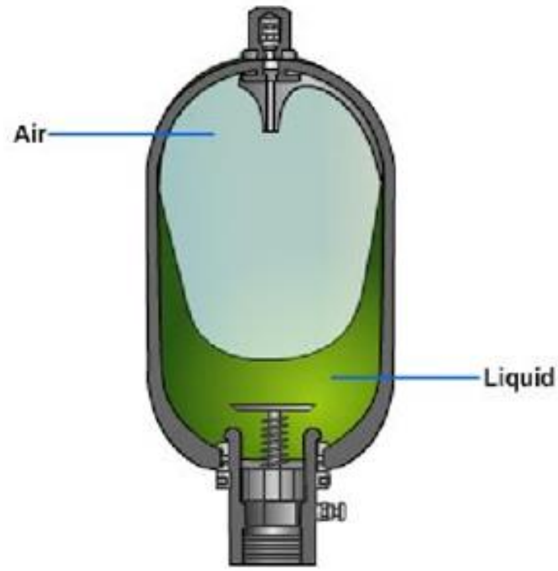



**Figure : b — Bladder-type accumulator.**

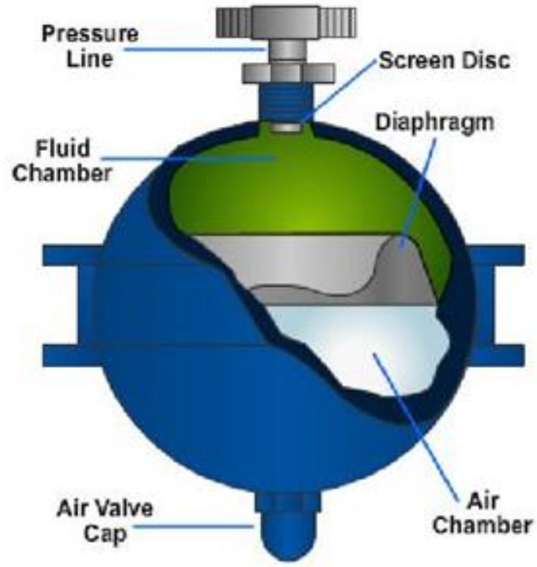



**Figure : c — Diaphragm-type accumulator.**

The spring-loaded accumulator is very similar to the weight-loaded accumulator except that springs do the loading (*Figure d*).

In operation, the pressure oil loads the piston by compressing the spring. When the pressure drops, the spring forces oil into the system

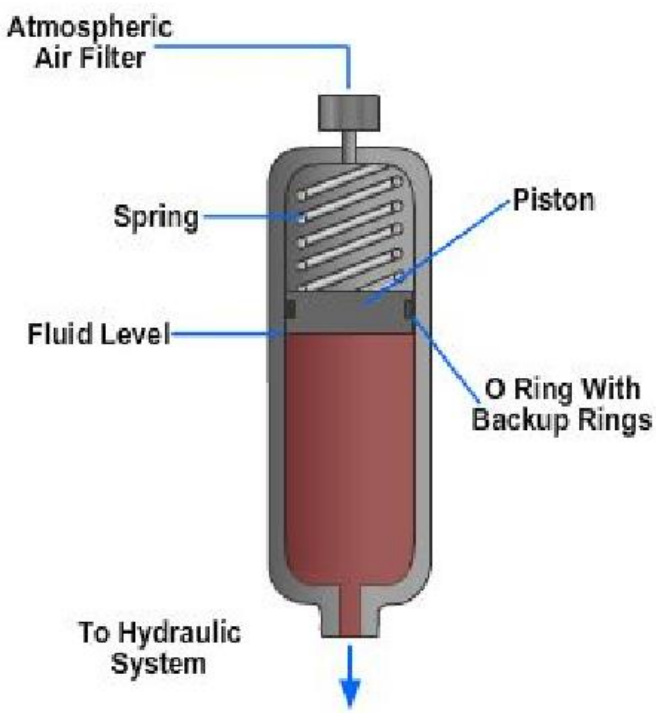



Figure: Spring – loaded accumulator

- ✓ **Coolers**

Some hydraulic systems require an oil cooler to help lower and control the operating temperature of the hydraulic fluid. Two types of coolers are common with hydraulic systems, the air cooler (*Figure A*) and the water cooler (*Figure B*).The air cooler is much like a radiator in an engine assembly, except that instead of coolant flowing through the tubes of the radiator, the hydraulic fluid flows through it. A cooling fan blows across the fins to cool the oil before it is returned to the reservoir.

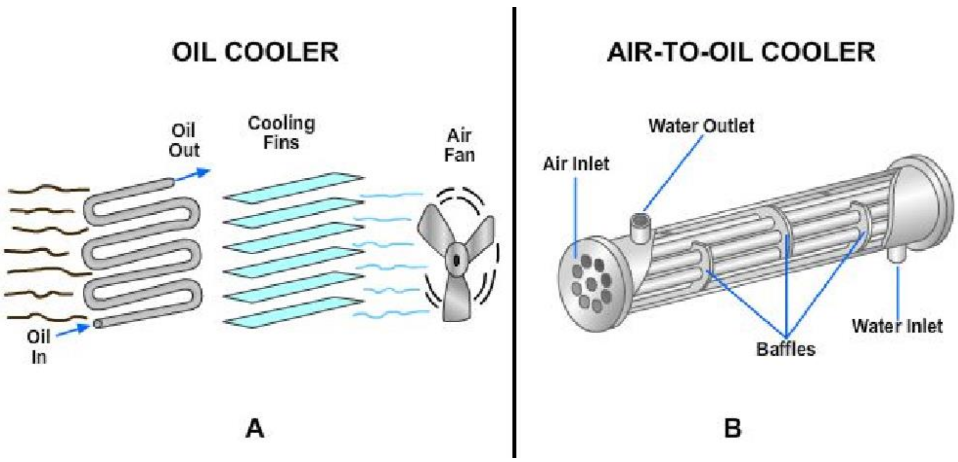



Figure: Types of oil cooler

The water cooler has water flowing through the center of the capsule and the hydraulic fluid is flowed into a series of tubes that surround the water jacket. The cool water removes the heat of the hydraulic fluid as it returns to the reservoir.

**Cooling Fan**

The cooling fan is run off an electrical circuit that blows across the tubes of the heat exchanger. This air circulation cools the hydraulic fluid before returning it to the reservoir

- ✓ **Heat exchangers**

Energy generated by prime movers transforms to thermal energy which increases the temperature
of the working fluid. High temperatures deteriorate the fluid properties and result in shorter fluid life. Hence it is required to cool the oil to certain level for smooth operation.

**Typical heat exchangers used are**:

- **Tubular heat exchangers:** This delivers cooling fluid through copper tubes to accomplish heat exchange between fluid and cooling water.

- **Plate heat exchanger:** This consists of many thin cooling plates which exchange heat with cooling water.
- **Air cooing radiator:** Forced air flows through tubes and cools the fluid
- **Refrigerant exchanger:** This is like a domestic refrigerator and dissipates heat from fluid. It consists of a hydraulic pump, a motor and thermos stat . It is used when accurate temperature control is needed.

**Heaters**: In cold regions, viscosity becomes high causing high pressure loss in the system. Hence electronic heater or steam heaters are used for heating the oil to the desired temperature.

✓ **Joints**

i. **Tubing, Piping, and Hose**

The three types of lines used in fluid power systems are tubing (semi rigid), pipe (rigid),and hose (flexible). A number of factors are considered when the type of line is selected for a particular system. These factors include the type of fluid, the required system pressure, and the location of the system. For example, heavy pipe might be used for a large stationary system, but comparatively lightweight steel tubing is used in the automotive brake system. Flexible hose is required in installations where units must be free to move relative to each other.

The choice between pipe and tubing depends on system pressure and flow. The advantages of tubing include easier bending and flaring, fewer fittings, better appearance, better reusability, and less leakage. However, pipe is cheaper and will handle large volumes under high pressures. Pipe is also used where straight-line hook ups are required and for more permanent installations.

In either case, the hydraulic lines must be compatible with the entire system. Pressure loss in the line must be kept to a minimum for an efficient system. Pipes for hydraulic systems should be made of seamless cold-drawn mild steel. Galvanized pipe should **NOT** be used because the zinc coating could flake or scale, causing damage to the valves and pumps. Tubing used in fluid power systems is commonly made from steel, copper, aluminium, and, in some instances, plastic. Each of these materials has its own distinct advantages or disadvantages in certain applications.
The use of copper is limited to low-pressure hydraulic systems where vibration is limited.

Copper has high resistance to corrosion and is easily drawn or bent. However, it is unsatisfactory for high temperatures and has a tendency to harden and break due to stress and vibration. Tubing constructed of cold-drawn steel is the accepted standard in hydraulics where high pressures are encountered. Steel is used because of its strength, stability for bending and flanging, and adaptability to high pressures and temperatures. Its chief disadvantage is its comparatively low resistance to corrosion. There are two types of steel tubing: seamless and electric welded. Aluminium is limited to low-pressure use, yet it has good flaring and bending characteristics.

Plastic tubing lines are made from a variety of materials; nylon is the most suitable for use in low-pressure hydraulic applications **ONLY**. There are three important dimensions of any tubular product: outside diameter (OD), inside diameter (ID), and wall thickness. Sizes of pipe are listed by the nominal (or approximate) ID and wall thickness. Sizes of tubing are listed by the actual OD and the wall thickness. The material, the inside diameter, and the wall thickness are the three primary considerations in the selection of lines for the circulatory system of a particular fluid power system.

The manufacturers of tubing and pipe usually supply charts, graphs, or tables which aid in the selection of proper lines for fluid power systems. These tables and charts use different methods for deriving the correct sizes of pipe and tubing. Line should normally be kept as short and free of bends as possible. However, tubing should **NOT** be assembled in a straight line because a bend tends to eliminate strain by absorbing vibration and it compensates for thermal expansion and contraction. Bends are preferred to elbows because bends cause less of a power loss. A few of the incorrect and correct methods of installing tubing are shown in *Figure 1.*

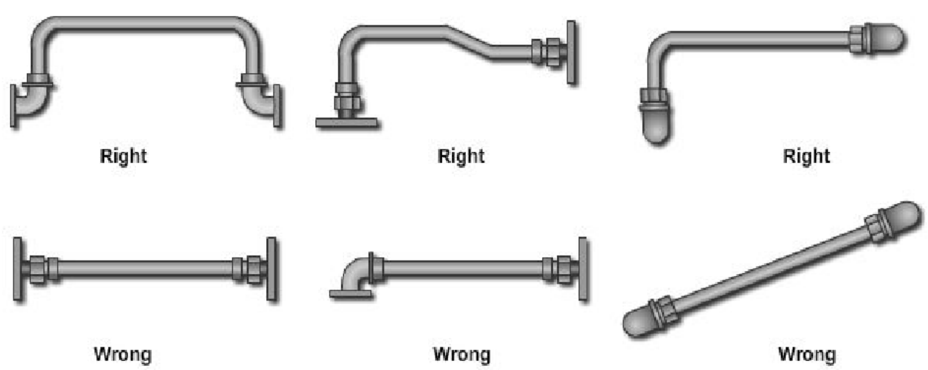



Figure: Correct and incorrect methods of installing tubing

Flexible hose is used in fluid power systems where there is a need for flexibility, such as connection to units that move while in operation or to units attached to a hinged portion of the equipment. It is also used in locations that are subjected to severe vibration. Flexible hose is usually used to connect the pump to the system. The vibration that is set up by the operating pump would ultimately cause rigid tubing to fail.


Figure: Flexible rubber hose construction

Rubber hose is designed for specific fluid, temperature, and pressure ranges and is provided in various specifications. Flexible hydraulic hose is composed of three basic parts: **The inner tube; the reinforcement layers and outer cover**

The inner tube is a synthetic rubber layer that is oil-resistant. It must be smooth, flexible, and able to resist heat and corrosion.

The reinforcement layers vary with the type of hose. These layers (or plies) are constructed of natural or synthetic fibers, braided wire, or a combination of these. The strength of this layer depends upon the pressure requirement of the system.

The outer cover protects the reinforcement layers. A special rubber is most commonly used for the outer layer because it resists abrasion and exposure to weather, oil, and dirt.

Flexible hose must **NOT** be twisted on installation since this reduces the life of the hose considerably and may cause fittings to loosen as well. You can determine whether or not a hose is twisted by looking at the lay line that runs along the length of the hose. This lay line should not tend to spiral around the hose.

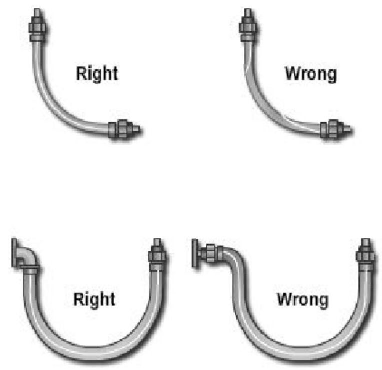



Figure: Correct and incorrect installation of flexible hose.

**Connectors and Fittings**

There are many types of connectors and fittings required for a fluid power system. The type of connector or fitting depends upon the type of circulatory system (pipe, tubing, or flexible hose), the fluid medium, and the maximum operating pressure of the system.

Some of the most common connectors and fittings are described in the following paragraphs.

- Threaded connectors are used in low pressure pipe systems

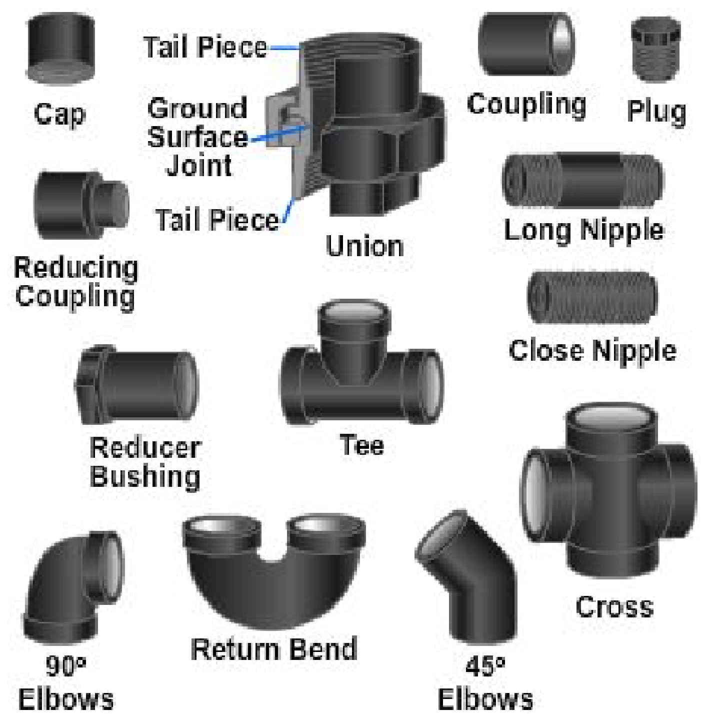
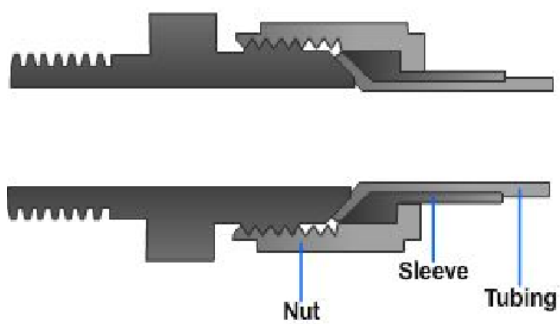


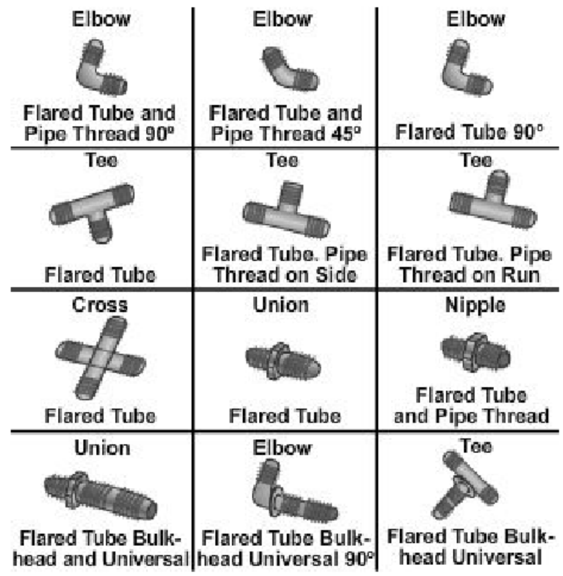

Figure: Threaded pipe connectors

Another material used on pipe thread is sealant tape, made by TEFLON®. This tape is made of polytetraflouroethylene (PTFE), which provides an effective means of sealing pipe connections and eliminates the need of having to torque connections to excessively high values to prevent leakage. It also provides for ease in maintenance whenever it is necessary to disconnect pipe joints.

Flared-tube connectors are commonly used in circulatory systems consisting of lines made of tubing. These connectors provide safe, strong, dependable connections without the necessity of threading, welding, or soldering the tubing. The connector consists of a fitting, a sleeve, and a nut.




— Flared-tube connector.

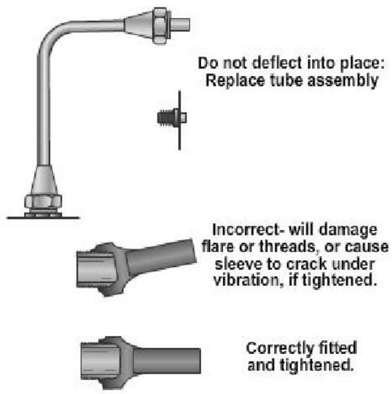



— Flared-tube fittings.

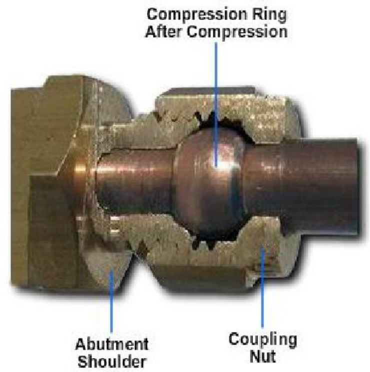
The fittings are made of steel, aluminium alloy, or bronze. The fitting used in a connection should be made of the same material as that of the sleeve, the nut, and the tubing. For example, use steel connectors with steel tubing and aluminium alloy connectors with aluminium alloy tubing. Fittings are made in union, 45-degree and 90-degree elbows, tees, and various other shapes.

- Flareless-tube

Flareless- tube connectors are available in many of the same shapes and threaded combinations as flared tube connectors. The fitting has a counterbore shoulder for the end of the tubing to rest against. The angle of the counterbore causes the cutting edge of the sleeve or ferrule to cut into the outside surface of the tube when the two are assembled.




— Correct and incorrect methods of installing flared fittings.



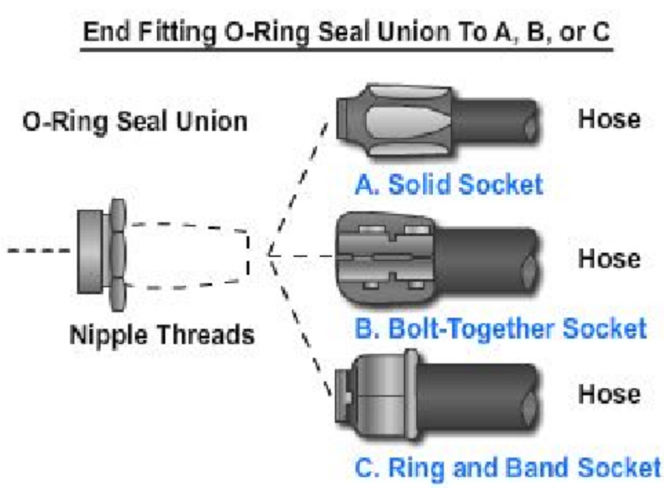

— Flareless-tube connector.

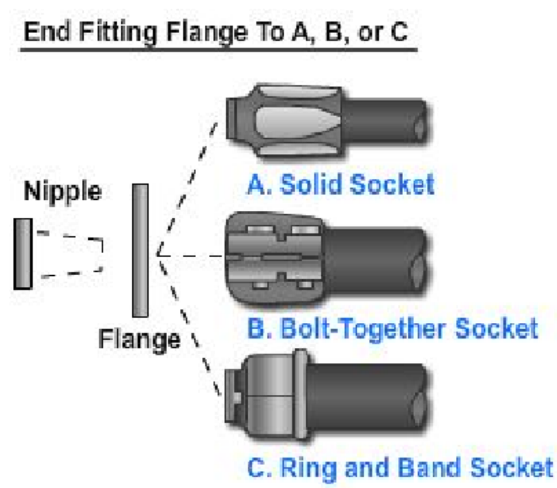
Before the installation of a new flareless-tube connector, the end of the tubing must be square, concentric, and free from burrs. For the connection to be effective, the cutting edge of the sleeve or ferrule must bite into the external surface of the tube.When tube-type fittings are being tightened, observe the following:

Tighten only until snug. **NEVER** over tighten. More damage has been done to tube fittings by over tightening than from any other cause.

- If a fitting starts to leak and appears loose, retighten only until the leak stops.
- Where necessary, use two wrenches on fittings to avoid twisting the lines.

There are various types of end fittings for both the piping connection side and the hose connection side of hose fittings.



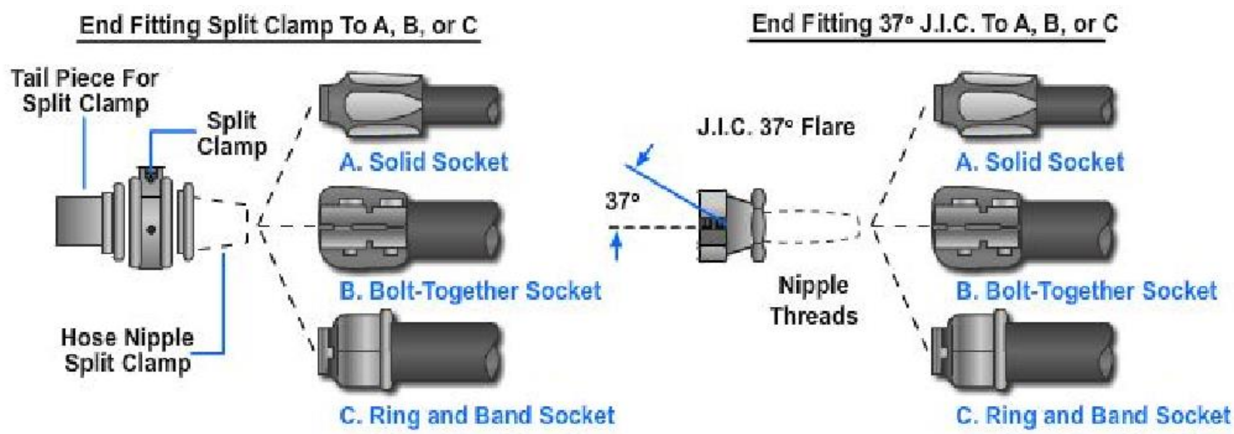



Figure: Flexible hose connectors.


If hoses and fittings are matched incorrectly, the results can be pinhole leaks, ruptures, heat buildups, pressure drops, cavitations, and other failures. Quick disconnect couplers are used where oil lines must be connected or disconnected frequently. They are self-sealing devices and do the work of two shutoff valves and a tube coupler.

These couplers are fast, easy to use, and keep oil loss at a minimum. More importantly, there is no need to drain or bleed the system every time a hookup is required. However, dust plugs must be used when the coupler is disconnected.

- ✓ **Flanged connectors**

Flange connections are used for larger pipes . The flange may either be screwed or welded onto the pipe. The diagram shows two flange connections, one for the pipe and one for the hose .B.S.F thread , metric fine thread and NPT(tapered thread) are commonly used in hydraulics as connecting threads.

Figure: Two flange connections

# LEARNING UNIT3: RUN PNEUMATIC/HYDRAULIC SYSTEMS

## LEARNING OUTCOME 3.1: USE SWITCHING/VALVES DEVICES

**TOPIC 1: Types of control**

Cylinders are the output elements of a pneumatic/Hydraulic system. There are two ways of controlling the cylinder motion (system output):

**Pneumatic cylinders can be controlled by the following methods:**

- Direct control of Single or Double acting cylinder
- Indirect Control of Cylinder with Single Piloted Final Control Valve
- Indirect Control of Cylinder with Double Piloted Final Control Valve
  In the indirect control actuation, a pilot signals from a 3/2 N.C. valve is used to activate pilot ports of final control valve.
    - ✓ **Direct control**

The simplest level of control for the single or double-acting cylinder involves direct control signals. Using this type of control, **the cylinder is actuated directly via a manually or mechanically actuated valve, without any intermediate switching of additional directional control valves.** If the port sizes of the valve are too large, the operating forces required may be too great for direct manual operation. Example Circuits below illustrate the idea of direct actuation.

**Reference values for limits of direct cylinder control:**
- Cylinder with piston diameter smaller than 40 mm
- Valves with connection sizes smaller than 1/4"

- **Direct Control of Single Acting Cylinder**

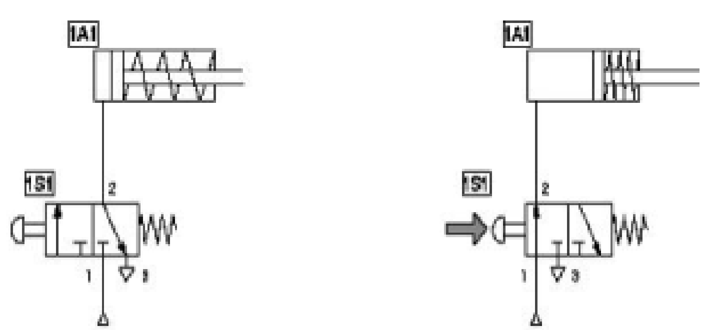



Figure: Direct Control of Single Acting Cylinder

Pneumatic cylinders can be directly actuated by actuation of final control valve, manually or electrically in small cylinders as well as cylinders which operates at low speeds where the flow rate requirements are less. When the directional control valve is actuated by push button, the valve switches over to the open position, communicating working source to the cylinder volume. This results in the forward motion of the piston. When the push button is released, the reset spring of the valve restores the valve to the initial position [closed]. The cylinder space is connected to exhaust port there by piston retracts either due to spring or supply pressure applied from the other port.

**Double acting cylinder**

**Direct control**

The only difference between a single acting cylinder and a double acting cylinder is that a double acting cylinder uses a 5/2 directional control valve instead of a 3/2 directional control valve (Figure below). Usually, when a double acting cylinder is not operated, outlet ‘B’ and inlet ‘P’ will be connected. In this circuit, whenever the operation button is pushed manually, the double acting cylinder will move back and forth once.

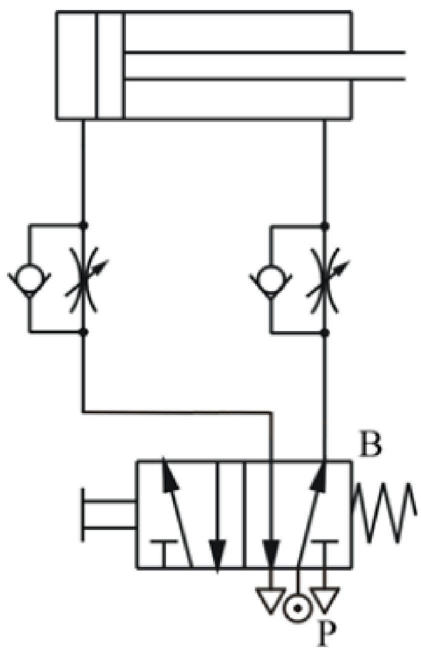



Figure: Circuit diagram of a double acting cylinder direct control circuit

- ✓ **Indirect control**

**Cylinders with a large piston diameter have a high air requirement**. A control element with high nominal flow rate must be used to actuate these. If the force should prove too high for a manual actuation of the valve, then an indirect actuation should be constructed, whereby a signal is generated via a second smaller valve, which will provide the force necessary to switch the control element.

**Indirect Control of Single Acting Cylinder**

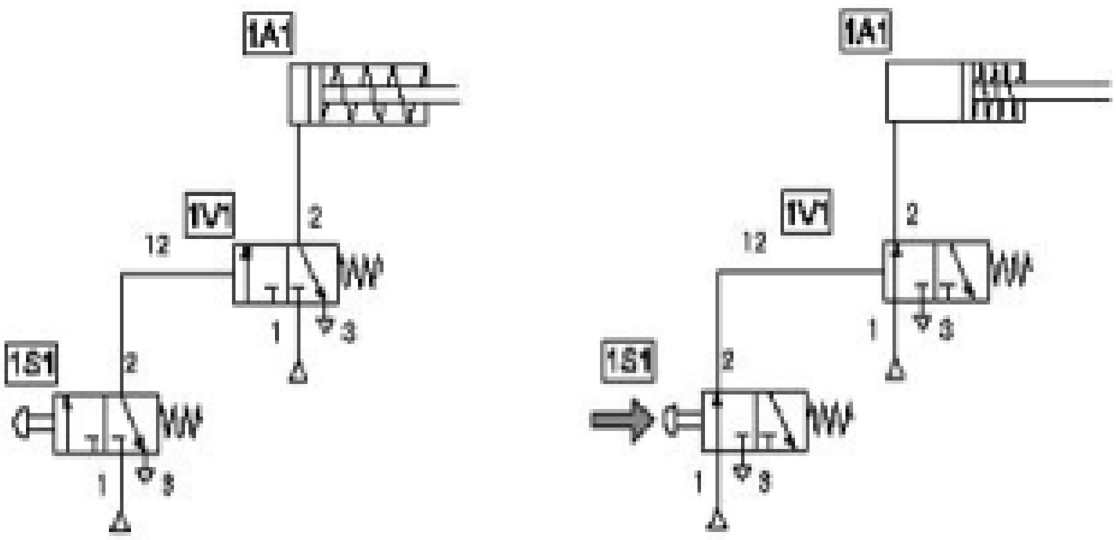
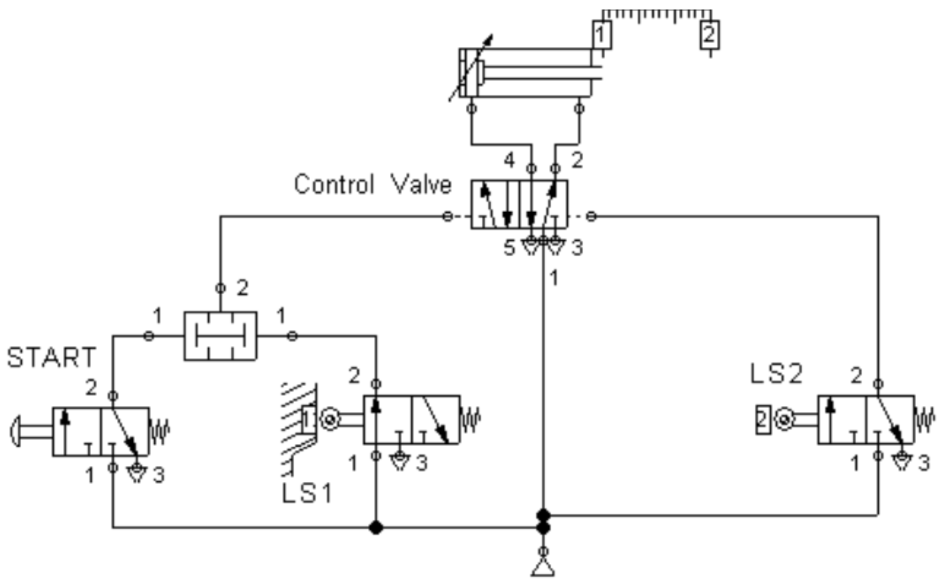



Figure: Indirect Control of Single acing cylinder

Large cylinders as well as cylinders operating at high speed are generally actuated indirectly as the final control valve is required to handle large quantity of air. In the case of pilot operated valves, a signal input valve [3/2 way N.C type, 1S1] either actuated manually or mechanically is used to generate the pilot signal for the final control valve. The signal pressure required can be around 1-1.5 bar. The working pressure passing through the final control valve depends on the force requirement [4-6 bar]. Indirect control as permits processing of input signals. Single piloted valves are rarely used in applications where the piston has t o retract immediately on taking out the set pilot signal -.suitable for large single acting cylinders.

**Double acting**

Design a pneumatic circuit such that a double acting cylinder advances upon pressing "START" push button if it is fully retracted and will retract upon reaching its full extent.
**(Use a 5/2 pneumatically actuated control valve and use limit switches to detect the position of the cylinder)**
The pneumatic circuit and parts' list needed to perform this operation are shown by Figure below




| Designation | Component Description |
|---|---|
| | Two pressure valve |
| Control Valve | Control Valve |
| START | START PB |
| LS1 | Limit switch 1 |
| LS2 | Limit switch 2 |
| | Compressed air supply |
| | Double acting cylinder |

- **TOPIC 2: Different valves used in hydraulic / hydraulic system**
    - ✓ **Loading valves**

A loading valve is a type of valve which is designed to provide a fixed back pressure for dosing pump(dosing pump: A small pump that is known as positive displacement pump. This means that it pumps at a very precise rate of flow and can pump a chemical or other substance into water, Steam or gas ) to work against .

Working against a fixed back pressure provides a number of advantages to many common dosing applications. For instance, when dosing into a pipeline, the pressure must be stable because when the pipe pressure/back pressure varies, the corresponding volume of reagent delivered by the pump will also vary.


Figure: Pressure loading valve

✓ **Control valves**

Control Valves are devices used to control pressure, flow direction, or flow rate in hydraulic circuits. The control valves utilize mechanical motion to control the distribution of hydraulic energy within the system.

Control valves are classified into three basic types, based on their function in the hydraulic system, as:

a. **Directional control valves (DCVs)**

They determine the path through which a fluid transverses a given circuit.

b. **Pressure control valves**

They protect the system against overpressure, which may occur due to a sudden surge as valves open or close or due to an increase in fluid demand.

c. **Flow control (or volume control) valves**

Flow control valves also known as **volume – control valves,** are used to regulate the volumetric flow of the compressed air to different parts of the pneumatic system.


Figure: Control valve

✓ **Pilot-operated valves**

With large capacity pneumatic valves (particularly poppet valves) and most hydraulic valves, the operating force required to move the valve can be large. If the required force is too large for a solenoid or manual operation, a two-stage process called pilot operation is used. The principle is shown in Figure below. Valve 1 is the main operating valve used to move a ram. The operating force required to move the valve, however, is too large for direct operation by a solenoid, so a second smaller valve 2, known as the pilot valve, has been added to allow the main valve to be operated by system pressure.

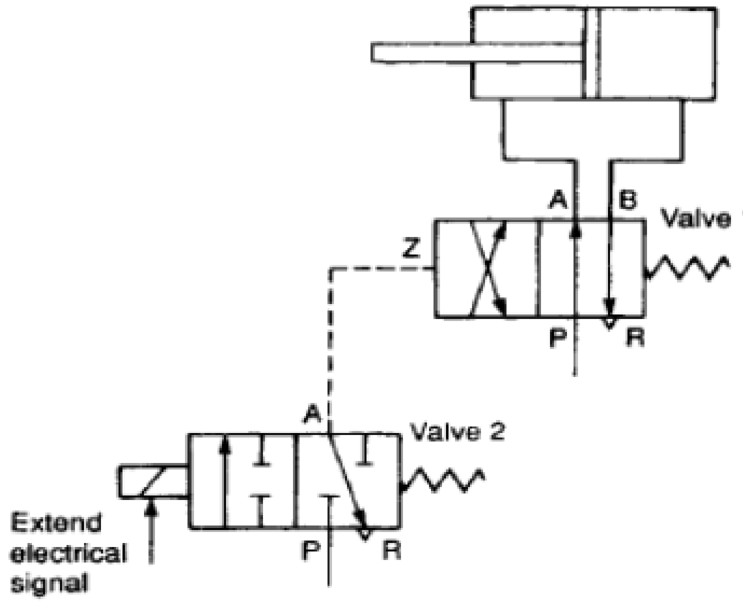



Figure: Pilot-operated valves

✓ **Check valves**

Check valve is a valve that normally allows fluid (liquid or gas ) to flow through it in only one direction.

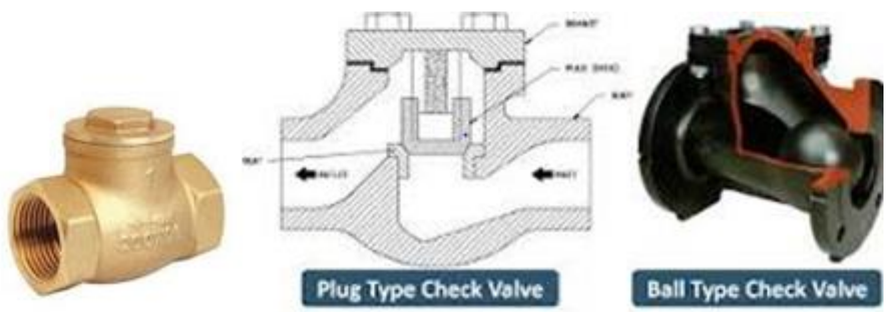



Figure: Check valve

✓ **Sequence valves**

Sequence valves are valves used extensively for sequencing operations when two or more cylinders are involved.

✓ **Time – delay valves**

The combined functions of various elements can produce a new function. The new component can be constructed by the combination of individual elements or manufactured in a combined configuration to reduce size and complexity.

The delay time is generally 0-30 seconds for both types of valves. An example is the timer which is the combination of a one way flow control valve, a reservoir and a 3/2 way directional control valve.

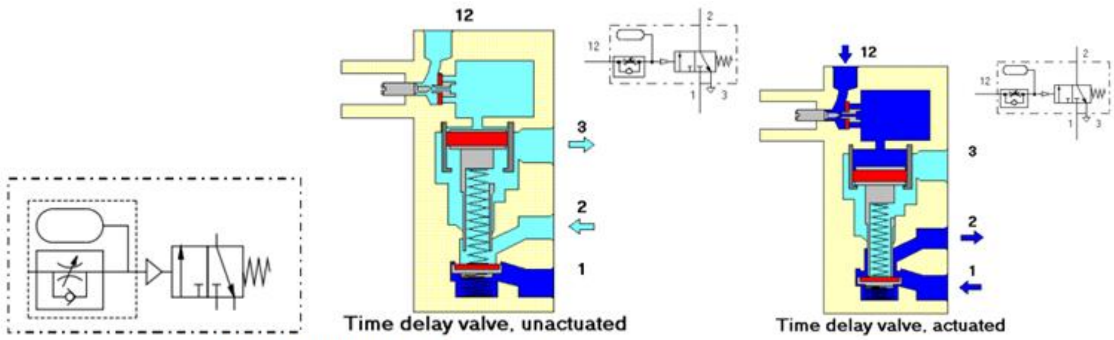
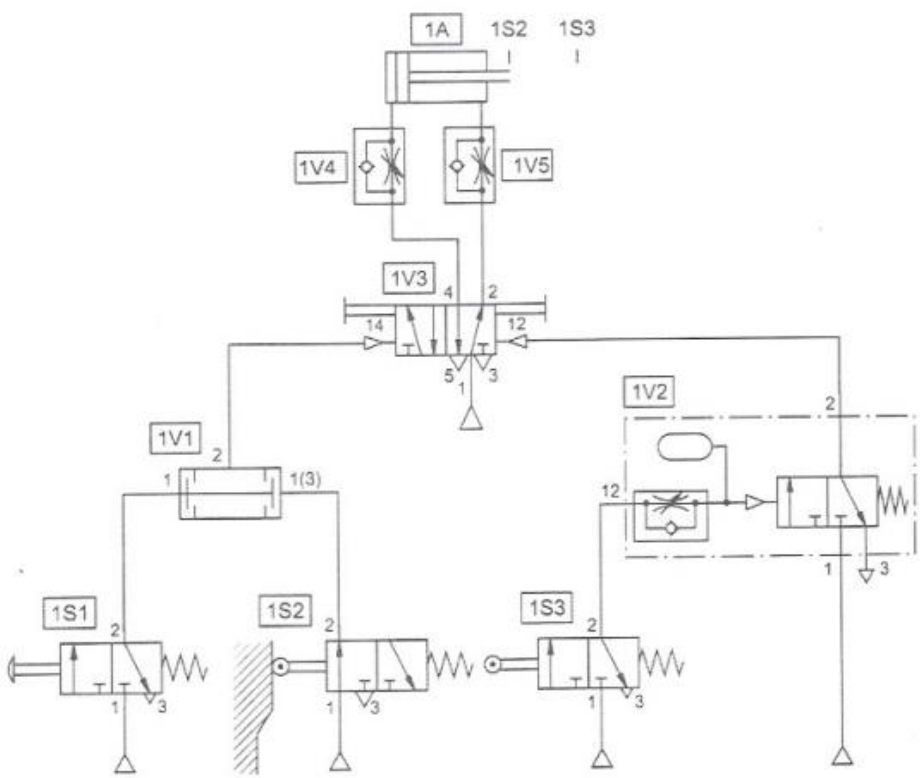


Figure: pneumatic Time delay valve

**Example 1:** *The timer delay valve*

A double-acting cylinder is used to press together glued component. Upon operation of a push button, the clamping cylinder extends. Once the fully advanced position is reached, the cylinder is to remain a time of T= 6 seconds and then immediately retract to the initial position.
The cylinder retraction is to be adjustable. A new start cycle is only possible after the cylinder has fully retracted.



*Circuit Diagram*

- ✓ **Servo- valves**

- These valves receive the output signal from the amplifier to actuate the servo valve torque motor.
- A servo valve is nothing but a DC valve having infinitely variable positioning capability. In other words, Servo valve is an infinite position valve.
- The servo valves are used to control not only the direction of fluid flow, but also the amount of flow. When servo valves are coupled with feedback devices, they can be used to control the position, velocity, and acceleration of the actuator accurately.

Types of servo valves

The important types of servo valves are given below:

1. Mechanical – type servo valve, and
2. Electro-hydraulic servo valve
   i. Single – stage servo valve
   ii. Two- stage servo valves
   iii. Jet pipe servo valve , and
   iv. Flapper jet servo valve

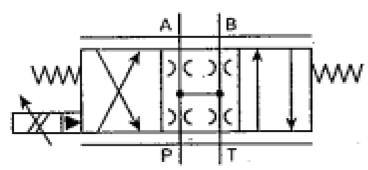



Figure: Symbol of a four- way servo valve

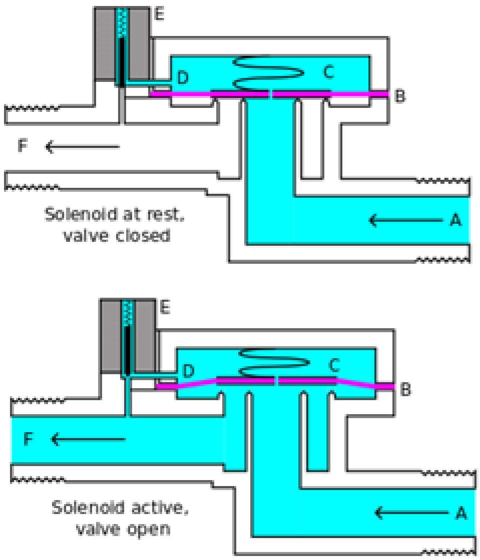
- ✓ **Cartridge valves**

Cartridge valve ,also known as 2/2-way valves or logic elements,are industrial hydraulic valves used for directional, pressure, check and  flow control. These cartridge valves are a compact design that can be used in hydraulic manifold systems for many types of industrial and mobile machinery.


Figure: Cartridge valve

- ✓ **Solenoid operated valve**

A solenoid valve is an electromechanical operated valve. They are the most frequently used control elements in fluidics. Their task is to shut off, release, dose, distribute or mix fluids. Solenoids offer fast and safe switching , high reliability, long service life, good medium compatibility of the materials used, low control power and compact design.




A – Input valve
B- Diaphragm
C- Pressure chamber
D- Pressure relief passage
E- Electro mechanical solenoid
F-Out put

Figure: Solenoid operated valve

## LEARNING OUTCOME 3.2: START PNEUMATIC / HYDRAULIC SYSTEMS

- **TOPIC 1: Methods of starting hydraulic /pneumatic systems**

In a hydraulic/Pneumatic system, **fluid power** provides the "**muscles**" or power to do work, while a **control** part provides the "**brain**" to command system operation. Control of a hydraulic/pneumatic system may range from the simple starting and stopping of the system to controlling extension and retraction of several cylinders in a completely automated factory.

A hydraulic/pneumatic system can be controlled either manually or automatically:

- **Manual** control: system operation is sequenced and commanded by an **operator** that decides each action to take.
- **Automatic** control: system operation is sequenced and commanded by a **controller** that decides each action to take. Automatic control can be accomplished by means of:

1. Electrical signals (**electrical control**);
2. Compressed air (**pneumatic control**);
3. Mechanical link (**mechanical control**).

Manual control is good for system operations which do not require constant repetition. An earth-moving truck such as those used in construction, farming, and mining is a common example of a machine requiring manual control. Since the operator must constantly change the position to where the shovel digs and the depth at which the shovel digs, automatic control could not be used because the sequence of operations is not repetitive.

In systems requiring the repetition of a series of operations, however, it would be inefficient to manually shift the hydraulic valves each time the direction of oil flow needs to be changed. As an example, Figure 1-1 shows manual and automatic (electrical) operation of a hydraulic drilling system.

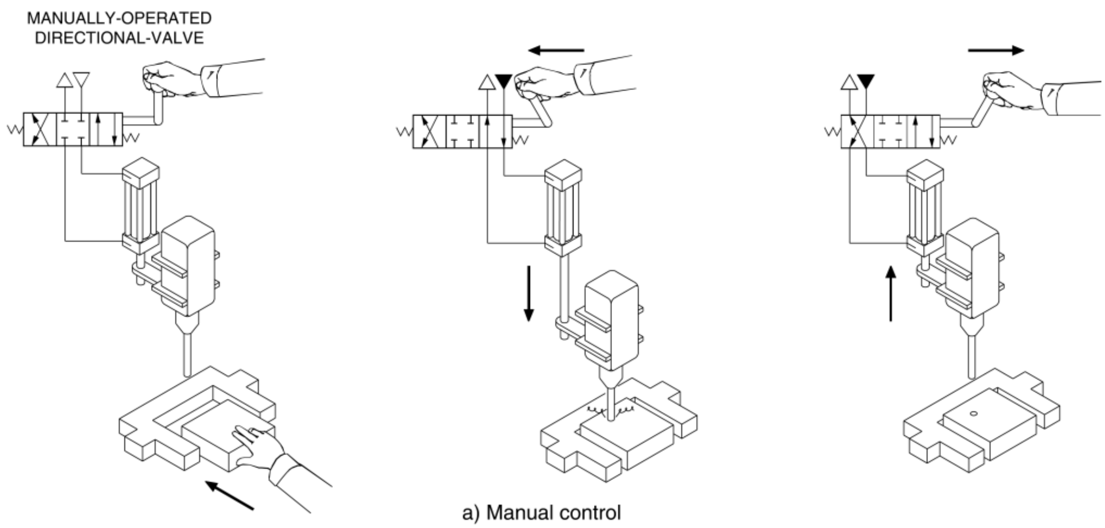


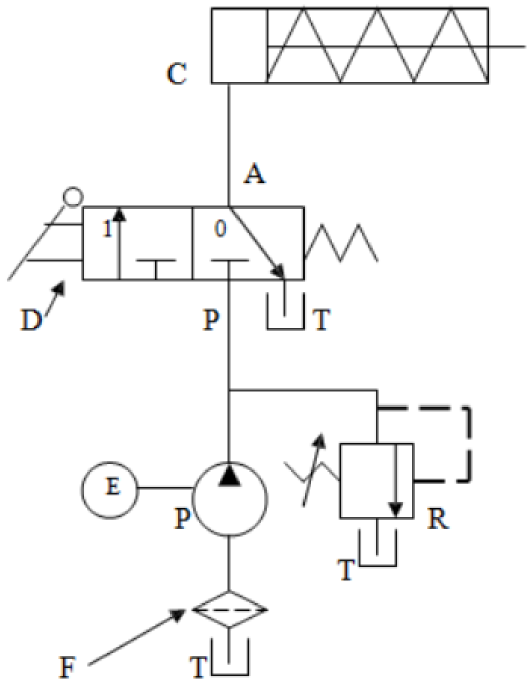

Figure a: Manual control

- **TOPIC 2: Selection of starting mode according to the work intended**

Below are other some examples of different starting mode according to intended work

1. **Control of a Single- Acting Hydraulic Cylinder**

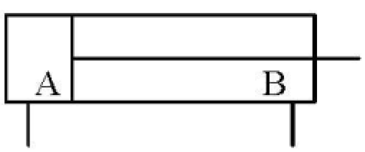
In single acting cylinder hydraulic force is exerted on the piston for forward movement (to right in the figure shown). For retraction, no hydraulic force is applied and the rod moves (to left) due to a spring force or weight of the piston and rod .Figure shows a two-position, three way, manually operated, spring offset directional control valve ( DCV ) used to control the operation of a single – acting cylinder.



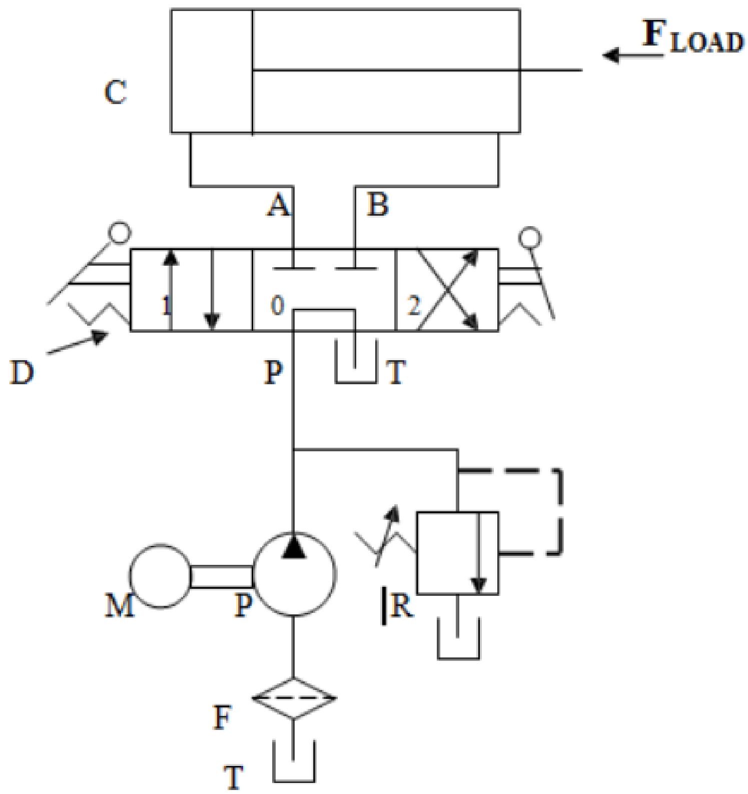

As valve is moved to occupy position 1 (left) flow goes to rod end and rod is pushed to right. When valve is moved to position 0, i.e. shifted to right indicated position, flow from pump is blocked in the valve. There is no hydraulic pressure on the piston side. The flow goes to tank via relief valve at the set pressure. The actuator moves to left due to spring force acting on the rod end of piston.

1. **Control of Double Acting Hydraulic Cylinder**:

Double –Acting cylinders can be extended and retracted hydraulically. Thus, an output force can be applied in two directions.




Double acting cylinder



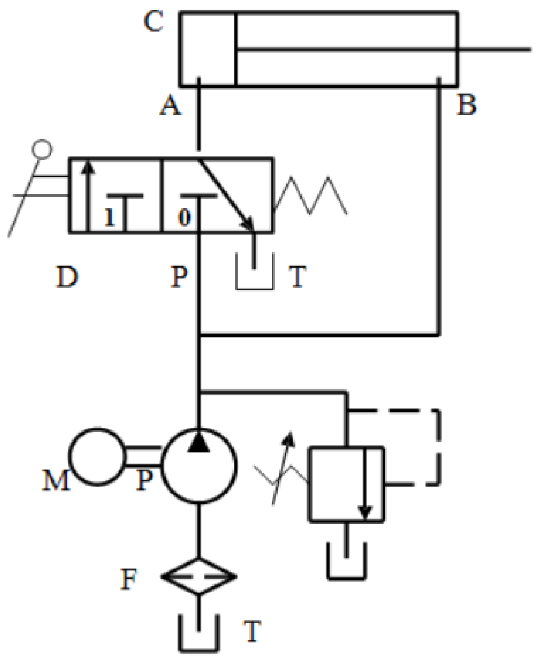

The valve is manual 3postion /4-way valve. In the neutral or valve central (0) position, oil from pump goes to tank, and no action on actuator. Note that the valve does not go through relief valve to tank, thereby saving power (Pressure set in relief valve x pump flow rate ).

There is minor power loss due to drop in valve orifices, and piping. In position 1 of valve, oil flow is P to A. ie. from pump to piston side and rod moves to right acting on the load.

Oil from rod side chamber of cylinder goes to tank (B to T). In position 2, Oil from pump goes to rod end (P to B) and Oil from piston end goes to tank. (A toT) thereby pushing the rod (load) to left.

2. **Regenerative circuit:**

Operation: Figure shows a regenerative circuit that is used to speed up the extending speed of a double-acting hydraulic cylinder.



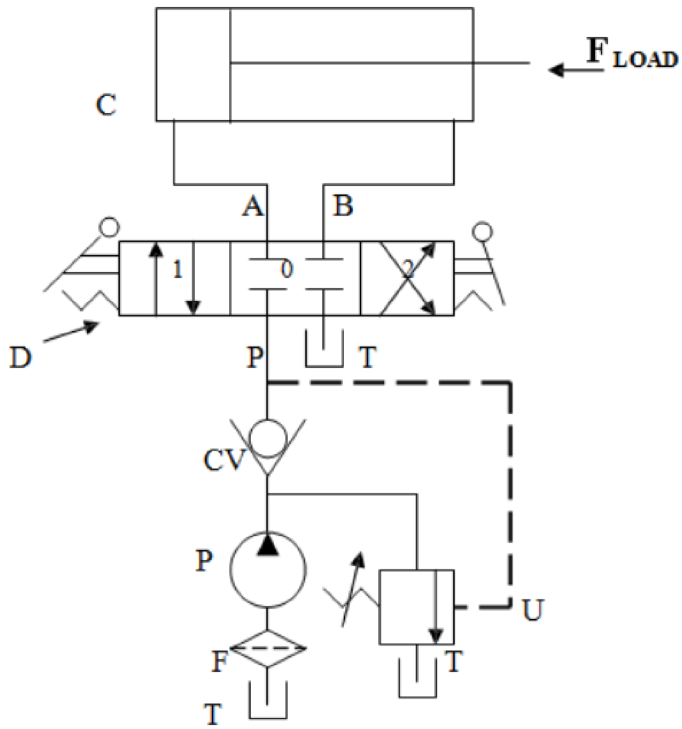

It can be seen that in position 1 when pump is connected to piston side chamber, ie., when main load is operated, fluid from piston side also flows into it. Thereby the flow rate is more than pump flow. Thus the velocity of actuation on piston side is increased by the ratio ( **Ap /Ar**), where Ap is the piston area and **Ar** is the rod area.

However, the net force due to the piston rod is reduced to **Ar x Pressure**. In position 2, when flow is directed to rod side, oil from the piston side flows to tank directly.

3. **Pump Unloading Circuit**

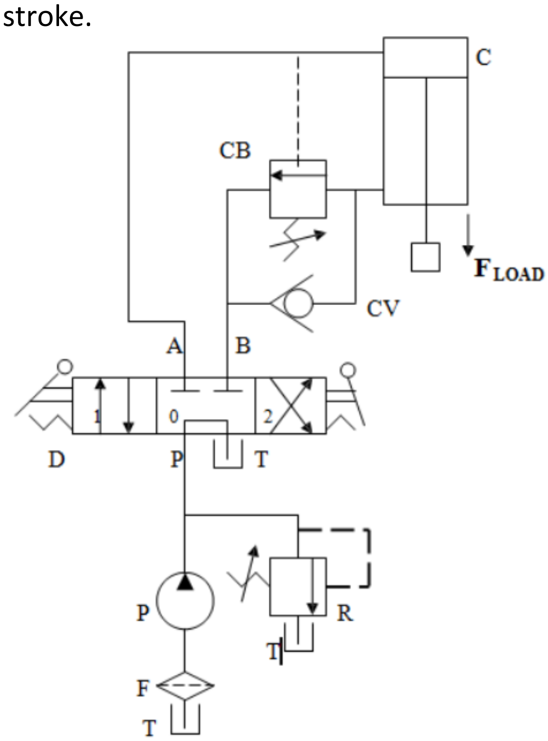
The figure shows a circuit using an unloading valve to unload a pump. The unloading valve opens when the cylinder reaches the end of its extension stroke because the check valve keeps high-pressure oil in the pilot line of the unloading valve. When the DCV is shifted to retract the cylinder, the motion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

This resets the unloading valve until the cylinder is fully retracted, at which point the unloading valve unloads the pump. Thus, the unloading valve unloads the pump at the ends of the extending and retraction strokes as well as in the spring-centered position of the DCV.




4. **Counter Balance Valve Application**

Counter balance valve is used to hold loads in vertical position without descending while idling in neutral position. Rod side fluid cannot flow unless a pilot pressure acts on the valve and permits flow to tank. The valve spring so set that pressure required is higher than for upward stroke.



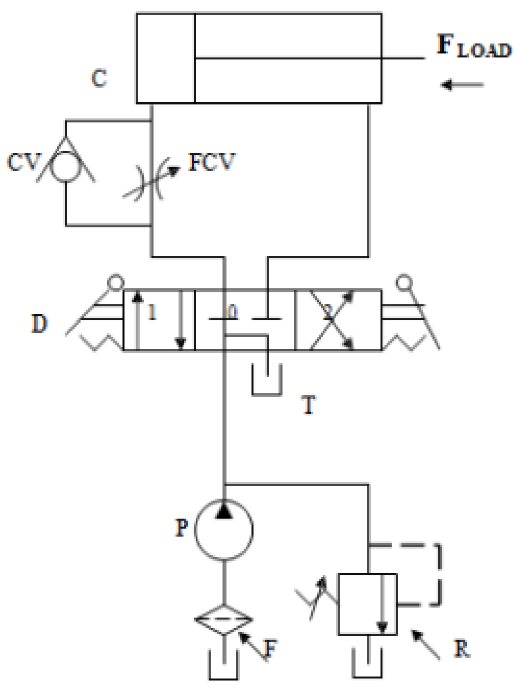
5. **Speed Control**

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

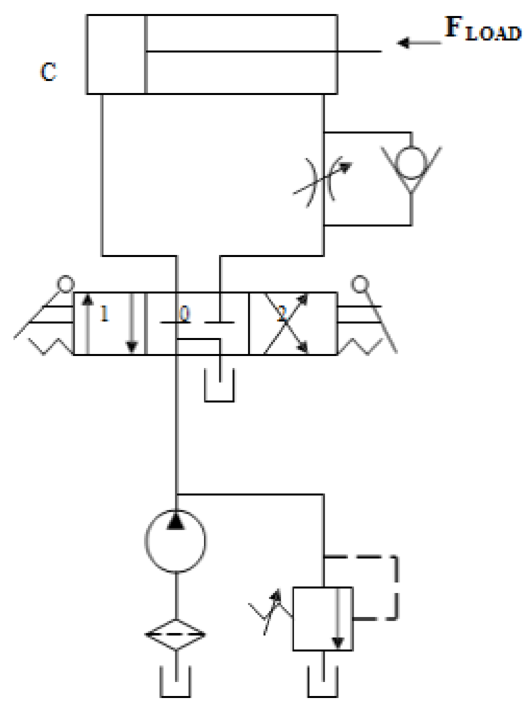
***There are 3 types of speed control:***

- Meter-in circuit ( Primary control )
- Meter-out circuit ( Secondary control )
- Bleed -off circuit ( By pass control )

1. **Meter – in Circuit**: In this type of speed control, the flow control valve is placed between the pump and the actuator. Thereby, it controls the amount of fluid going into the actuator. Figure below shows meter-in circuit.When the direction is reversed, oil from piston side flows to tank via check valve as well as FC valve freely. The excess flow is dumped to tank via relief valve.



Meter – in circuit.



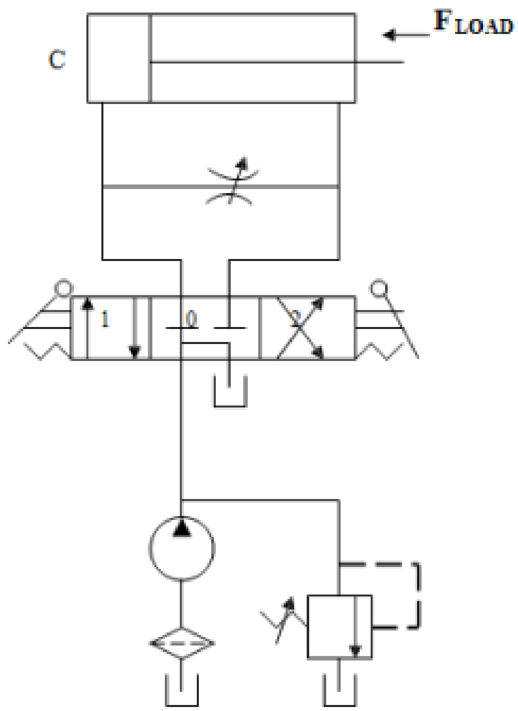
Meter – out Circuit.

2. **Meter – out Circuit**: In this type of speed control, the flow control valve is placed between the actuator and the tank . Thereby, it controls the amount of fluid going out of the actuator and thereby the speed of retraction.

Meter out circuits are useful to control free fall of loads due to gravity etc. connected to the load. Oil is dumped at load pressure but not at relief valve set pressure. However, meter –out can lead to high pressure intensification sometimes twice supply pressure, leading to damage of seals etc. Still it is favored in drilling, reaming and milling when it is required to control the tool feed rate.

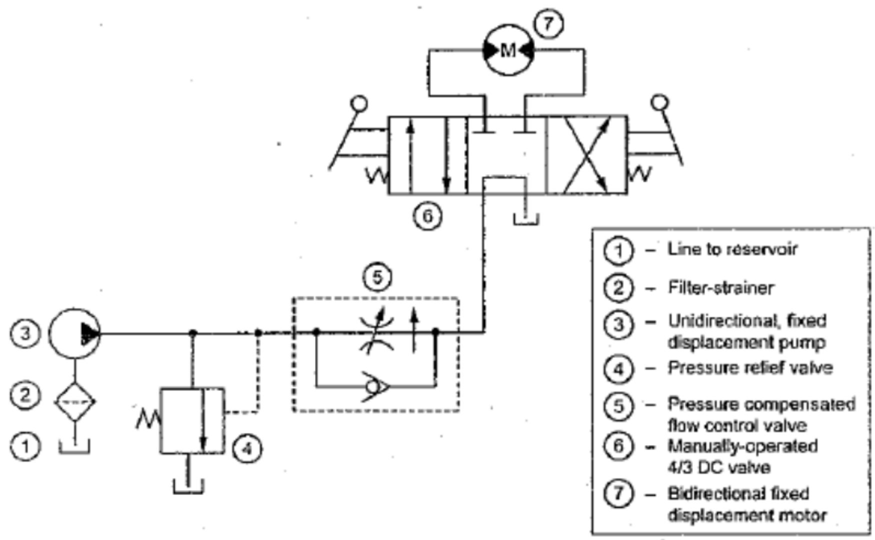
3. **Bleed off circuit**:

This circuit is used to overcome the disadvantages of meter-in and meter out circuits. Here, a flow control valve is kept between either ends. Flow is controlled in each direction, and excess flow to tank is not through relief valve.

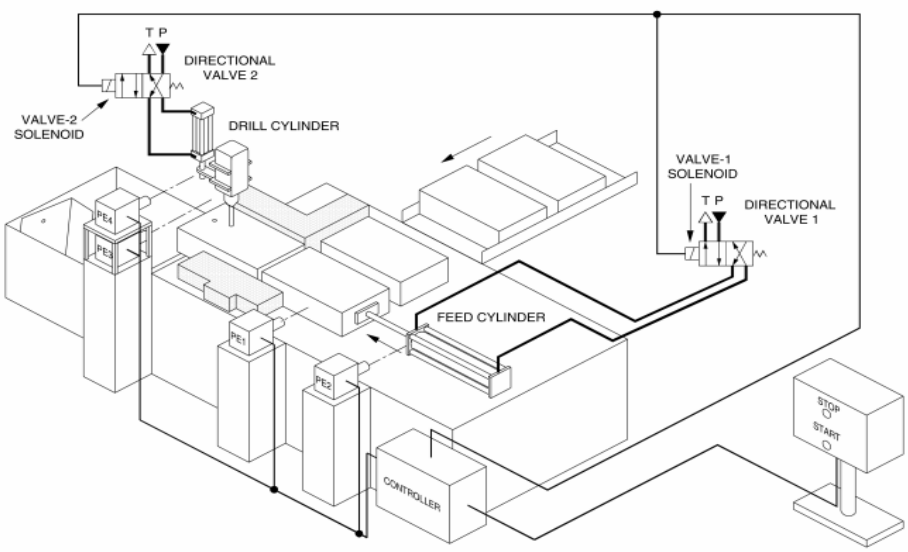



Bleed – 0ff Circuit.

**SPEED CONTROL OF HYDRAULIC MOTOR**




**AUTOMATIC CONTROL**



b) Automatic (electrical) control

Figure: Automatic control

**Basic principles of electrical control**

Electrical control is by far the most popular type of automatic control used for industrial hydraulic applications. As Figure 1-2 shows, an electrical control circuit consists of the following parts:

1) **Input element(s)**
2) **Controller**
3) **Actuating mechanism(s)**

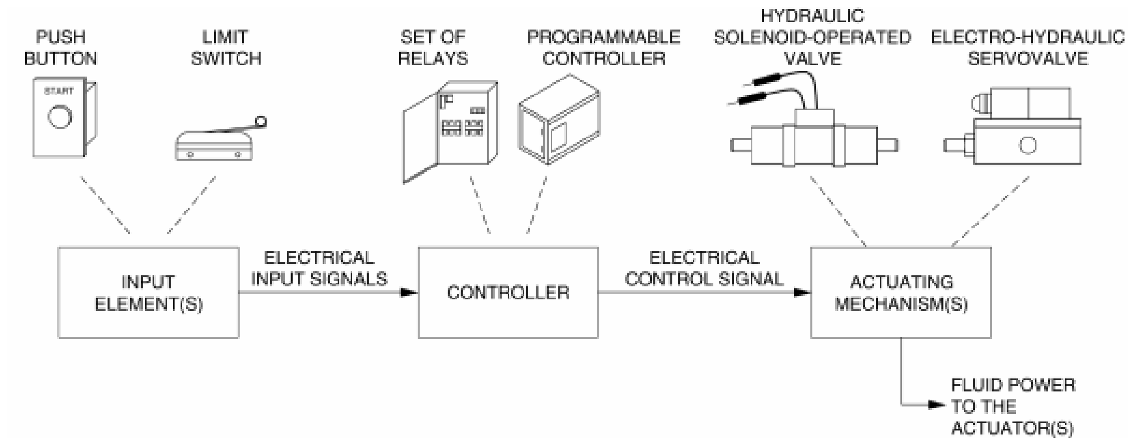



**Figure: Breakdown of an electrical control circuit.**

An **input element** is a device that provides an electrical signal to indicate that a hydraulic actuator (cylinder or motor) has reached a specific position, or that it is time to start the sequence of operations. Examples of input elements are limit switches, pushbutton switches, and relay contacts. The signal issued from input elements called **input signal** because it is sent to the input of a controller.

A **controller** is a device that decides what action to take based on the signals sent to it from the input element(s). The controller may be a set of electromechanical relays, a programmable logic controller (PLC), or a computer. The signal issued from the controller is called **control signal** because it is used to control the motion of a hydraulic actuator through an actuating mechanism.

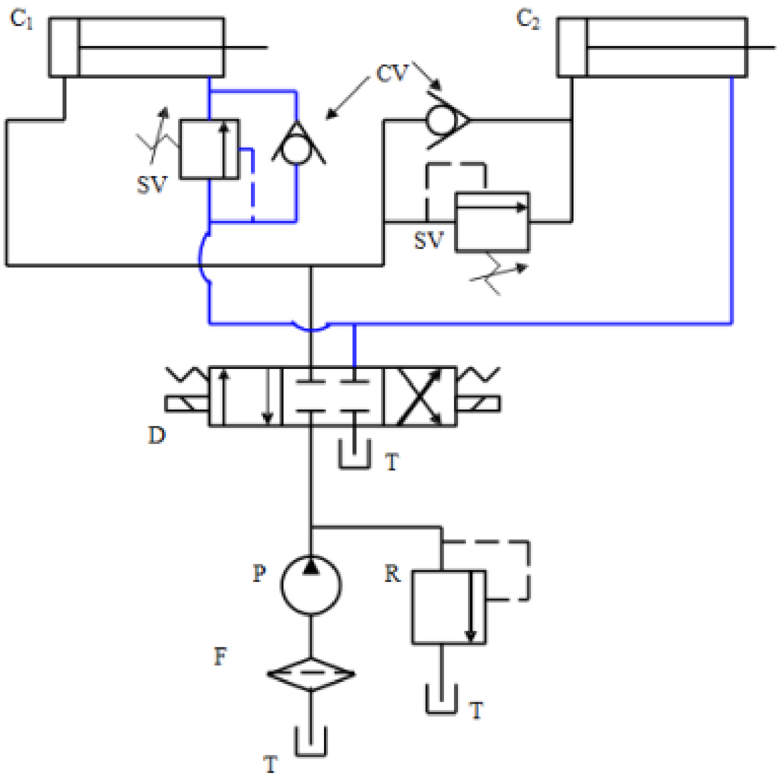
An **actuating mechanism** is a device that provides oil flow to a hydraulic actuator according to the control signal sent to it from the controller. Examples of actuating mechanisms are hydraulic solenoid-operated valves and electro-hydraulic servo valves.

**Some examples of automatic control are listed below:**

6. **Hydraulic Cylinder Sequencing Circuits:**

Figure shows an example where two sequence valves are used to control the sequence of operations of two double-acting cylinders C1 and C2 . When the DCV is shifted into its left position, the left cylinder extends completely, and pressure builds up and only when the left cylinder pressure reaches the pressure setting of sequence valve, the sequence valve connected to the right cylinder opens and permits flow to rod end of C2, and extend it.

If the DCV is then shifted to right position, flow to rod end of C1 is blocked, but flows freely to rod end of C2. After C2 retracts fully, pressure builds up till the valve connected to C1 opens. Thus the sequence is C1Ext - C2Ext - C2Retr – C1 Retr. One can find the application of this circuit in press circuit. For example, the left cylinder the clamping cylinder C1 could extend and clamp a workpiece. Then the right cylinder C2, the punching cylinder extends to punch a hole in the workpiece. The right cylinder then retracts the punch , and then the left cylinder retracts to declamp the workpiece for removal.




Cylinder Sequencing circuit

7. **Automatic Cylinder Reciprocating System**

(i) **Using Sequence Valves**

**Operation**: In the left position of valve shown, P is connected to rod-side, and the rod retracts. After piston reaches the left end, pressure builds up on rod side which opens the sequence valve on the right and permits pilot hydraulic line to act on the main DCV to switch to right position. Check valves allow pilot oil to leave either end of the DCV while pilot pressure is applied to the opposite end.

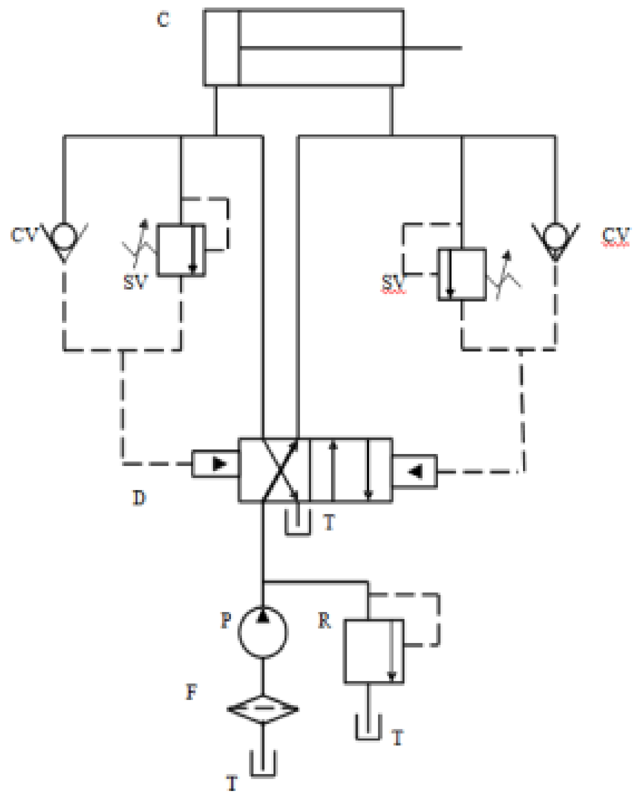
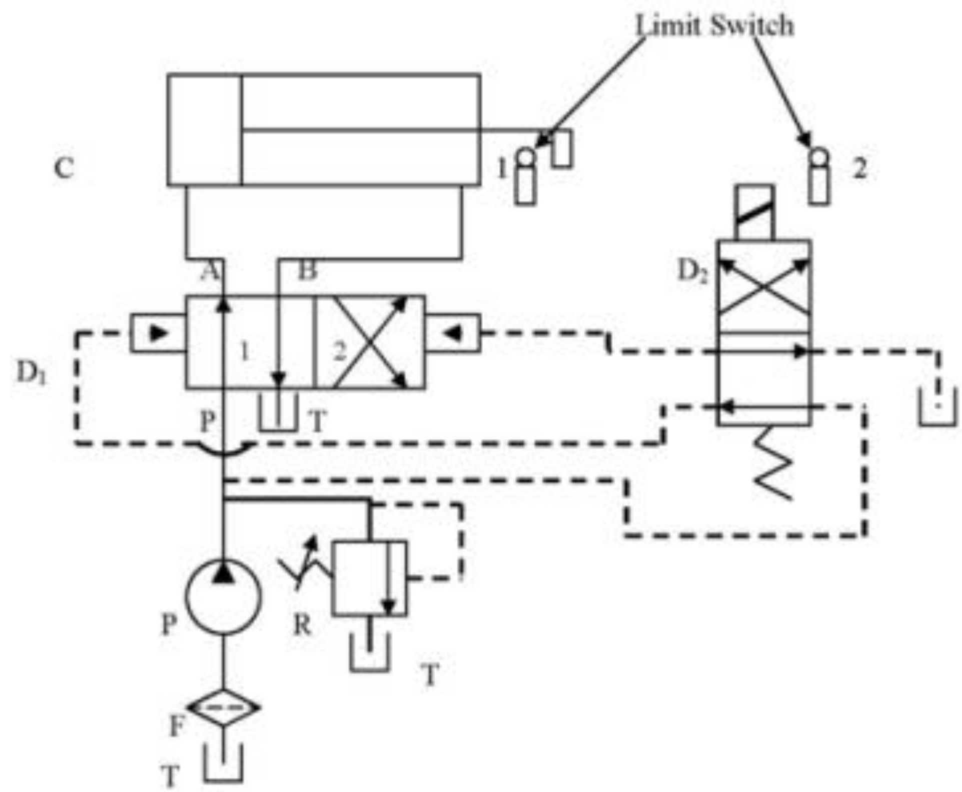



Figure: Automatic cylinder reciprocating system using sequence valve

(ii) An alternative circuit is shown using limit switches and solenoid valve, and a pilot operated DCV.

**Operation:**

Suppose the left position of the main DCV is on. Then the piston rod moves to right .It hits the limit switch 2 which energizes solenoid valve D2 which shifts the solenoid operated DCV (D2) to position (top as shown) which now permits pilot oil from D2 to right end of DCV D1 changes D1 position 2 flow is now to rod end rod moves to left till it hits limit switch 1.Now the reverse of the above sequence is repeated so that Position 1 of the main DCV becomes operative. Thus it leads to automatic reciprocation of the actuator between the limit switch positions.




Automatic Cylinder Reciprocating System using DCV's.

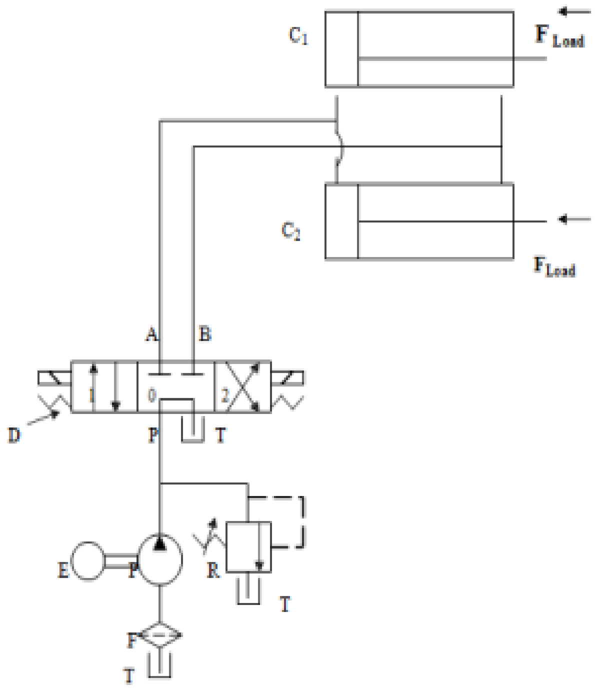
8. **Cylinder Synchronizing Circuits** :

Circuits are shown for synchronizing the operation of two cylinders (ie simultaneous equal movement).

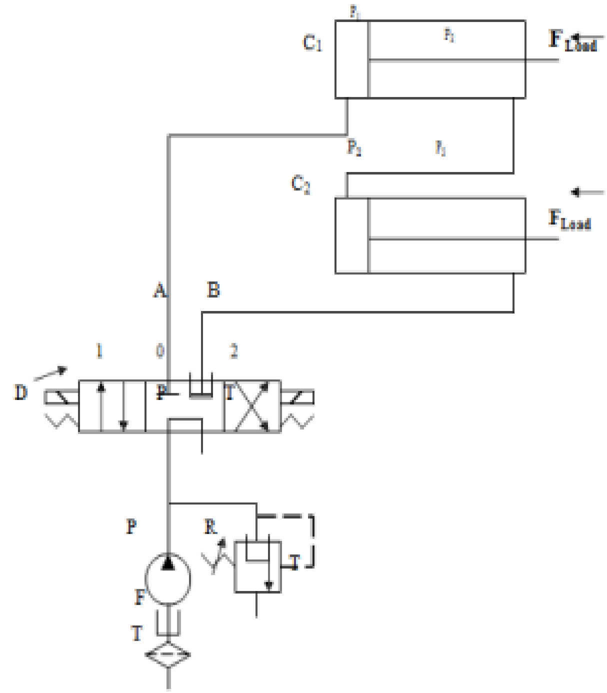
**a. Cylinder connected in Parallel**

In the circuit shown, piston or rod ends of both cylinders are connected to one line. Thus oil flows simultaneously. However, if load on one cylinder is more, the other cylinder needing less pressure operates first, and after completion of stroke, pressure builds up to operate the second cylinder. This operation is not synchronized. The problem may arise with slight differences in the size of cylinders as well.

b. **Cylinders connected in Series**: The rod end of C1 is connected to piston end of C2. Thus C1 and C2 have to move together. However, for to have equal stroke, rod end area of C1 should be equal to piston area of C1. Also, rod end of C2 has to have high pressure to do work by C2. Hence piston side pressure would be that much higher.



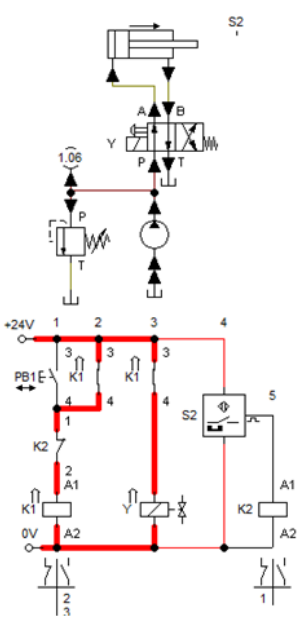

Cylinder hooked in parallel for synchronizing
(will not operate)



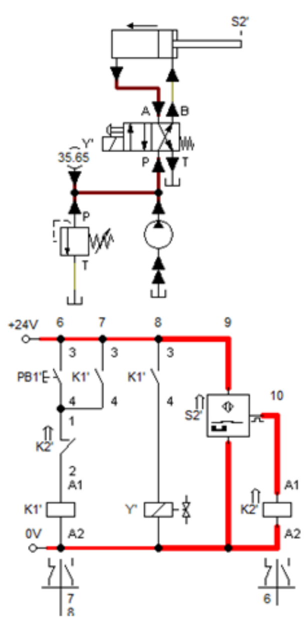

Cylinder hooked in Series for synchronizing
( Will Operate )

- **SEMI- AUTOMATIC**

Semi- automatic operation of a double- acting hydraulic cylinder using a sensor .The hydraulic part and the electrical part of the circuit for the semi-automatic operation of a double-acting hydraulic cylinder using a proximity sensor (S2) are given in the Figure below which is self explanatory.



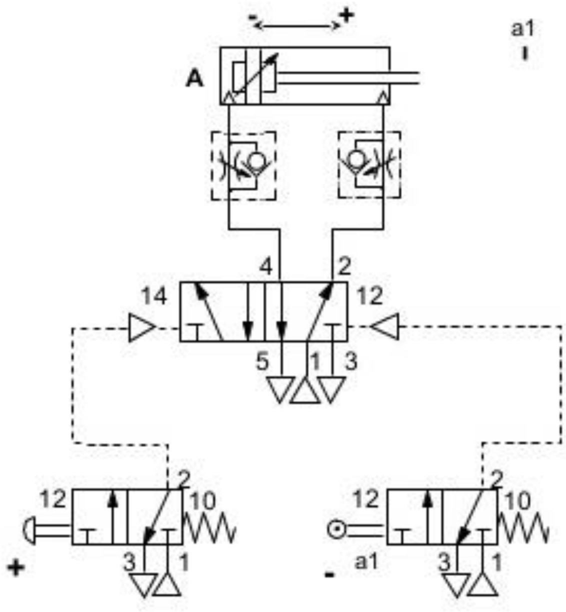

Position when the cylinder is extending




Position when S2 is just sensing

## Semi-automatic control

- Manual remote start of a double acting cylinder with automatic return
- Cylinder identified as "A"
- Trip valve operated at the completion of the plus stroke identified as "a1"




**LEARNING OUTCOME 3.3: CONTROL PNEUMATIC/ HYDRAULIC SYSTEMS**

- **TOPIC 1: Control parameters in pneumatic/ Hydraulic systems:**
    - ✓ **Pressure control**

What is pressure and why is it so valuable for precise control?

Pressure is the force on a unit of area or total force divided by the area on which the force is applied. The pressure in a hydraulic system is caused by a force compressing oil in a confined volume or by adding fluid to the confined volume.

Pressure control is achieved in hydraulic systems by metering the flow of a fluid into or out of a constrained volume. Relief valves and pressure-reducing valves are not pressure controllers. They limit or reduce pressure, but they do not really control pressure to a desired value. Pressure-reducing valves can only reduce pressure, and only by a set ratio. The output pressure is limited by the input pressure. Relief valves only limit pressure to a set value. Another limitation of these types of devices is that they use springs and are only proportional-control devices. They have no rate control or ability to change different pressures on the fly.

- ✓ **Temperature control**

Hydraulic systems are used for precise control of a large force in many industrial, mobile, and aerospace applications. To maintain system performance it is important to control the fluid temperatures.

Temperatures above recommended limits cause reduced system life due to lower fluid viscosity leading to poor lubrication, higher internal leakage, higher risk of pump cavitation, thermal degradation of seals and other components. Temperatures below the recommended range increase hydraulic fluid viscosity leading to higher stress on pumps, valves, fittings, seals, and other components.

Thermal bypass is necessary to maintain fluid temperature control in hydraulic and lube oi systems used in industrial, mobile and aerospace applications. ThermOmegaTech’s TBV’s provide precise thermostatic control for heat exchangers and fuel oil coolers in dozens of applications, typically in military aircraft.

Our 3-way temperature control valves (also known as thermostatic control valves, TCVs, or temperature regulators,) use our self-actuating thermostatic technology to monitor the inlet flow and divert the fluid based on temperature. Cooler fluid will go through the bypass of the valve directly to the reservoir or bypass loop while hot fluid will activate the thermal actuator, causing the internal cartridge to close and forcing the fluid through the system cooler.

½" Thermostatic Mixing/Diverting Valve

1" Thermostatic Mixing/Diverting Valve

2" Thermostatic Mixing/Diverting Valve

**Thermal control in hydraulic systems offers a number of performance, economic, and environmental benefits including:**

- Maintaining correct temperature keeps hydraulic fluid within its recommended viscosity range ensuring that mechanical components are properly lubricated and hydraulic devices run at peak efficiency.
- Keeping temperatures down helps ensure the hydraulic fluid and other system components last longer. Excess heat degrades hydraulic fluid, forms harmful varnish on component surfaces, and deteriorates seals.
- Operating within recommended temperature ranges increases a hydraulic system’s availability and efficiency, improving equipment productivity.
- Increased machine uptime and fewer shutdowns reduce service and repair costs.

✓ **Air flow control**

Flow Control Valves are used to reduce the rate of flow in a section of a pneumatic circuit, resulting in a slower actuator speed. Unlike a Needle Valve, a Flow Control Valve regulates air flow in only *one direction*, allowing free flow in the opposite direction.

There are two types of air flow control valves:

1. A meter – in flow control valve (also known as a reverse flow control valve) restricts the flow to an actuator.
2. A meter- out flow control valve regulates the exhaust flow from an actuator. These are the most commonly used air flow control valves.

Flow Control Valves

✓ **Oil flow control**

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

✓ **Oil level control**

Oil level indicators

A range of oil level gauges, dome sights, level and column level indicators made of different plastic or metallic materials, resistant to contact with liquid and different oils, at low or high temperatures. These hydraulic components are ideal for the visual control of the level of fluids on tanks or hydraulic systems. The column level indicators are available with or without built-in thermometer and with or without protective shroud. The executions with screws or SUPER-technopolymer shrouds or with stainless steel inserts are ideal for applications requiring corrosion resistance, such as in the food or pharmaceutical industry.

## LEARNING OUTCOME 3.4: USE SAFETY EQUIPMENT

- **TOPIC 1: Identification of hazards due to the operation of pneumatic and hydraulic system**

**Potential Hazards due to the operation of pneumatic system**

There are several potential dangers associated with the use of pneumatic tools. The main hazard is being struck by one of the tool's attachments (e.g., a drill bit) or by the fastener the tool is discharging (e.g., staples).

Pneumatic tools that discharge nails, rivets, or staples and operate at pressures more than 100 pounds per square inch should be equipped with a special device to keep fasteners from being ejected unless the muzzle is pressed against the work surface.

**Hazards of compressed air and compressed air equipment**

- Flying particles and debris – can result in eye injuries, cuts/scrapes or other significant injuries to almost any body part;
- High pressure air – can result in air injection into the body leading to potential injuries such as air embolism, ruptured ear drums or organs, and dislodged eye balls;
- High noise – can result in temporary or permanent hearing loss.

**Safe Work Practices**

1. Wear appropriate personal protective equipment (PPE) when using pneumatic tools and equipment, such as hearing protection and safety glasses with side shields or goggles. Additional PPE such as a face shield, gloves or steel-toed shoes, may also be required, depending on the hazards encountered.
2. Ensure all connections and couplings are secure, and hold the open end of the hose firmly to avoid uncontrolled “whipping” of the hose.
3. Coil the hose (without kinks) and hang it over a broad support when not in use. Do not leave the hose lying on the ground where it can become damaged or cause a trip hazard.
4. When using an air nozzle for cleaning equipment, removing dust from hard to reach areas on equipment, clearing lines, etc., ensure that the air pressure exiting the nozzle is 30 psi or less and use effective chip guarding, such as barriers, baffles or screens:
    - Use the lowest pressure necessary to perform a job task;
    - Adjust the air regulator to reduce the air pressure; or
    - Use a safety tip on the air nozzle to maintain air pressure below 30 psi should the tip of the air nozzle become blocked or dead-headed.
5. Never point the nozzle of an air hose at anyone and never use compressed air to clean debris from a person’s skin or clothing.
6. Ensure all air receivers are equipped with a pressure gauge, safety release valve and a drain valve located at the bottom of the receiver.
7. Never use compressed air to transfer flammable liquids.
8. Only use tanks and valves that have been constructed and installed in accordance with the A.S.M.E. Boiler and Pressure Vessel Code, Section VIII Edition 1968.

9. Follow the manufacturer’s recommendations for care and maintenance of compressed air equipment, including portable units. Items that require inspection or servicing include: drain lines, air-line particulate filters, safety devices, air filters, condenser coils, etc.

10. Before conducting any repairs to the pressure system of air compressors, receivers or compressed air equipment, ensure all hazardous energy sources are locked and tagged out, and all pressure has been released.

**Danger from belt drive**

**Danger of serious injury from rotating belt drive**

Touching the rotating belt drive can result in severe crushing or even severance.

- Do not open the casing while the machine is switched on.
- Isolate all phases from the power supply (all conductors).(switch off the main isolator)
- Ensure that the power supply cannot be switched on again (lock off).
- Work carefully.

**Danger from fan wheel**

### Danger of serious injury from rotating fan wheel

Touching a rotating fan wheel can result in serious laceration or even severance.

☞ Do not open the enclosure while the machine is switched on.

☞ Isolate all phases of the main power supply. (switch off the mains isolating device)

☞ Ensure that the power supply cannot be switched on again (lock off).

☞ Work carefully.

### Further dangers

### Handling cooling and lubricating fluids

- Avoid contact with skin and eyes.
- Do not inhale oil mist or vapor.
- Do not eat or drink while handling cooling and lubricating fluids.
- Fire, open flame and smoking are strictly forbidden.

**Basic Pneumatic Tool Safety**

- Use the right tool for the job and review the manufacturer's instructions before using any tool.
- Do not operate the tool at a pressure above the manufacturer's rating.
- Wear safety glasses or a face shield, safety shoes or boots, and hearing protection.
- Set up screens or shields in areas where nearby workers may be exposed to flying fragments, chips, dust, and excessive noise.
- Ensure that the compressed air supplied to the tool is clean and dry. Dust, moisture, and corrosive fumes can damage a tool. An in-line filter, regulator, and lubricator may increase the life of the tool.
- Keep tools clean, lubricated, and maintained according to the manufacturer's instructions.

**Hydraulic Hazards due to the operation of pneumatic system**

Hydraulic equipments and systems are designed to accomplish work using confined liquid pressure to produce a greater mechanical force. The operators/ maintenance crews are subjected to hazards from high pressure liquids and large mechanical forces. Hydraulic systems store fluid under high pressure.
The workmen are exposed to following hazards:

- Burns from hot, high-pressure fluid
- Injection of fluid into the skin
- Fire Hazards
- Bruises, cuts or abrasions from flailing hydraulic lines
- Injury of people due to unexpected movement of equipment.
- During maintenance of equipment and their parts
- Injury due to sudden release of residual pressurized oil.
- Slippage due to oily floor area.
- Electric shock from electrical motors/ A.C. Solenoids

**Follow these rules for safe hydraulics operation.**

- Always lower the hydraulic working units to the ground before leaving the machine.
- Park the machinery where children cannot reach it.

- Block up the working units when you must work on the system while raised; do not rely on the hydraulic lift.
- Never service the hydraulic system while the machine engine is running unless absolutely necessary (bleeding the system).
- Do not remove cylinders until the working units are resting on the ground or securely on safety stands or blocks; shut off the engine.

Five basic safety rules can help prevent hazards associated with the use of hand and power tools:

- Keep all tools in good condition with regular maintenance.
- Use the right tool for the job.
- Examine each tool for damage before use and do not use damaged tools.
- Operate tools according to the manufacturers' instructions.
- Provide and use properly the right personal protective equipment.

- **TOPIC 2: Safety equipment used in Hydraulic/Pneumatic system:**

**Personal protective equipment**

Employers have duties concerning the provision and use of personal protective equipment (PPE) at work - Article 16 - Occupational Safety and Health Convention, 1981 (No. 155) .

PPE is equipment that will protect the user against the risk of accidents or of adverse effects on health. It can include items such as safety helmets, gloves, eye protection, high-visibility clothing, safety footwear, safety harnesses and respiratory protective equipment (RPE).

**General safety rules**

These safety rules apply:

- Always keep the work area clean.
- Pay attention to the risks presented by gas and vapors in the work area.
- Avoid all electrical dangers. Pay attention to the risks of electric shock or arc flash hazards.
- Always bear in mind the risk of drowning, electrical accidents, and burn injuries.

**Why is PPE important?**

Making the workplace safe includes providing instructions, procedures, training and supervision to encourage people to work safely and responsibly. Even where engineering controls and safe systems of work have been applied, some hazards might remain.

These include injuries to:

- the lungs, e.g. from breathing in contaminated air;
- the head and feet, e.g. from falling materials;
- the eyes, e.g. from flying particles or splashes of corrosive liquids;
- the skin, e.g. from contact with corrosive materials;
- the body, e.g. from extremes of heat or cold.

PPE is needed in these cases to reduce the risk.

What should employers do?

- Only use PPE as a last resort.
- If PPE is still needed after implementing other controls (and there will be circumstances when it is, e.g. head protection on most construction sites), they must provide this for their workers free of charge.
- They must choose the equipment carefully (see selection details below) and ensure workers are trained to use it properly, and know how to detect and report any faults.

**When selecting and using PPE**

- Choose products which are suitable to the residual risk and are the required standard, suppliers can advise you.
- Choose equipment that suits the user – consider the size, fit and weight of the PPE. If the users help choose it, they will be more likely to use it.
- If more than one item of PPE is worn at the same time, make sure they can be used together, e.g. wearing safety glasses may disturb the seal of a respirator, causing air leaks.
- Instruct and train people how to use it, e.g. train people to remove gloves without contaminating their skin. Tell them why it is needed, when to use it and what its limitations are.

**Other advice on PPE**

- Employers should never allow exemptions from wearing PPE for those jobs that 'only take a few minutes'.
- Employers should check with the supplier on what PPE is appropriate – explain the job to them.
- Employers, if in doubt, should seek further advice from a specialist adviser.

**Maintenance**

PPE must be properly looked after and stored when not in use, e.g. in a dry, clean cupboard. If it is reusable it must be cleaned and kept in good condition.

**Employers and workers should think about**

- using the right replacement parts which match the original, e.g. respirator filters;
- keeping replacement PPE available;

- who is responsible for maintenance and how it is to be done;
- having a supply of appropriate disposable suits which are useful for dirty jobs where laundry costs are high, e.g. for visitors who need protective clothing.

Workers must make proper use of PPE and report its loss or destruction or any fault in it.

**Employers should monitor and review**

- Checking regularly that PPE is used. If it isn't, find out why not.
- Safety signs can be a useful reminder that PPE should be worn.
- Make note of any changes in equipment, materials and methods – they may need to update what they provide.

**Emergency equipment**

Careful selection, maintenance and regular and realistic operator training is needed for equipment for use in emergencies, like compressed-air escape breathing apparatus, respirators and safety ropes or harnesses.

**Safety equipment**

Use safety equipment according to the company regulations. Use this safety equipment within the work area:

- ✓ Helmet
- ✓ Safety goggles, preferably with side shields
- ✓ Protective shoes
- ✓ Protective gloves
- ✓ Gas mask
- ✓ Hearing protection
- ✓ First-aid kit
- ✓ Safety devices

  **NOTICE:** Never operate a unit unless safety devices are installed.

# LEARNING UNIT 4: PERFORM THE ROUTINE MAINTENANCE

## Learning outcome 4.1: interpret the nameplate/ manufacturer's manual

- **TOPIC 1: User manual and the service manual for pneumatic/ Hydraulic equipment/ materials**

The user manual and service manual of hydraulic/pneumatic system include:

- Equipment/ materials descriptions
- Warranty
- Safety and equipments instructions
- Operators instructions
- Maintenance and servicing
- Technical information

- Storage
- Etc
-

At receipt of the material:

- ✓ Check the completeness of the supply, by referring to the packing list;
- ✓ Check the tag number, serial number and technical information in the nameplate with reference to the order acknowledgement.
- ✓ The materials/ equipments are delivered with plugged connections. Which must remain plugged if not utilized or must be re-plugged with the relevant plug or reconnected after any testing operation.

Carry out a preliminary verification in order to ensure:

- ✓ The integrity of the material and the absence of damages;
- ✓ The integrity of the painting. If necessary, carry out the paint touch up, by following the instructions
  of the painting specification (please refer to the technical documentation);
- ✓ The presence of the plugs on all the pneumatic and (where present) electric connections.

- **TOPIC 2: The service manual and nameplate for pneumatic /Hydraulic systems' components:**

Most equipment nameplates will have some common items of information. Many of these are self explanatory, and include:

- Manufacturer
- Manufacturer's address
- Model number
- Serial number
- Certification mark(s)

This general information can be useful in finding out more details about particular through the manufacturer's published information.

### i. Compressor

Model and important technical information is to be found on the machine nameplate. The nameplate is found inside the machine. It is fixed to the outside of the control cabinet.

The nameplate

| | |
|---|---|
| Model | |
| Part no. | |
| Year | |
| Serial no. | |
| psig | |
| cfm | |
| Voltage | |
| Hz/RPM | |
| Package FLA | |
| Phase | |
| HP | |
| Wiring Diagram | |
| FOR SERVICE, REFER TO EQIPMENT NUMBER | |

Table1: Name plate

- **Weight**

Maximum weight is shown. Actual weight of individual machine is dependent on equipment fitted.

| | |
|---|---|
| Weight [lb] | |

Table: weight

- **Temperature**

| | |
|---|---|
| Minimum cut---in temperature [˚ F] | |
| Typical airend discharge temperature during operation [˚ F] | |
| Max. airend discharge temp. (automatic shut---down) [˚ F] | |

Table: Temperature

- Ambient condition

| | |
|---|---|
| Maximum elevation [ft.] | 3000 |
| Ambient temperature [˚ F] | 40 – 105 |
| Inlet air / cooling air temperature [˚ F] | 40 – 105 |
| Maximum relative inlet air humidity at 88 ˚ F [%] | 100 |
| Maximum relative inlet air humidity at 105 ˚ F [%] | 60 |

* Higher elevation permissible only after consultation with the manufacturer

- **Delivery**

| **Maximum working pressure [psig]** | **Delivery [cfm]** |
|---|---|
| 110 | 21 |
| 125 | 20 |
| 145 | 1 |
| | |
| | |

- **Sound level**

Operational state

Under load at rated speed, rated delivery and rated pressure. Measuring conditions: Free---field measurement to CAGI/PNEUROP PN8 NTC 2.3 at 1 m distance

| | |
|---|---|
| Sound level [dB(A)] | 66 |

Table: Example of sound level

### ii. Hydraulic pumps

**Nameplate information**

**important information for ordering**

Every pump has a nameplate that provides information about the pump. The nameplate is located on the pump casing. When you order spare parts, identify this pump information:

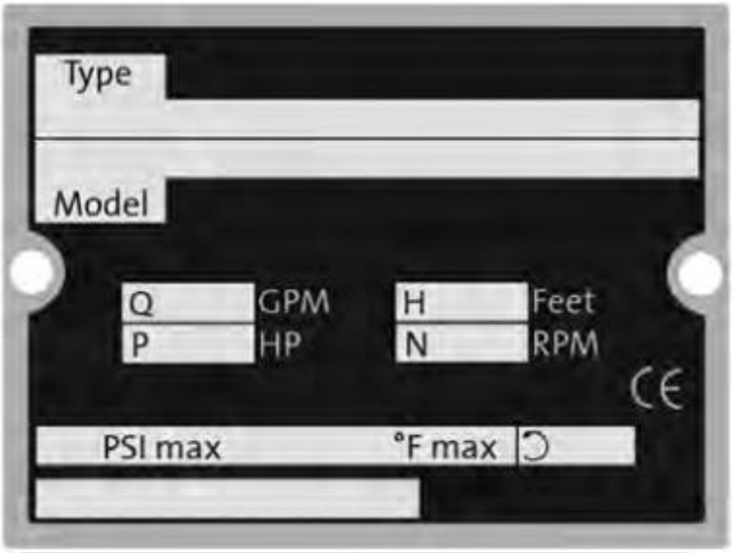
- Model
- Size
- Serial number

Items specific to pumps may include:

- **Rated Flow (Q)** - gallons or liters per minute (GPM or lpm)
- **Head pressure at rated flow** - feet of water, pounds per square inch (psi), pascals (pa)
- **Power** – Horsepower (HP)
- **Rated rotational speed** – revolutions per minute (RPM)
- **Maximum pressure** – feet of water, psi
- **Maximum fluid temperature** – degrees Fahrenheit or Celsius (oF or oC)

Other information that may appear on the nameplate, or may be encoded in the Type or Model number, may include:

- **Type of pump** – centrifugal
- **Materials used in components** – Seals, impellers, shafts, etc.
- **Number of stages**
- **Number of impellers**



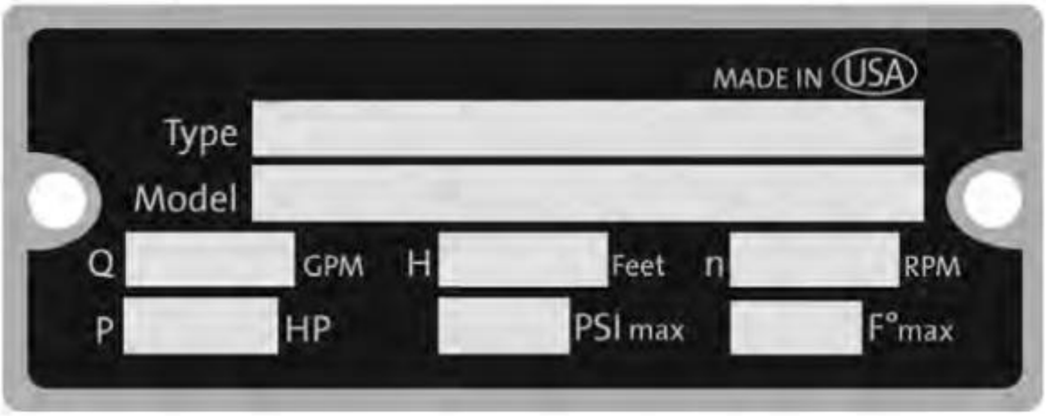




**Figure : Pump's nameplate**

**Nameplate types**

| Nameplate | Description |
|---|---|
| Pump casing | Provides information about the hydraulic characteristics of the pump.<br>The formula for the pump size is: Discharge x Suction - Nominal Maximum Impeller Diameter in inches.<br>(Example: 2x3-8) |
| Bearing frame | Provides information about the lubrication system used. |
| ATEX | If applicable, your pump unit might have an ATEX nameplate affixed to the pump, the baseplate, or the discharge head. The nameplate provides information about the ATEX specifications of this pump. |
| IECEx | If applicable, your pump unit might have the following IECEx nameplate affixed to the pump and/or baseplate. The nameplate provides information about the IECEx specifications of this pump. |
| Other | If applicable, additional information, warnings or cautions may be noted. |

**Nameplate on the pump casing using English units**

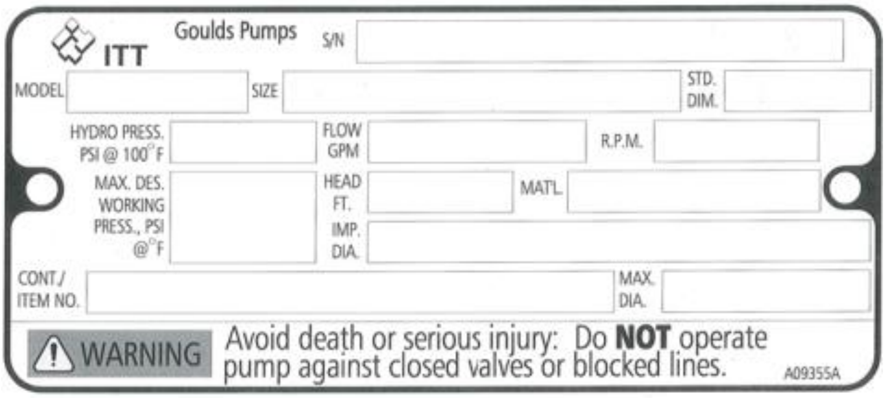



**Table 1: Explanation of nameplate on the pump casing**

| Nameplate field | Explanation |
|---|---|
| S/N | Goulds serial number |
| Model | Pump model |
| Size | Size of the pump |
| Std. Dim | Standard Dimensional designation |
| Hydro Pressure | Hydrostatic pressure at 70°F, in pounds per square inch |
| Max. Design Working Press. | Maximum working pressure in pounds per square inch |
| RPM | Rated pump speed, in revolutions per minute |
| Head | Rated pump head in feet |
| Material | Pump material |
| Impeller Diameter | Impeller trim diameter |
| Cont/Item No | Purchaser's contract or item number |
| Max. Dia | Impeller maximum diameter |

## Nameplate on the bearing frame


**Table 2: Explanation of the nameplate on the bearing frame**

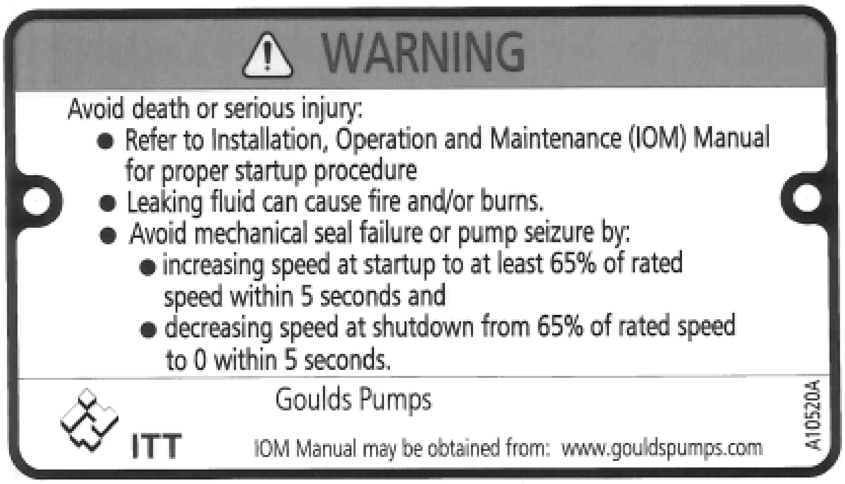
| Nameplate field | Explanation |
|---|---|
| Assembled in | Country in which final unit built |
| Year built | Year in which final unit built |
| S/N | Serial number |
| Bearing O.B. | Outboard bearing number/designation |
| Bearing I.B. | Inboard bearing number/designation |
| Lubrication | Type of lubrication of pump |

## ATEX nameplate


**Product Description**

| Nameplate field | Explanation |
|---|---|
| II | Group 2 |
| 2 | Category 2 |
| G/D | Pump can be used when gas and dust are present |
| T4 | Temperature class |

**Warning nameplate**




The nameplate shown is the standard warning and is applicable for most pumps. You must refer to the start up procedures in the IOM for any specific instructions that may be different.
The instructions in the IOM will take precedence.

### iii. Hoses and tubing

A **hose** is a flexible hollow tube designed to carry fluids from one location to another. Hoses are also sometimes called *pipes* (the word *pipe* usually refers to a rigid tube, whereas a hose is usually a flexible one), or more generally *tubing*. The shape of a hose is usually cylindrical (having a circular cross section).

Hose design is based on a combination of application and performance. Common factors are size, pressure rating, weight, length, straight hose or coil hose, and chemical compatibility.

Applications mostly use nylon, polyurethane, polyethylene, PVC, or synthetic or natural rubbers, based on the environment and pressure rating needed. In recent years, hoses can also be manufactured from special grades of polyethylene (LDPE and especially LLDPE). Other hose materials include PTFE (Teflon), stainless steel, and other metals.

**Applications**

Hoses can be used in water or other liquid environments, or to convey air or other gases. Hoses are used to carry fluids through air or fluid environments, and they are typically used with clamps, spigots, flanges, and nozzles to control fluid flow.

Specific applications include the following:

- A garden hose is used to water plants in a garden or lawn, or to convey water to a sprinkler for the same purpose.
- A tough hose is used to water crops in agriculture for drip irrigation.

- A fire hose is used by firefighters to convey water to the site of a fire.
- Air hoses are used in underwater diving to carry air from a surface compressor or from air tanks. (See also snorkeling.) Industrial uses for operating flexible machinery and worktable tooling such as pneumatic screw drivers, grinders, staplers, etc.
- Automotive hoses are used in automobiles to move fluids around for use in cooling, lubrication, and/or hydraulics. Hoses are also used to convey pressure or vacuum signals to control circuits or gauges, as well as conveying vacuum to heating, cooling, brake, and/or locking systems.
- In chemistry and medicine, hoses (usually called *tubes*) are used to move liquid chemicals or gases around.
- A fuel hose carries fuel.
- In the oil industry high pressure hoses are used to move liquids under high pressures.

**iv. Flanges**

Flanges offer advantages over their fitting counterparts and can connect ports directly to tubes and hoses without having to use threaded connectors or adapters.

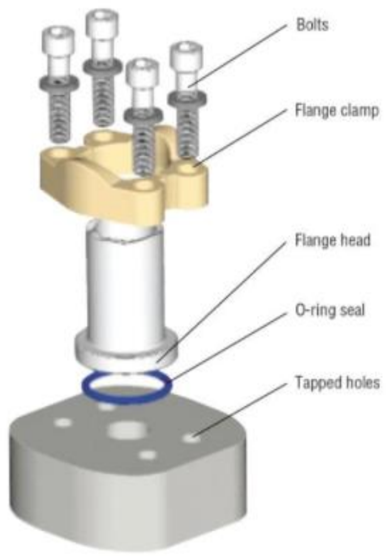



Figure: Four-Bolt flange port connection components

Flange connections are used in the most demanding mobile equipment applications because they:
• Are well suited for high pressure, shock and vibration, especially in larger sizes,
• Allow easy connection between hose and tube/pipe where flexibility is needed, without adding adapters,
• Allow for easy connection between rigid lines (tube-to-tube or pipe-to-pipe) and aid in installation and repair,
• Maintain a high resistance to loosening in severe hydraulic service,
• Can be assembled with reasonable assembly torques, even in larger sizes, and
• Can be assembled in close quarters where wrench swing clearance would be problematic.

**Basic design**

The 4-bolt flange port connection consists of four primary components: flange head, O-ring, flange clamp (captive or split) and four bolts. The port is simply a flow passage surrounded by four tapped holes that accept the clamping bolts. Typically, the flat-machined surface of the port compresses the O-ring contained in the groove of the flange head when the bolts are tightened. The bolts, placed through the flange clamp, squeeze on the flange head, compressing the O-ring in the groove leaving no leak path or possibility of O-ring extrusion, Figure 1.

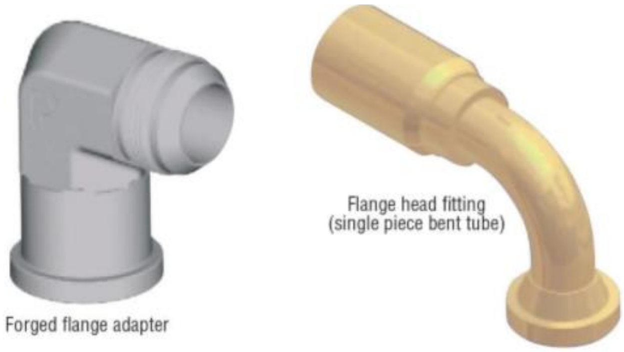



Figure: Popular adapters for connecting flanges to other types of connectors

For pipe or tube connections, a flange head with a machined O-ring groove is typically welded or brazed on. An alternative is to place a flat face flange onto the end of the tube or pipe and use a bonded elastomeric seal plate as the seal between the two flat surfaces. This eliminates the need for welding or brazing.

Hose connections can be achieved with a single-piece flange, Figure 2, that is crimped onto the end of the hose. Such flange adapters are used to adapt either tube or hose to a four-bolt flange connection. When using flange adapters, the pressure rating of the threaded end should be taken into consideration.

**Types of flanges**

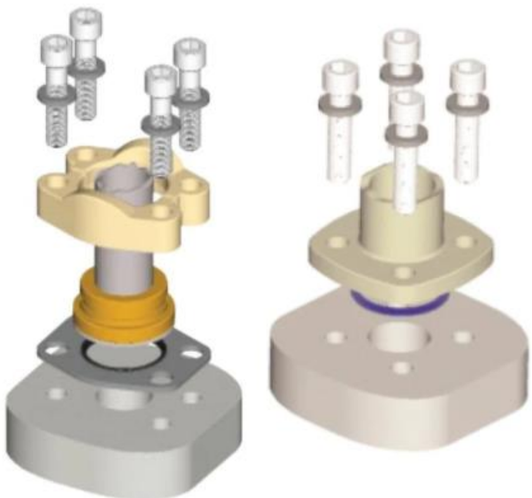
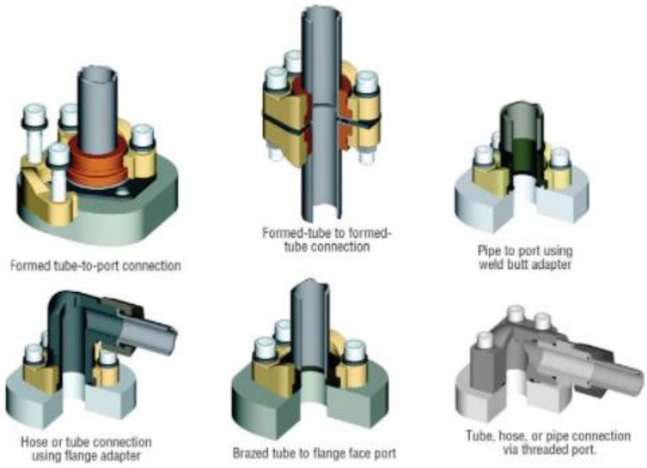


Figure: Four- bolt flange connections

**Applications**

The hydraulic flange connection was developed as a large-sized high-pressure connection. While large-sized threaded connections require a very high assembly torque to resist high pressures, flange port connections divide the assembly torque among multiple bolts, each of which requires much less torque. Large threaded connections also present assembly difficulties especially where wrench clearance is limited.




The variety of standard flange configuration options make them suitable for most hydraulic applications. Click on image for larger view.

### v. Valves

VALVE'S NAMEPLATE

A nameplate indicates the model number, valve size, pressure rating, trim material, date of manufacture and other major specifications of the control valve. Before installing the control valve, make sure that the specifications indicated on the nameplate conform to the conditions of use. The nameplate also indicates the product number ( PROD.NO.) of the control valve.

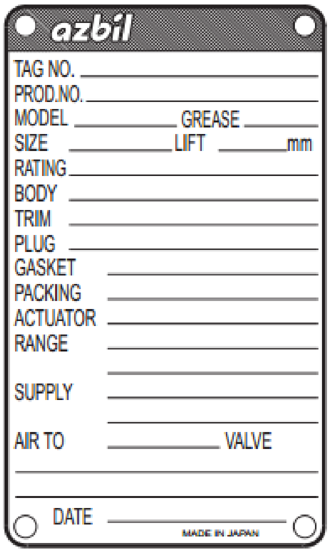



Figure : Nameplate of valve

### vi. Electrical motor

The National Electric Code requires that motor nameplates include the following information in addition to the manufacturer's name and address:

- **Rated voltage(s)**
- **Rated full-load amperage** at each voltage level (FLA)
- **Frequency** – typically 60 or 50hz
- **Phase** – Single or three phase
- **Speed -** Rated full-load speed (in RPM)

- **Insulation Class and rated ambient temperature** – Insulation class may be B, F and H, and the rated ambient temperature is the maximum allowable ambient temperature during operation.
- **Rated Horsepower**
- **Time Rating** – Usually continuous duty, but some motors may be rated for as low as 5 minutes of continuous operation.
- **Locked-rotor code letter**

Other motor data may include:

- **Frame size**
- **NEMA design letter** – indicates the relationship between speed and torque
- **Full-load efficiency**
- **Power factor**

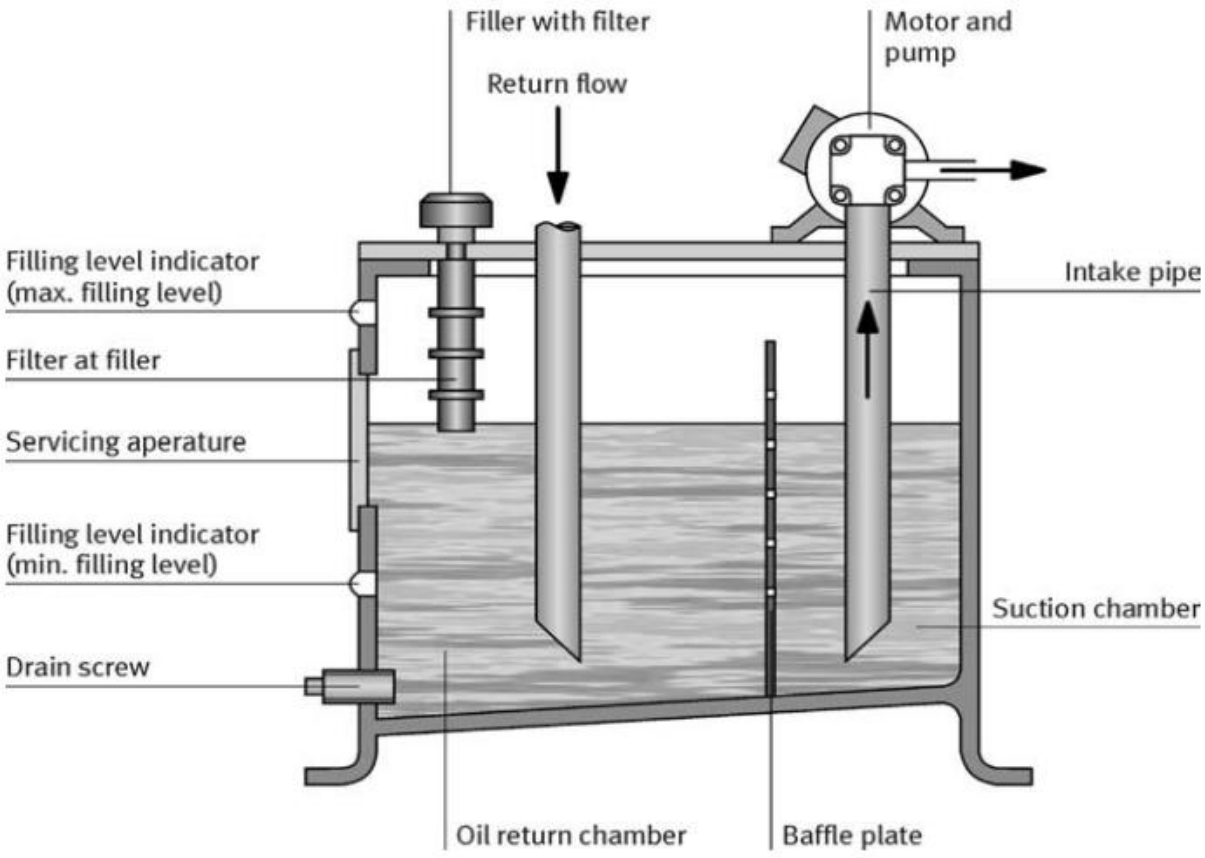

Figure: Electrical name plate

**vii. Reservoir / tank**

The purpose of the hydraulic reservoir is to hold a volume of fluid, transfer heat from the system, allow solid contaminants to settle and facilitate the release of air and moisture from the fluid.

**The tank in a hydraulic system fulfils several tasks. It:**

• Acts as intake and storage reservoir for the hydraulic fluid required for operation of the system;
• dissipates heat;
• separates air, water and solid materials;
• supports a built-in or built-on pump and drive motor and other hydraulic components, such as valves, accumulators, etc.




### viii. Hydraulic and pneumatic cylinders

**Legend for Safety Symbols**

Explanation of Warning Symbols (Where Applicable)

Before carrying out any operation on the actuator, the electric power supply (if present) must be shut-off.

Risk of explosion: before carrying out any operation on the actuator, the actuator must be isolated from the pneumatic supply source.

Before carrying out any operation on the actuator, the control group (if present) must be discharged from the pressure therein trapped, particular care shall be taken on storage tanks and pressure filters.

Every operation on the actuator must be performed by qualified personnel, equipped with safety clothes and devices (gloves, helmet, glasses, etc.).

During the operation on the actuator, the operator must pay attention to the presence of liquids potentially noxious for the health and the environment.

- If the actuator is provided with spring container:
  ***Warning:***
  *DO NOT OPEN AND/OR FORCE THE SPRING CONTAINER*

The spring container contains one or more compressed springs.
A forced or non-controlled opening of the container can cause the non-controlled and violent ejection of material potentially harmful to people and/or capable of causing damage to property.
The opening and disposal of the spring container must be carried out only by authorized personnel.
Please contact Cameron in case of any doubt or for further information.

**Safety of the Power Supply Connection (If Applicable)**

Before carrying out any operation on the actuator, check that the power supply is off.
Before connecting the actuator:
• Verify the absence of the power supply and always connect the ground cable to the actuator first.
• Check that the power supply line characteristics are in accordance with the nameplate and installation manual data.

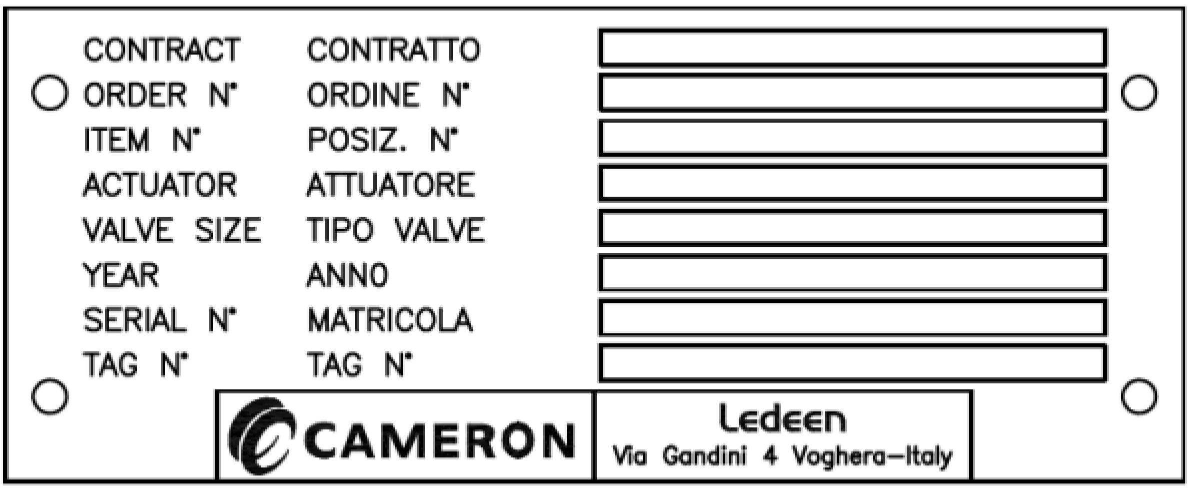
**Safety Recommendations**

Check that the ground resistance complies with the limits allowed by the National Laws relevant to the country where the actuator is installed. If the actuator is stored/installed in a hazardous area, do not use open flames and/or devices that could cause sparks. At the end of any intervention on the actuator please check that all the boxes and covers are properly closed.

**Actuator Name plate description**

The actuator nameplate shows the following data:
1. Contract No.
2. Order No.
3. Item No.
4. Actuator model
5. Valve size
6. Year of manufacturing
7. Actuator Serial No.
8. Actuator Tag No.
9. Name and complete address of the manufacturer

See example of nameplate below



## X. Pressure reducing valves

The pressure reducing valve may be used for water hammer protection under properly defined conditions. The water hammer events are so fast that the relief of pressure by this means requires very special rapid response valves designed for the particular system.

Pressure relief valves may also be used as an added precaution where some other method is in place as the basic protection device, such as an air vessel.

There are also by-pass valves which are required to operate when a pump stops due to a power failure or normal trip, anticipating the eventual return flow, and then being required to be closed to prevent the excessive waste of the return flow.

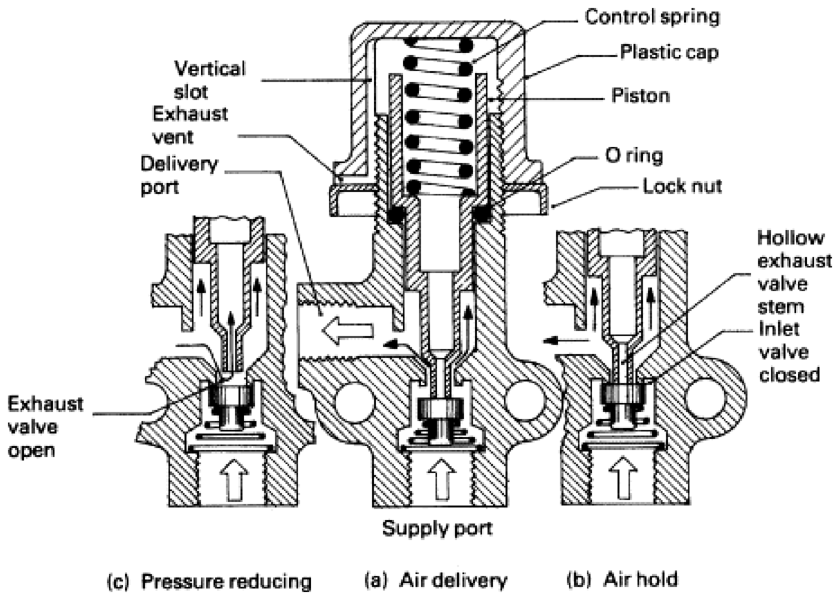



Figure: Pressure reducing valve

## XI. Accumulators

**Manual Instructions**

Damaged or lost data plates must be replaced! The operation of a hydraulic accumulator without nameplate is not allowed.

**Operating**

The operating of hydraulic accumulators and equipment must be carried out by qualified personnel. Hydraulic accumulators are subject of monitoring processes (Please contact your notified body). The information and data on the nameplate must be considered. The following information is displayed on the accumulator:

- HENNLICH- HCT-logo
- Indication of the accumulator-type
- Item number of the hydraulic accumulator
- Permissible operating data
- Temperature range TS in ° C
- Maximum allowable pressure PS in bar
- Allowed Fluid group
- Manufacturing date mm / yy
- Nominal volume of the hydraulic accumulator in liters
- Test pressure PT in bar

- Date of test YY / MM
and for volumes > 1 liter:
- CE logo and identification number of the notified body
and on some nameplates:
- Warnings and safety instructions ( "Danger", "only nitrogen use", etc. or any similar indication)
- Maximum permissible pre-charging pressure
- Total weight in kg

**Strictly forbidden are:**
- Welding on hydraulic accumulators, soldering, drilling or carry out of work, which can change the mechanical properties of the pressure device.
- Change of the hydraulic accumulator or its components

**Maintenance / Repair**

Before the disassembly of the hydraulic accumulator out off the fluid side from the system, it must be ensured that the hydraulic accumulator is completely depressurized on the liquid- and system side. Before the dismantling the hydraulic accumulator please ensure that the accumulator is fully exonerated the gas side and the accumulator is completely separate from the system of the fluid side (caution regarding out-gassing!)
Before the dismantling of the accumulator all externally mounted components must be removed on liquid side (such as reducers, and other accessories).If the accumulator is completely relieved (gas and liquid side) is the liquid valve must be open.

## XII. Couplings

A **coupling** is a device used to connect two shafts together at their ends for the purpose of transmitting power. The primary purpose of couplings is to join two pieces of rotating equipment while permitting some degree of misalignment or end movement or both.
In a more general context, a coupling can also be a mechanical device that serves to connect the ends of adjacent parts or objects. Couplings do not normally allow disconnection of shafts during operation, however there are torque limiting couplings which can slip or disconnect when some torque limit is exceeded. Selection, installation and maintenance of couplings can lead to reduced maintenance time and maintenance cost

**Types**

**Clamped** or **compression rigid** couplings come in two parts and fit together around the shafts to form a sleeve. They offer more flexibility than sleeved models, and can be used on shafts that are fixed in place.

They generally are large enough so that screws can pass all the way through the coupling and into the second half to ensure a secure hold.

**Flanged rigid couplings** are designed for heavy loads or industrial equipment. They consist of short sleeves surrounded by a perpendicular flange. One coupling is placed on each shaft so the two flanges line up face to face. A series of screws or bolts can then be installed in the flanges to hold them together. Because of their size and durability, flanged units can be used to bring shafts into alignment before they are joined together.

**Examples of rigid couplings**

Rigid couplings are used when precise shaft alignment is required; shaft misalignment will affect the coupling's performance as well as its life.

## XIII. Hydraulic and pneumatic solenoids

A solenoid-operated valve (SOV) is an on/off electro-magnetic valve that is controlled by a discrete electrical signal from a control system. In process control applications, SOVs are generally used to pressurize or de-pressurize on/ off actuators.

Figure: Pilot- operated solenoid valve

| Problem | Probable cause | Possible solution |
|---|---|---|
| **All valves** | | |
| Wire drawing | Dirt or foreign matter is lodged on seat | Preferably install new valve. Install strainer close to valve inlet. |
| **Coil failure** | Overvoltage | Check voltage at coil. Voltage must conform to name-plate rating. |
| | Damaged core or core tube causing inrush current to be drawn continuously | Check for damaged core and core tube, or damaged spring. Check for scale or foreign matter on the core or inside the core tube. Clean thoroughly and replace any damaged parts (contact us). |
| | Excessive foreign matter jamming core in core tube | |
| | Excessive fluid pressure | Reduce pressure or install suitable valve. |
| | Excessive ambient or fluid temperature | Refer to the data listed for temperature classes E, F and H (Section A, page V030). |
| | Missing solenoid parts | Install missing coil or housing and other metal parts or properly install incorrectly assembled metal parts. The metal parts and housing (if used) form part of the magnetic circuit and are required to provide the impedance needed to limit current draw. |
| | Moisture inside solenoid enclosure | Waterproof the entrance conduit to prevent entry of moisture. If valve is mounted outdoors, check to see that<br>- coil connector is properly mounted (and connector seal is in place);<br>- enclosure (if used) is weatherproof and seal is in place and in good condition.<br>Use appropriate sealant where required.<br>Select solenoids for use in damp or humid atmospheres:<br>- IP65 = moulded coil and connector (most catalogue valves)<br>- IP67 = valve or coil with M12 connection and connector (series 302, M12 coil)<br>- IP67 = metal enclosure (example WP/WS/etc.). |
| | ATEX 94/9/EC versions: Binding core, excessive supply voltage, excessive ambient or fluid temperature may cause the thermal fuse to open | No reset possible. Replace the solenoid operator/coil (contact us). |
| **Pressure operated valves** | | |
| Valve will not operate **when operator is supplied with pilot pressure (working state)** | Pressure operated valve | Check the pressure on the supply side of the valve; it must correspond to the values indicated on the nameplate.<br>Caution: Observe the minimum pilot pressure values for the valve in NO or NC function with fluid entry above disc or back pressure. |
| Internal leaks | Incorrect outlet pressure; disc/seat etc. not leaktight | Disassemble the valve body and clean the internal parts. Replace disc seal or valve, if necessary.<br>Make sure to use recommended types of fluids.<br>Do not use “compact” type valves (page V405) or cast iron valves with flanges on steam circuits. |
| Leaks at pilot connection | Incorrect pilot pressure | Check that pilot valve is properly tightened on valve operator. Observe tightening torques.<br>When installing a pilot valve with mounting pad to ISO 15218, check for correct position of mounting interface surface and seal supplied with the valve. Install the pilot directly on the mounting interface/seal. |
| Wire drawing | Dirt or foreign matter is lodged on seat | Preferably install new valve. Install strainer close to valve inlet. |

TROUBLESHOOTING GUIDE

## XIV. Rotary actuators

### Actuator nameplate

The nameplate is stuck on the diaphragm casing. It includes all details required to identify the device:

1 Type number
2 Country of origin
3 Material configuration number
4 Serial number
5 Actuator area
6 Bench range in bar
7 Bench range in psi
8 Operating travel in mm
9 Operating range in bar

10 Operating range in psi
11 Permissible supply pressure pmax in bar
12 Permissible supply pressure pmax in psi
13 Symbol indicating fail-safe action
    Actuator stem extends (FA)
    Actuator stem retracts (FE)
    Manual override
14 Diaphragm material
15 Connecting thread
16 Date of manufacture
17 Data Matrix code

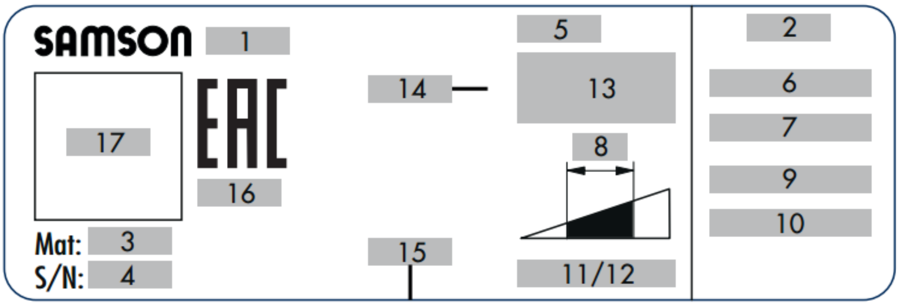



Figure: Actuator's nameplate

The operators assigned to the actuator's maintenance must be authorized personnel or otherwise must have attended a training course dedicated to the use and maintenance of the actuator.

## XV. Pneumatic/Hydraulic fittings

Hydraulic fittings are parts used to connect hoses, pipes, and tubes in hydraulic systems. Hydraulic equipment generally operates under high pressures and is often not a fixed system. Consequently, hydraulic fittings need to be strong, versatile, and reliable to operate safely and effectively in their respective applications. These fittings typically adhere to strict standards which dictate fitting construction, dimensions, and pressure ratings.

Hydraulic Pipes, Tubes, and Hoses

It is important to distinguish what type of hydraulic equipment is being connected in the system to determine what fittings are appropriate.

- **Hydraulic tubes** are seamless precision pipes specially manufactured for hydraulics. The tubes have standard sizes for different pressure ranges, with standard diameters up to 100 mm. Tubes lengths are interconnected via flanges, welding nipples, flare connections, or by cut-rings. Direct joining of tubes by welding is not acceptable since the interior cannot be inspected.
- **Hydraulic pipes** are larger diameter hydraulic tubes. Generally these are used for low pressure applications or when hydraulic tubes are not available. They can be connected by welds or threaded connections. Because of the larger diameters the pipe can usually be inspected internally after welding.
- **Hydraulic hose** is graded by pressure, temperature, and fluid compatibility. Hoses are used in applications where pipes or tubes are not suitable, usually to provide flexibility for machine operation or maintenance. The hose consists of multiple layers of rubber and steel wire. Hydraulic hoses generally have steel fittings swaged on the ends. The weakest part of hydraulic hose is the connection of the hose to the fitting, which is why proper fitting selection and installation is essential in high pressure applications.

Types of Fittings

Hydraulic fittings are distinguished based on the connection type and function it performs.

**Connection Type**

Hydraulic fittings are attached via a number of different connection methods, each with its own conveniences and advantages.

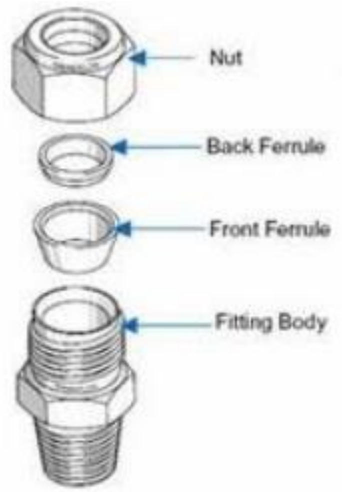
Compression Fittings

Compression fittings include all types of fittings which use compressive force to connect the vessel to the fitting.

- **Standard compression fittings** use metal gaskets, rings, or ferrules which form a seal on the vessel through compression. The compression is typically made by tightening a nut onto the fitting over the piping and ferrule, compressing, and securing the vessel inside. Standard compression fittings do not require tools to assemble, making them convenient for quick field installations.

*Image Credit: Carr Lane Manufacturing*

- **Bite-type fittings** are compressive fittings with a sharpened ferrule that "bites" the vessel when compressed and provides the seal. Bite-type fittings, like standard compressive fittings, require no special tools to assemble, but provide a stronger, higher pressure connection.
- **Mechanical grip fittings** are two-ferrule assemblies. The back ferrule grips the vessel while pressing up against the front ferrule, which spring-loads the front ferrule and creates a seal between the piping and fitting body. These fittings can be reassembled multiple times without damaging components or piping. They have good resistance to mechanical vibration.




- **Flare fittings** consist of a body with a flared or coned end. Special flaring tools are used to install the vessel inside the flared end, providing a deep seal. Flare fittings can handle higher pressures and a wider range of operating parameters than standard compression fittings.

Image Credit: Parker Hannifin

*Crimp Fittings*

Crimp fittings involve placing hose over a tubular end and crimping against it with a sleeve, ring, or crimp socket. These fittings typically require crimping tools or machines to make the connections.

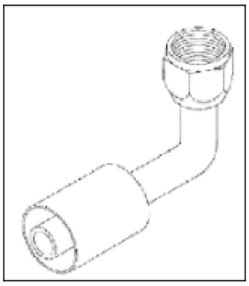


Image Credit: Digital Dezines | Parker Hannifin

*End Fittings*

End fittings provide specific surfaces for connecting vessels in hydraulic systems.

- **Clamp ends** are fittings which allow hoses or tubes to be clamped over the part.
- **Plain ends** are fittings with surfaces which allow pipes or tubes to be connected by adhesive, solder, welding, or other permanent means. Welding, when done properly on compatible materials, provides a strong and reliable connection.

*Flange Fittings*

Flange fittings are rims, edges, ribs, or collars with flush surfaces perpendicular to the attached pipe or tube. These surfaces are joined and sealed via clamps, bolts, welding, brazing, and/or threading. For more information on flanges, visit the Pipe Flanges Selection Guide on GlobalSpec.

Image Credit: Main Manufacturing, Inc.

*Push-to-Connect*

Push-to-connect fittings have ends that are designed to accept tubing by pushing it into the end. These fittings typically disconnect via some type of collar retraction. These connections are convenient for sections of the system requiring frequent disconnection and reconnection.

Image Credit: Parker Hannifin

*Threaded Fittings*

Threaded fittings have screw threads (built-in grooves) on their inner (female) or outer (male) surfaces designed to accept connections with matching threads. Threads which provide a simple connection but no seal are called straight threads. Tapered threads are designed to provide a tight seal for gases or fluids under pressure. Seal reliability can be improved by adding a coating or seal tape (Teflon). Especially precise threads are called "dry fit", meaning they seal without the need for an additional sealant, which is important in applications where sealant addition could cause contamination or corrosion.

*Image Credit: Grainger Industrial Supply*

- TOPIC 3: Service manual and nameplate for measuring instrument used in pneumatic/ hydraulic systems
    i. **Pressure gauges**

What is a pressure gauge?

A pressure gauge is a device which measures the pressure in a gas or liquid. Pressure gauges are widely used all over the world in industrial environments because of its affordable price.

These Pressure sensors are among the most often used instruments in a plant. But because of their great numbers, attention to maintenance can be compromised. As a consequence, it is not uncommon in older plants to see many gauges out of service.

This is unfortunate because, if a plant is operated with a failed pressure switch, the safety of the plant may be compromised. Conversely, if a plant can operate safely while a gauge is defective, it shows that the gauge was not needed in the first place. Therefore, one goal of good process instrumentation design is to install fewer but more useful and more reliable pressure gauges.

Digital Pressure Gauge with Analogue wireless transmission Learn more about pressure gauges Low-Pressure Diaphragm Gauges. One way to reduce the number of gauges in a plant is to stop installing them on the basis of habit (such as placing a pressure gauge on the discharge of every pump). Instead, review the need for each device individually.

Figures: Digital and Analogue pressure gauge

During the review one should ask: "What will I do with the reading of this gauge?" and install one only if there is a logical answer to the question. If a air pressure gauge only indicates that a pump is running, it is not needed, since one can hear and see that. If the gauge indicates the pressure (or pressure drop) in the process, that information is valuable only if one can do something about it (like cleaning a filter); otherwise it is useless.

If one approaches the specification of pressure gauges with this mentality, the number of gauges used will be reduced. If a plant uses fewer, better gauges, reliability will increase.

Failures and Pressure Gauges

Two common reasons for gauge failure are pipe vibration and water condensation, which in colder climates can freeze and damage the pressure gauge housing.

The delicate links, pivots, and pinions of a traditional gauge are sensitive to both condensation and vibration. The life of the filled pressure gauge is longer, not only because it has fewer moving parts, but because its housing is filled with viscous oil. This oil filling is beneficial not only because it dampens pointer vibration, but also because it leaves no room for humid ambient air to enter.

### ii. Flow meters

A flow meter is a device used to measure the volume or mass of a gas or liquid. Flow meters are referred to by many names, such as flow gauge, flow indicator, liquid meter, flow rate sensor, etc. depending on the particular industry. However, they all measure flow. Open channels, like rivers or streams, may be measured with flow meters. Or more frequently, the most utility from a flow meter and the greatest variety of flow meters focus on measuring gasses and liquids in a pipe. Improving the precision, accuracy, and resolution of fluid measurement are the greatest benefits of the best flow meters.

**Why do I need a precision flow meter?**

You might not! Precision flow meters are used to provide accurate monitoring and/or flow control. Some industrial applications require precise calculation of quantity, such as precision servo-valve development for the aerospace industry. On the other hand, an application to measure water flow to a vineyard may only require a measurement accuracy of 5% to 10%.

**The various types of flow meters**

- Positive Displacement (Also known as a volumetric flow meter or PD flow meter)

Positive displacement flow meters are unique as they are the only meter to directly measure the actual volume. All other types infer the flow rate by making some other type of measurement and equating it to the flow rate. With PD meters, the output signal is directly related to the volume passing through the meter. Includes bi-rotor types (gear, oval gear, helical gear), nutating disc, reciprocating piston, and oscillating or rotary piston.

Piston flow meter Gear flow meter Helical flow meter

Figure: Various types of flow meter

- **Mass flow meter**

The output signal is directly related to the mass passing through the meter.

Thermal and Coriolis flow meters fall into this category.

- **Velocity flow meter**

The output signal is directly related to the velocity passing through the meter.

**What type of flow meter is best?**

There are no "universal" flow meters which are suitable for all applications. Selecting the proper technology for your application requires writing a flow specification which covers the use of the meter. There are usually trade-offs with each meter type, so knowing the critical specifications will be important.

### iii. Viscometer

Viscometers measure the viscosity and flow properties of fluids. Viscosity arises from the internal friction of a fluid and is defined as a liquid's resistance to flow or shear stress.

**Applications of viscometers**

Viscometers have wide and varied applications in the materials science and chemical industries for materials such as oil, asphalt, plastics, wax, paints, coatings, and adhesives. They are also used for food and beverages and personal-care products such as cosmetics, shampoo, and toothpaste.

Measuring viscosity is important when considering process conditions for materials that need to be pumped or piped. Viscosity also affects dipping and coating performance, which is particularly relevant to paints and inks.

Viscosity is a very useful indirect measure of material properties including molecular weight and density, both of which affect flow behavior. Viscometers can therefore be used to monitor batch consistency and quality control.

**Example applications include:**

- Measuring the flow of engine oil under different temperature conditions
- Analyzing the flow properties of milk to design suitable piping systems
- Checking the viscosity of jams and syrups to ensure batch consistency.

Since changes in viscosity reflect changes to molecular weight, viscometers are used to characterize plastics. They are particularly useful in polymer synthesis since the flow rate can be used to determine the change of polymer length through different processes.

In many industrially useful cases, viscosity decreases as enzymatic activity increases. Viscometers are used to determine the activity of enzymes such as cellulase, protease, amylase, and pectinase.

**Types of viscometers**

There are many ways to measure viscosity, but they break down into two basic methods. Either an object, such as a sphere or a rotor blade, moves through a stationary material, or the material flows through or past a stationary object. In either case, the resistance to flow is measured.

- Capillary viscometers

Also known as u-tube or glass viscometers, capillary viscometers are often used in laboratory settings. Viscosity is measured by timing how long it takes for a transparent or translucent fluid to flow between two points of a capillary tube.

For opaque liquids, it is hard to determine when the sample has passed a point in the tube, so it is necessary to use reverse-flow viscometers that only wet the timing section of the viscometer capillary during the actual measurement.

The Cannon-Fenske Opaque, Zeitfuchs Cross-Arm, and BS/IP/RF Viscometers from CANNON Instrument Co. (State College, PA; www.cannoninstrument.com) are all reverse-flow types.

Reverse-flow viscometers must be cleaned, dried, and refilled before a repeat measurement can be made.

Capillary viscometers can be manual or automatic. Automatic instruments use infrared optical sensors for transparent samples, or thermal sensors for opaque samples.

- Rotational viscometers

Simple rotational viscometers, also known as Brookfield type viscometers, use a torsion spring to measure the torque required to rotate a spindle in the material. Changing rotor speed and size allows for the measurement of different ranges of viscosity.


Figure: Viscometer

**iv. Thermometer**

The temperature of the hydraulic fluid in hydraulic systems can be measured either with simple measurement devices (thermometer) or with a measuring device that issues signals to the control unit.

The simplest method is measuring the temperature of the pressure fluid in the tank. However, this method constitutes a rough estimate and does not allow conclusions to be drawn regarding the temperature of the pressure fluid at certain locations within the system.

For example, the temperature of the pressure fluid may be very high at certain throttle points. If the temperature of the pressure fluid must be known at certain points within the hydraulic system, pressure-resistant sensors must also be fitted at these locations.

The temperature measurement is particularly important as high temperatures (> 60°) lead to premature ageing of the hydraulic fluid and seals. Large differences in temperature also result in large differences in the viscosity of the medium. To keep the temperature constant, thermo switches or thermostats are used, which switch on the cooling or heating system when necessary.

## Learning outcome 4.2: Identify status indicators/ alarming signal for pneumatic / hydraulic systems

- **TOPIC 1: Actuators positions indicators**

  **i. Sensors**

Pneumatic/hydraulic cylinders carry many advantages in terms of relatively low first cost, application simplicity, and durability. To integrate a pneumatic cylinder into an automated system, electrical signals must be supplied to the controller indicating the position status of the cylinders. Toward that end, pneumatic cylinder manufacturers, machine builders, and end users have developed a number of ways to detect extension or retraction of a pneumatic cylinder and provide an electrical signal to the control system.

**Position-Sensing Techniques**

One position-sensing technique is to install external electromechanical limit switches or inductive proximity switches that detect metal targets on the moving parts of the machine. The disadvantages of this approach include the cost and complexity of the brackets and associated hardware, the difficulty of making adjustments, and the increased physical size of the overall assembly. Another problem is that the external hardware is prone to damage and misalignment from everyday incidental contact or impact.

A more popular and widely used method is to attach magnetically actuated switches or sensors to the sides of the cylinder, or into a slot extruded into the body of the cylinder. Magnetic-field sensors detect a magnet mounted in the moving piston through the aluminum wall of the cylinder. In most applications, magnetic sensors provide end-of-stroke detection in either direction; however, installation of multiple sensors along the length of a cylinder allows detection of several discrete positions.

Switches (top) detect targets for end-of-stroke sensing. Magnetic-field sensors mounted to the cylinder (bottom) provide a more versatile and reliable switching solution. Here, reed switches are attached to tie rods.

**Two different types of cylinder magnets are commonly used with magnetic field sensors:**

- The first—and probably the most widespread—is the axially **magnetized magnet**, which is ideal for actuating most reed switches. When viewed from the side, this magnet has the north and south poles next to each other in the axial plane.
- The other common cylinder magnet is **radially magnetized**, which works well with Hall-effect sensors. Instead of the north and south poles next to each other, one is the inner diameter and the other is the outer diameter. The Hall-effect sensor only looks for a magnetic pole; it does not matter if it is north or south.

**Magnetic Sensor Types**

The simplest magnetic field sensor is the reed switch.

This device consists of two flattened ferromagnetic nickel and iron reed elements, enclosed in a hermetically sealed glass tube. The glass tube is evacuated to a high vacuum to minimize contact arcing. As an axially aligned magnet approaches, the reed elements attract the magnetic flux lines and draw together by magnetic force, thus completing an electrical circuit.

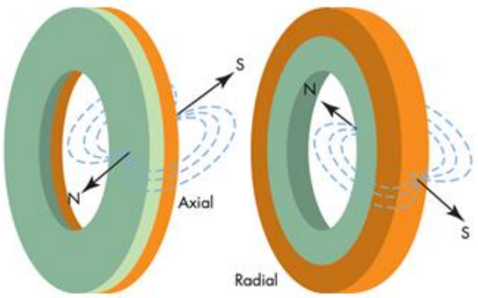
The magnet must have a strong enough Gauss rating, usually in excess of 50 Gauss, to overcome the return force, i.e., spring memory, of the reed elements.

**Reed switches**—The benefits of reed switches are that they are low-cost, they require no standby power, and they can function with both ac and dc electrical loads. However, reed switches are relatively slow to operate, and therefore may not respond fast enough for some high-speed applications. Since they are mechanical devices with moving parts, they have a finite number of operating cycles before they eventually fail.

Switching high-current electrical loads can further cut into their life expectancy. In addition, low-cost reed switches can sometimes deliver multiple switching points as the twin lobes of certain magnets pass by. Lastly, reed switches installed in high shock and vibration applications may exhibit contact bounce or even become physically damaged. In many automated factories, reed switches are a major source of unplanned downtime. In plants with hundreds of reed switches, failures can occur almost hourly and represent a continuous maintenance headache, not to mention lost productivity.

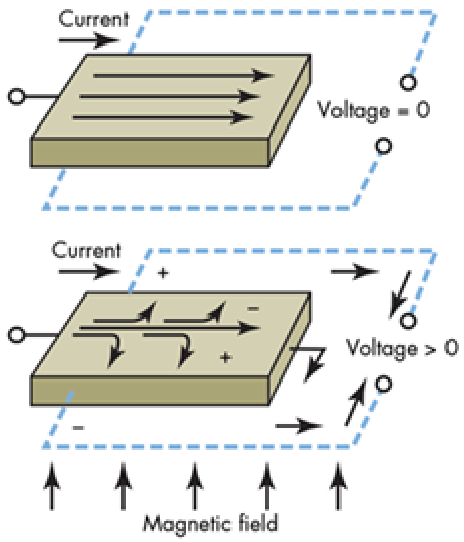
**Hall-effect sensors**—Hall-effect sensors are solid-state electronic devices. They consist of a voltage amplifier and a comparator circuit that drives a switching output. In a Hall-effect sensor, a steady dc current passes through the thin Hall-effect chip. The distribution of electrons across the element is uniform and the current moves in a straight line, with no potential difference generated at the outputs (located on the sides of the chip). As a radially oriented magnet approaches, the magnetic field is perpendicular to the current flow through the Hall element. The presence of the perpendicular magnet pushes the electrons out of their straight-line path and toward one side of the chip.

The imbalance of electron charge thus creates a potential voltage across the Hall-effect element. The small micro-voltage that is created is proportional to the strength of the magnetic field. Once the voltage amplitude generated across the chip has satisfied the threshold level of a comparator circuit, the sensor output switches on.




Magnets embedded in a pneumatic cylinder as piston transmit either magnetic fields oriented either axial or radial directions.

Because Hall-effect sensors are electronic devices, they have no moving parts. Unlike a reed switch, their response time is not dependent on magnetic force overcoming mechanical inertia. They operate faster and are more resistant to shock and vibration.



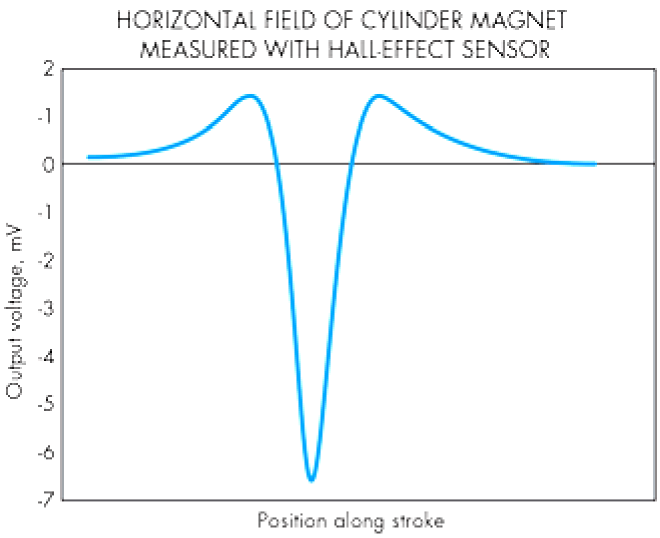

This simplified representation shows how a magnetic field affects a Hall-effect sensor as output.

It might seem like an easy solution to simply replace reed switches with Hall-effect sensors. The problem is that the magnetic field orientation of a cylinder designed for reed switches may be axial, whereas the orientation for a Hall-effect sensor is radial. There is a chance that a Hall-effect sensor will not operate properly when activated by an axially oriented magnet. Another concern is that Hall-effect sensors typically have rather low sensitivity, such that the magnetic field strength must be in the 30-60 Gauss range. Finally, some inexpensive Hall-effect sensors are susceptible to double switching, which occurs because the sensor will detect both poles of the magnet, not simply one or the other.

**Anisotropic magneto-resistive sensors**—Another type of solid-state magnetic field sensor is the anisotropic magneto-resistive (AMR) variety. The operating principle of AMR sensors is simple: the sensor element undergoes a change in resistance when a magnetic field is present, changing the flow of a bias current running through the sensing element.

A comparator circuit detects the change in current and switches the output of the sensor. Compared to Hall-effect sensing technology, which generates a tiny microvolt-level signal, the AMR element responds with a more robust 3% to 4% change in bias current. This results in more noise immunity and less susceptibility to false tripping.

This graph shows typical output voltage of a Hall-effect sensor based on an external magnetic field.




Typically, AMR sensors are about 200 times more responsive than Hall-effect sensors for a given magnetic field strength. The practical magnetic field strength required to operate an AMR sensor can be as low as 15 Gauss. Improvements in AMR technology now allow these sensors to detect both axially and radially magnetized magnets.

**COMPARISON OF SENSOR TECHNOLOGIES**

| | Reed | Hall Effect | AMR | GMR |
|---|---|---|---|---|
| Sensing Element Size | Large | Small | Medium | Small |
| Construction | Mechanical | Solid State | Solid State | Solid State |
| Magnet Strength Required | Medium | High | Low | Low |
| Sensitivity | Medium | Low | High | High |
| Temperature Stability | Medium | Low | Medium | High |
| Power Consumption | Zero | Low | High | Low |
| Noise Immunity | High | Low | High | High |
| Switching Speed | Low | High | High | High |
| Mechanical Robustness | Low | Medium | High | High |
| Electrical Robustness | Low | Low | High | High |
| Double Switch Points | Yes | Possible | No | No |

**ii. Limit valves**

The purpose of a limit switch is to provide a discrete open or close signal to the control system when the valve reaches a specific position within its range of travel. Limit switches are also used for process monitoring, troubleshooting, or start up /shutdown verification. The limit switch receives position feedback from the valve stem or shaft and will send either a wired or a wireless signal to the control system. There are many different switch technologies available, such as proximity, solid state, magnetic, and contact closure.

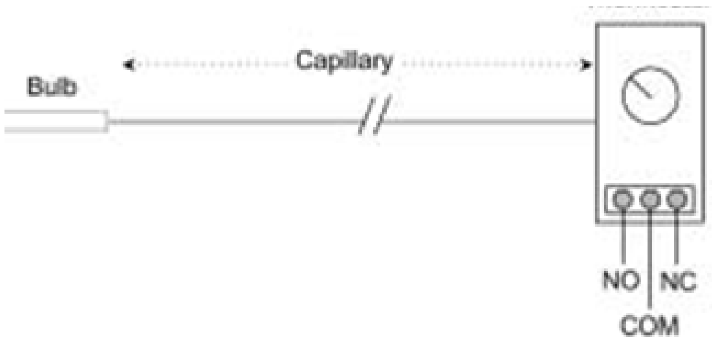
- **TOPIC 2: Identification of alarms signals and status indicators for pneumatic systems**

**i. Temperature sensors**

Pneumatic temperature sensor systems are mostly used in HVAC systems for transmitting temperature signals to a control system.

The bulb includes a temperature-dependent refrigerant that extends or contracts. This result in a shift in the stress in the capillary as the bulb and capillary are in a closed system.

The capillary is linked to a diaphragm that either activates a snap-action switch within a thermostat (for on / off control) or moves a slide-wire resistor center button (for control modulation).




**Working of sensor:**

In on / off command, at a specified temperature, the thermostat can be set to close or open the switch. Usually some differential (hysteresis) is constructed into the switch so that when the temperature of the bulb is close to the set point, it does not open and close rapidly.

The circuit works comparable to a Wheatstone bridge when used to modulate control with the engine equilibrium relay attempting to match the thermostat slider position.

**Advantages of pneumatic temperature sensor:**

- Do not require an electric power source to operate
- Reliable in commercial use
- They are particularly useful for freeze protection control on a coil, since the bulb can be of any size.

**Disadvantages of pneumatic temperature sensor:**

They are difficult to fix if the bulb or capillary spring a leak, if this happen the thermostat should throw away.

**ii. Air pressure relay**

The pressure relay can be used in pneumatic, hydraulic and oil system. In the process of operation, the pressure relay can provide an electrical signal to regulate the working condition when sense pressure rises above or falls below the selected setting.

**iii. Pneumatic controllers**

**What is a Pneumatic Controller?**

A pneumatic controller is a mechanical device designed to measure temperature or pressure and transmit a corrective air signal to the final control element.

Bourdon tubes, bellows, temperature elements, or displacers are used as the sensing elements. The power supply and output of a pneumatic controller is compressed air or natural gas. The input signal to the controller is mechanical movement provided by the sensing element that is being used to sense the process. Sensing elements are sized to provide the optimum control for the application.

Pneumatic controllers are used in automatic control systems for flow rate, pressure, temperature, level, and other parameters of industrial processes.

Figure: Pneumatic controller

### iv. Air flow control valves

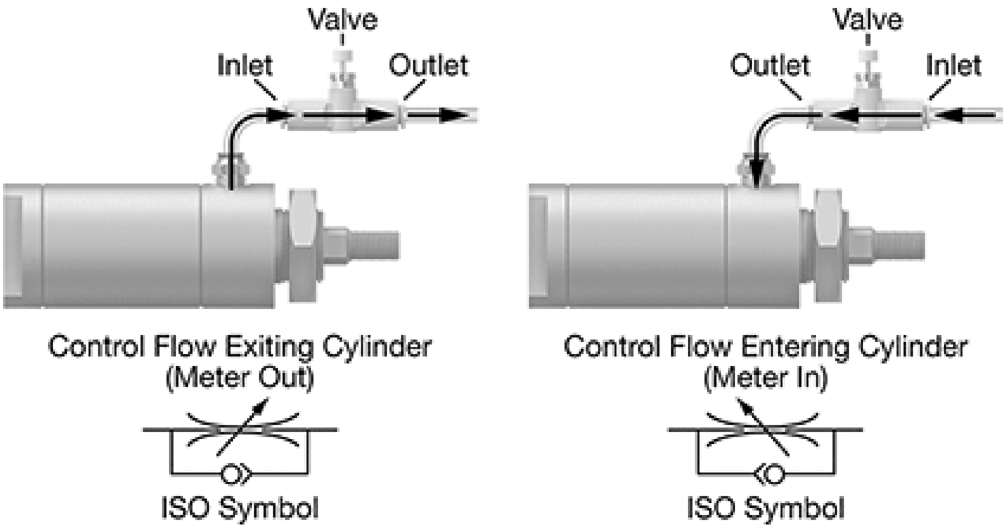
Also known as cylinder speed controls, flow control valves let you control the extension or retraction speed of your air cylinder. They regulate airflow as it passes from the valve's inlet to its outlet. Air flows freely in the opposite direction. Use the dial on the valve to adjust the airflow rate.

Connect flow control valves to the port of your cylinder. Choose a valve to control airflow as it exits the cylinder (meter out) or control airflow as it enters the cylinder (meter in). When in doubt, meter out.

**SCFM** (standard cubic feet per minute) is the volumetric flow rate of air at a given pressure.

**Flow coefficient (Cv)** is a measurement that indicates how much airflow a control valve can provide to your cylinder. The higher the flow coefficient value, the higher the airflow rate. Looking at valves with the same port size, but different flow coefficient values and are not sure which one to choose? Select the one with the higher flow coefficient value because low airflow can slow down your entire system.

**ISO symbols**, found on most flow control valves, depict the direction of airflow through the valve.



### v. Valves positioners

- Function : The fundamental function of a positioner is to deliver pressurized air to the valve actuator, such that the position of the valve stem or shaft corresponds to the set point from the control system.
- Positioners are typically used when a valve requires throttling action.
- A positioner requires position feedback from the valve stem or shaft and delivers pneumatic pressure to the actuator to open and close the valve. The positioner must be mounted on or near the control valve assembly.
- Categories : There are three main categories of positioners, depending on the type of control signal, **the diagnostic capability, and the communication protocol: pneumatic analog and digital.**

**Operation**

In a common pneumatic positioner the position of the valve stem or shaft is compared with the position of a bellows that receives the pneumatic control signal. When the input signal increases, the bellows expands and moves a beam.

The beam pivots about an input axis, which moves a flapper closer to the nozzle. The nozzle pressure increases, which increases the output pressure to the actuator through a pneumatic amplifier relay.

The increased output pressure to the actuator causes the valve stem to move. Stem movement is fed back to the beam by means of a cam.

As the cam rotates, the beam pivots about the feedback axis to move the flapper slightly away from the nozzle. The nozzle pressure decreases and reduces the output pressure to the actuator. Stem movement continues, backing the flapper away from the nozzle until equilibrium is reached. When the input signal decreases, the bellows contracts (aided by an internal range spring) and the beam pivots about the input axis to move the flapper away from the nozzle. Nozzle pressure decreases and the relay permits the release of diaphragm casing pressure to the atmosphere, which allows the actuator stem to move upward. Through the cam, stem movement is fed back to the beam to reposition the flapper closer to the nozzle. When equilibrium conditions are obtained, stem movement stops and the flapper is positioned to prevent any further decrease in actuator pressure.

The second type of positioner is **an analog I/P positioner**. Most modern processing units use a 4 to 20 mA DC signal to modulate the control valves. This introduces electronics into the positioner design and requires that the positioner convert the electronic current signal into a pneumatic pressure signal (current-to-pneumatic or I/P).

In a typical analog I/P positioner, the converter receives a DC input signal and provides a proportional pneumatic output signal through a nozzle/flapper arrangement. The pneumatic output signal provides the input signal to the pneumatic positioner. Otherwise, the design is the same as the pneumatic positioner

While pneumatic positioners and analog I/P positioners provide basic valve position control, digital valve controllers add another dimension to positioner capabilities.

This type of positioner is a microprocessor-based instrument. The microprocessor enables diagnostics and two-way communication to simplify setup and troubleshooting.

In a typical digital valve controller, the control signal is read by the microprocessor, processed by a digital algorithm, and converted into a drive current signal to the I/P converter. The microprocessor performs the position control algorithm rather than a mechanical beam, cam, and flapper assembly. As the control signal increases, the drive signal to the I/P converter increases, increasing the output pressure from the I/P converter. This pressure is routed to a pneumatic amplifier relay and provides two output pressures to the actuator. With increasing control signal, one output pressure always increases and the other output pressure decreases

- Double-acting actuators use both outputs, whereas single-acting actuators use only one output. The changing output pressure causes the actuator stem or shaft to move. Valve position is fed back to the microprocessor. The stem continues to move until the correct position is attained. At this point, the microprocessor stabilizes the drive signal to the I/P converter until equilibrium is obtained.
- In addition to the function of controlling the position of the valve, a digital valve controller has two additional capabilities: diagnostics and two-way digital communication.
- Widely used communication protocols include HART, FOUNDATION fieldbus, and PROFIBUS.

- **Advantages of placing a smart positioner on a control valve:**

1. Automatic calibration and configuration of positioner. 2. Real time diagnostics. 3. Reduced cost of loop commissioning, including installation and calibration. 4. Use of diagnostics to maintain loop performance levels. 5. Improved process control accuracy that reduces process variability.

### vi. The flapper-nozzle

The **nozzle and flapper mechanism** is a displacement type detector which converts mechanical movement into a pressure signal, by covering the opening of a **nozzle** with a flat plate called the **flapper**. This restricts fluid flow through the nozzle and generates a pressure signal.

It is a widely used mechanical means of creating a high gain fluid amplifier. In industrial control systems they played an important part in the development of pneumatic PID controllers and are still widely used today in pneumatic and hydraulic control and instrumentation systems.

- **Operating principle**

The operating principle makes use of the high gain effect when a "flapper" plate is placed a small distance from a small pressurized nozzle emitting a fluid.

The example shown is pneumatic. At sub-millimeter distances a small movement of the flapper plate results in a large change in flow. The nozzle is fed from a chamber which is in turn fed by a restriction, so changes of flow result in changes of chamber pressure. The nozzle diameter must be larger than the restriction orifice in order to work. The high gain of the open loop mechanism can be made linear using a pressure feedback bellows on the flapper to create a force balance system with a linear output. The "live" zero of 0.2 bar or 3 psi is set by the bias spring which ensures that the device is working in its linear region.

The industry standard ranges of either 3-15 psi (USA), or 0.2 - 1.0 bar (metric), is normally used in pneumatic PID controllers, valve positioning **servomechanisms** and force balance transducers.

- **Application**

The nozzle and flapper in pneumatic controls is a simple low maintenance device which operates well in a harsh industrial environment, and does not present an explosion risk in hazardous atmospheres. They were the industry controller amplifier for many decades until the advent of practical and reliable electronic high gain amplifiers. However they are still used extensively for field devices such as **control valve positioners** , and I to P and P to I converters.

- A proportional controller

The set point is transmitted through the flapper plate via the fulcrum to close the orifice and increase the chamber pressure. The feedback bellows resists and the output signal goes to the control valve which opens with increasing actuator pressure. As the flow increases, the process value bellows counteracts the set point bellows until equilibrium is reached. This will be a value below the set point, as there must always be an error to generate an output. The addition of an integral or "reset" bellows would remove this error.

The principle is also used in hydraulic systems controls.

- **TOPIC 3: Identification of alarms signals and status indicators for hydraulic systems:**

### i. Temperature sensors

Temperature sensors, temperature detectors and temperature switches convert the temperature of liquid media into a digital or analog electrical signal. The simple design allows reliable temperature measurement and good signal evaluation. Because of their stability and robust stainless steel construction, temperature sensors can also be used in applications with extreme process temperatures that are stable in the long term, e.g. in fluid technology industrial applications or refrigeration technology. The temperature detector can be equipped with different detector components and electrical connections according to customer requirements. Installation is carried out either directly in the tank or in the pressure line.

Temperature ranges: from -200 °C to +180 °C

Maximum operating pressure P max: up to 500 bar

Measuring principle: Resistance thermometers (e.g. PT100, PT1000), thermo elements (e.g. PTC, NTC)

### ii. Closed loop controller

Systems in which the output quantity has no effect upon the input to the control process are called open-loop control systems, and that open-loop systems are just that, open ended non-feedback systems.

The quantity of the output being measured is called the “feedback signal”, and the type of control system which uses feedback signals to both control and adjusts itself is called a **Close-loop System**.

A **Closed-loop Control System**, **also known as a *feedback control system*** is a control system which uses the concept of an open loop system as its forward path but has one or more feedback loops (hence its name) or paths between its output and its input. The reference to “feedback”, simply means that some portion of the output is returned “back” to the input to form part of the systems excitation.

Closed-loop systems are designed to automatically achieve and maintain the desired output condition by comparing it with the actual condition. It does this by generating an error signal which is the difference between the output and the reference input. In other words, a “closed-loop system” is a fully automatic control system in which its control action being dependent on the output in some way.

The term **Closed-loop control** always implies the use of a feedback control action in order to reduce any errors within the system, and its “feedback” which distinguishes the main differences between an open-loop and a closed-loop system.
The accuracy of the output thus depends on the feedback path, which in general can be made very accurate and within electronic control systems and circuits, feedback control is more commonly used than open-loop or feed forward control.
Then we can define the main characteristics of **Closed-loop Control** as being:

- To reduce errors by automatically adjusting the systems input.
- To improve stability of an unstable system.
- To increase or reduce the systems sensitivity.

- To enhance robustness against external disturbances to the process.
- To produce a reliable and repeatable performance.

### iii. Flow control valves

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

- **Different types of flow measurement**

Controlling flow of a fluid-power system does not necessarily mean regulating volume per unit of time from a valve. Flow rate can be specified three different ways, so it is important to be aware of how flow is to be specified or measured:

**Volumetric flow rate**, $\mathbf{Q_v}$, expressed in units of in.$^3$/sec or min - or cc/sec or cc/min in SI metric measure - is used to calculate the linear speeds of piston rods or rotational speeds of motor shafts.

**Weight flow rate**, $\mathbf{Q_w}$, expressed in units of lb/sec or lb/min, is used to calculate power using English units of measure.

**Mass flow rate**, $\mathbf{Q_g}$, expressed in units of slugs/sec or slugs/min for English measure - or kg/sec or kg/min in SI metric measure - is used to calculate inertia forces during periods of acceleration and deceleration.

- Comparison of different types of flow control valve

| **Which flow control to use for an application** | |
|---|---|
| **Application** | **Type of flow-control valve** |
| Load on the actuator *and* supply pressure both are constant: ±5% accuracy | Non-compensated, fixed or variable flow control, depending on application |
| Load on the actuator, supply pressure, or both undergo changes: ±3-5% accuracy | Pressure-compensated, fixed or variable flow control, depending on application |
| Load on the actuator, supply pressure, or both change, and fluid temperature varies ±30° F (±17° C): ±3-5% accuracy | Pressure- and temperature-compensated, fixed or variable flow control |
| **The best type of flow control valve to use depends on the design parameters of the application. Above are general guidelines based on common application characteristics.** | |

### iv. Valve positioned

A valve Positioner is a device used to increase or decrease the hydraulic load pressure driving the actuator until the valve's stem reaches a "POSITION" balanced to the output SIGNAL from the process variable instrument controller. Valve positioners are used on controlling valves where accurate and rapid control is required without error or hysterises.

**Positioner Advantages**

- Precise positioning can cope with large variations in forces acting on plug
- Rapid positioning
- Removes stiction and friction effects of gland
- Removes effects of large distances between valve and positioned
- Eliminates hysteresis

**When should a positioner be fitted:**

A positioner should be considered in the following circumstances:

- When accurate valve positioning is required;
- To speed up the valve response. The positioner uses higher pressure and greater air flow to adjust the valve position;
- To increase the pressure that a particular actuator and valve can close against. (To act as an amplifier);
- When the valve pressure drop at the maximum operating flow rate, exceeds 5 bar for single seated valves or 10 bar for double seated valves;

### v. Pressure indicators

A pressure gauge is a fluid intensity measurement device. Pressure gauges are required for the set-up and tuning of fluid power machines, and are indispensable in troubleshooting them. Without pressure gauges, fluid power systems would be both unpredictable and unreliable. Gauges help to ensure there are no leaks or pressure changes that could affect the operating condition of the hydraulic system.

The hydraulic system is designed to work in a set pressure range so the gauge must be rated for that range. Hydraulic pressure gauges are available to measure up to 10,000 psi, although maximum hydraulic pressure is typically in the 3,000 to 5,000 psi range. Hydraulic gauges are often installed at or near the pump's pressure port for indication of system pressure, but can be installed anywhere on the machine where pressure needs to be monitored especially if sub-circuits operate at a pressure rate different from pump pressure, such as after a reducing valve. Often, pressure-reducing valves have a gauge port to tap into, allowing you to directly monitor its downstream pressure setting.

Pressure gauges have been used in fluid power systems for well over a hundred years, so it might be a surprise that pressure gauge designs continue to evolve. The evolution of pressure gauges for fluid power applications has, generally, been an increase in application specific features. For instance, pressure gauges are now more routinely designed with hydraulic friendly pressure connections (such as SAE/Metric straight threads) to prevent system leaks. Analog gauges with custom scales are more common and digital pressure gauges with customizable firmware allow process measurement of pressure-based measurement of leaks or other parameters like torque, load, force and hardness.

The hydraulic gauge can withstand different pressure ranges based on what type of gauge style it is and what material it is made out of. Because of this, the gauge style and the material make up two of the most important selection criteria for gauges.

They are many types of gauge styles, the most common being Bourdon tubes and bellow gauges. Bourdon tubes function by taking the pressure and converting it into mechanical energy. This energy moves a dial in the gauge, displaying the current amount of pressure in the system. Bourdon tube gauges are currently some of the most common gauges and have different configurations such as curved, helical and spiral. The different style of tubing, the size of the tube and the material it is made out of all vary based on the pressure range. One important characteristic to note is the cross section of the tubing changes with increasing pressure. Generally, as the working pressure of the gauge increases, the shape of the cross section of the tube's design will gradually change from an oval shape to a circular shape.

Figure: Bourdon gauge

**Applications of the hydraulic pressure gauge**

- For measuring points with high dynamic pressure loads or vibrations
- For gaseous and liquid media that are not highly viscous or crystallising and will not attack copper alloy parts
- Hydraulics
- Compressors

## LEARNING OUTCOME 4.3: DIAGNOSE FAULTS AND TROUBLE SHOOTING

- **TOPIC 1: Technique of putting tag signs**:
  - ✓ **Danger and warning signs on the systems that are shut down for maintenance**
  
  **Maintenance, Repair & Service**

Use these Maintenance, Repair and Service Signs to warn employees and visitors about potential dangers of using equipment that may be in need of repair or equipment that requires special use such a disconnecting before servicing or to clean the equipment after use. These safety signs not only protect the employee they protect your equipment as well.

Below are some examples of warning and danger signs


CAUTION
DO NOT ATTEMPT TO ADJUST MACHINERY WHILE IN MOTION
CAUTION
DO NOT OPERATE THIS MACHINE WITHOUT GUARDS IN PLACE
CAUTION
Before cleaning or servicing disconnect power supplies.
NOTICE
AIR PRESSURE 30 P.S.I. FOR CLEANING PARTS AND EQUIPMENT
NOTICE
CLEAN MACHINE AT THE END OF EACH SHIFT
CAUTION
READ DIRECTIONS BEFORE SERVICING
CAUTION
READ INSTRUCTIONS BEFORE USING
CAUTION
STOP MACHINERY TO CLEAN, OIL OR REPAIR
CAUTION
READ INSTRUCTIONS BEFORE OPERATING
CAUTION
DO NOT OPERATE MACHINERY WITHOUT GUARDS. DO NOT REMOVE GUARDS, CLEAN, OIL OR REPAIR MACHINERY WHILE IN MOTION
CAUTION
DO NOT OPERATE MACHINE UNDER REPAIR
CAUTION
DO NOT OPERATE MEN WORKING ON REPAIRS
OUT OF ORDER


OUT OF SERVICE FOR REPAIRS
WARNING
MACHINE UNDER REPAIR DO NOT OPERATE
WARNING
DO NOT USE THIS EQUIPMENT
DANGER
IF MACHINE IS NOT OPERATING PROPERLY ADVISE SUPERVISOR IMMEDIATELY
DANGER
DO NOT USE MACHINE UNDER REPAIR
DANGER
DO NOT CLEAN OR REPAIR MACHINERY WHILE IN MOTION
DANGER
DO NOT OPERATE CONTROLS WHILE THIS SIGN IS IN PLACE
DANGER
DO NOT START THIS MACHINE
CAUTION
DO NOT REMOVE GUARDS, CLEAN, OIL, OR REPAIR MACHINERY WHILE IN MOTION

- **TOPIC 2: Troubleshooting procedure as described by the manufacturer**

Troubleshooting industrial hydraulic components — such as pumps, cylinders, valves, actuators, and hydraulic motors — requires a sound understanding of the operation and functional relationship of the components in the system.

Troubleshooting occurs at either start-up or breakdown. Taking a systematic approach to diagnostics and testing helps identify problems and provides the information needed to quickly repair or replace hydraulic components.

**Some basics to remember**

- **Take nothing for granted**: When a problem occurs, make sure a safe condition exists and find out whether this or a similar event has happened before. Resist the temptation to "dive in" with repairs before asking the right questions. Review a system schematic, determine whether the machine is an open- or closed-loop system, and think through different problem scenarios.

- **Know the system**: While reviewing the schematic, identify the recommended system pressure, pump types, valves, accumulators, and actuators, and the machine's sequence of operation. Review any available service bulletins.

- **Visually inspect and operate the machine**: Get familiar with the machine's mechanisms and general layout. Ask the machine operator pertinent questions. Then, only after you have determined that a safe operating condition exists, operate the machine to identify system pressure, whether manual controls are hard or sloppy, and to see if there are any unusual odors or visible external leaks.

- **Check all services to the machine**: Identify electricity to the machine, high-pressure steam pipes, gas lines or other power devices, and determine whether accumulators should or have been discharged.

- **Isolate legs of the circuit and avoid open lines**: Always think about safety first. Understand that a problem in one leg of the circuit may be caused by a problem in another leg of the circuit, such as slow actuator speed.

- **Identify the problem:** There may be hidden causes. Make a list of all possible causes Consider what you found while operating the machine and focus on the most likely cause. Remember that one failure may be the result of another failure.

- **Match the problem to the cause**: Compare your list of possible problems with the principles of component and system operation. For example, pressure equals force and flow equals speed.

- **Reach a conclusion and test it**: Review your list of causes and decide which are the most likely and which are the quickest and easiest to test. Test components before replacing them; analyze the information gathered and eliminate possible causes.

- **Report your findings**: Make notes of your findings on the schematic, talk with plant decision makers, and create a machine file so that your findings are well documented. This will help to establish failure patterns.

- **Repair and/or replace components**: This is a stop-gap measure. The continued repair and/or replacement of a component is solving a symptom of a problem rather than solving the real problem. What is causing the component to continually fail? Answer that question and you have truly solved the machine problem.

While doing troubleshooting and repair work, think in terms of preventive maintenance, which is essential to extending uptime, increasing production, and enhancing quality.

- **TOPIC 3: Identification of probable faults**

  ✓ **Hydraulic/pneumatic leakages**

**Hydraulic system leaks**

There are hundreds of causes of leaks – but they fall into two general categories: internal and external.
i. Internal leakage does not result in actual loss of oil from the system – but it does reduce system efficiency. ii. External leakage results in direct loss of oil – and can have other undesirable effects as well.

**Internal leakage**

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

However, too much internal leakage will slow the operation of the system and waste power through generation of heat. In some cases, it may cause cylinders to creep or drift – or cause loss of oil control in the valves.
Internal leakage increases with the normal wear of parts. Leakage is accelerated by using oil which has too low a viscosity, because such oil thins faster at higher temperatures. High pressures also force more oil out of leaking points in the system. This is one reason why excessive pressures can actually reduce the efficiency of a hydraulic system. Internal leaks are hard to detect. All you can do is monitor the system for sluggish action or creeping and drifting. If these signs appear, it's time to test the system and pinpoint the trouble.

**External leakage**

External oil leaks not only look bad but also can be expensive and hazardous. A drop of oil every second from a leaking container can cost the operator a significant amount of money. A small drip of oil can also be a sign of an impending hydraulic failure, such as a hose rupture, which might cause injury and/or put the machine out of operation.

Every joint in a hydraulic circuit is a potential point of leakage. This is why the number of connections in a system should be kept to a minimum. Components can leak – but care in the assembly and use of new seals and gaskets
during overhaul will help to reduce this problem. The lines that connect the different parts of the system are the main sources of external leakage. Proper fitting and maintenance of hoses, tubes and pipes are important to reduce this problem.

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

● If the reservoir oil level is lower than normal, check all external oil lines for leaks.
● The rubber cover on flexible hoses may crack or split without actually leaking – but check very closely for internal damage. The depth of the crack is the deciding factor. Any oil dampness is a sign that the hose is leaking.
● Air leaks in suction lines are hard to locate. One way of finding them is to pour oil over the points where you suspect leaks. If the noise or bubbling in the system stops, you've located the leak.

● If line connections are leaking, tighten only until the leak stops. If the connection will not stay tightened, the threads are probably stripped and the connector must be replaced. If the connector will tighten but still leaks, check for a cracked line flare or a damaged seal. Remember, more damage has been done to line connectors by over-tightening than by any other cause.

● After stopping leaks in a system, remember to warm it up and cycle the equipment and check at the trouble spots to be *sure* leaks have stopped.
● Recheck the system oil level and replace any oil lost through leaks or broken connections.

**Protection of hydraulic leakage**

Maintain cleanliness around work surroundings.
Good housekeeping standard to be maintained in the hydraulic room, machine parts/ hoses and floor made to be free from Oil smears.

All oil leakage and rise in temperature must be attended immediately. Allow proper ventilation all-around in the cellar.

Proper natural/ mechanical ventilation to be provided in the hydraulic room for extraction of hydraulic fume,

- ✓ Noise level in the cellars must not exceed 85 dba. Anti vibration pads to be periodically & replaced , if required.
- ✓ Install a Fire Extinguisher (Dry Chemical or CO2) near the hydraulic system.
- ✓ Oil Cellar must have fire hydrant lines as per standard (IS 3844:1989 ) .
- ✓ Suitable automatic Fire Detectors and suppression system to be provided in hydraulic room for early detection and suppression of fire.
- ✓ Suitable personnel protective equipment (PPEs) like Spectacles, Gloves (preferable Nitrile), Oil resistant aprons etc to be used by the person working on hydraulic systems.

Probably the most common injury associated with hydraulic systems is the result of pinhole leaks in hoses. These leaks are difficult to locate. A person may notice a damp, oily, dirty place near a hydraulic line. Not seeing the leak, the person runs a hand or finger along the line to find it.
When the pinhole is reached, the fluid can be injected into the skin as if from a hypodermic syringe. Immediately after the injection, the person experiences only a slight stinging sensation and may not think much about it.

Several hours later, however, the wound begins to throb and severe pain begins. By the time a doctor is seen, it is often too late, and the individual loses a finger or entire arm. Unfortunately, this kind of accident is not uncommon. To prevent this type of injury, run a piece of wood or cardboard along the hose (rather than fingers) to detect the leak

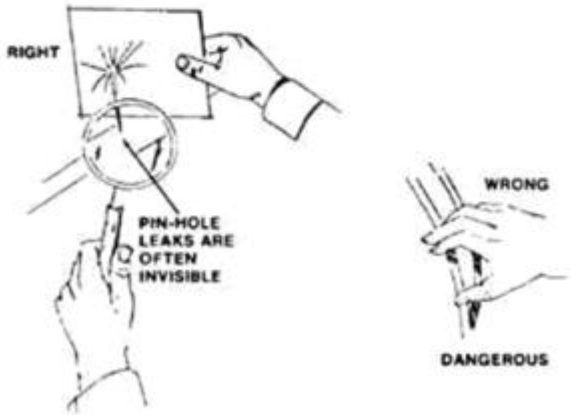



Figure: Detecting pinhole leaks in a hydraulic system

- ✓ System of periodical cleaning of drip tray for preventing spillage to be put in place and the drip tray to be periodically cleaned.
- ✓ Full body showers/ eye wash showers to be provided in the close vicinity of hydraulic system for drenching / flushing of eyes of persons affected by hydraulic oil and location to be displayed with proper signage.

**Audit**

- ✓ A system of Audit is to be developed to conduct periodic audit of hydraulic systems.

**Records**

- ✓ Records on Inspection and Maintenance of Hydraulic Systems shall be available at Department.
- ✓ Records on Hydraulic System Audit shall be maintained by the Department and auditing agency.

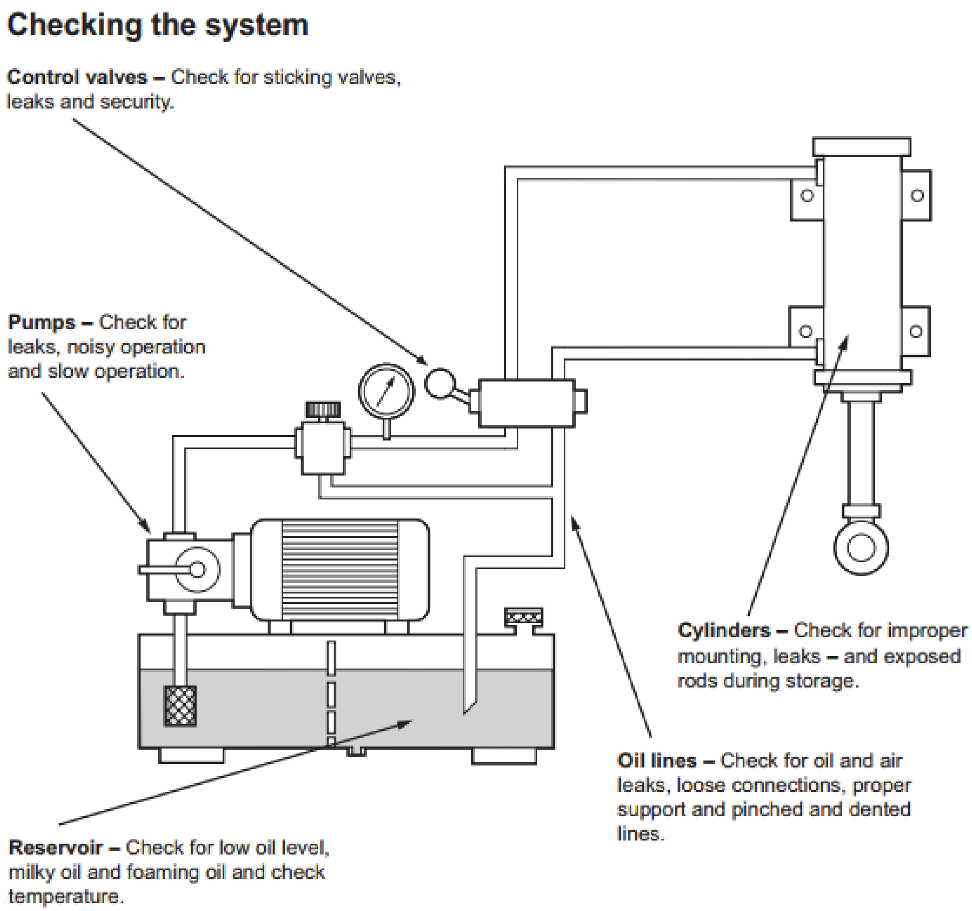



*Figure: system checks*

**Table below shows other probable faults**

| Symptom | Cause | Remedy |
|---|---|---|
| The flow rate is too low. | The back pressure is too high. | Open the discharge valve a little further. |
| | | Reduce the resistance in the discharge pipe. Clean the filter if necessary. |
| | | Use a larger impeller. Make sure to take note of the available motor power. |
| | The speed is too low. | Increase the speed. Check the available motor power. |
| | | Compare the speed of the motor with the specified pump speed. See the rating place. |
| | | When you adjust the speed (frequency transformer), check the reference value settings. |
| | The impeller diameter is too small. | Use a larger impeller. Check the available motor power. |
| | The pump and/or pipes are not complete-ly filled with liquid. | Fill the pump and/or pipes with liquid. |
| | | Vent the pump and/or pipes. |
| | The pump or suction/intake pipe is blocked. | Clean the pipes. |
| | There is an air pocket in the pipeline. | Vent the pipes. |
| | | Improve the pathway of the pipes. |
| | The NPSH is too low. | Increase the liquid level. |
| | | Increase the suction pressure. |
| | | Reduce the resistance in the intake/suc-tion pipe. Change the course and pipe size, open the shutoff valves, and clean the filters. |
| | Air is being sucked into the pipes. | Increase the liquid level. |
| | | Check that the suction pipe is vacuum-tight. |
| | | Provide valves and fittings in the suction pipe with water seal. |
| | The direction of rotation is wrong. | Change the motor rotation. |
| | The inner components are suffering from wear. | Replace the worn parts. |
| | Density and/or viscosity of the pumped liquid is too high. | Seek assistance |
| The flow rate stops after a period of time. | The pump or suction/intake pipe is blocked. | Clean the pipes. |
| | The NPSH is too low. | Increase the liquid level. |
| | | Increase the suction pressure. |
| | | Reduce the resistance in the intake/suc-tion pipe. Change the course and pipe size, open the shutoff valves, and clean the filters. |
| | Air is being sucked into the pipes. | Increase the liquid level. |
| | | Check that the suction pipe is vacuum-tight. |
| | | Provide valves and fittings in the suction pipe with water seal. |
| | The inner components are suffering from wear. | Replace any worn parts. |
| | The density and/or viscosity of the pumped liquid is too high. | Seek assistance. |

| Symptom | Cause | Remedy |
|---|---|---|
| The head is too low. | The back pressure and discharge pressure are too low. | Throttle the discharge valve. |
| | The speed is too low. | Increase the speed. Check the available motor power. |
| | | Compare the speed of the motor with the specified pump speed. See the rating plate. |
| | | When you adjust the speed (frequency transformet), check the reference value settings. |
| | The impeller diameter is too small. | Use a larger impeller. Make sure to check the available motor power. |
| | The pump and/or pipes are not completely filled with liquid. | Fill the pump and/or pipes with liquid. |
| | | Vent the pump and/or pipes. |
| | The pump or suction/intake pipe are blocked. | Clean the pipes. |
| | There is an air pocked in the pipeline. | Vent the pipeline. |
| | | Improve the path of the pipes. |
| | The NPSH of the system is too low. | Increase the liquid level. |
| | | Increase the suction pressure. |
| | | Reduce the resistance in the intake/suction pipe. Change the course and pipe size, open the shutoff valves, and clean the filters. |
| | Air is being sucked into the pipes. | Increase the liquid level. |
| | | Check that the suction pipe is vacuum-tight. |
| | | Provide valves and fittings in the suction pipe with water seal. |
| | The direction of rotation is wrong. | Change the motor rotation. |
| | The inner components are suffering from wear. | Replace the worn parts. |
| | The density and/or viscosity of the pumped liquid is too high. | Seek assistance. |
| The head is too high. | The speed is too high. | Reduce the speed. |
| | | Compare the speed of the motor with the specified pump speed. See the rating plate. |
| | | When you adjust the speed (frequency transformer), check the reference value setting. |
| | The impeller diameter is too large. | Use a smaller impeller. |

| Symptom | Cause | Remedy |
|---|---|---|
| The drive mechanism is overloaded | The back pressure and discharge pressure are too low. | Throttle the discharge valve. |
| | The speed is too high. | Reduce the speed. |
| | | Compare the speed of the motor with the specified pump speed. See the rating plate. |
| | | When you adjust the speed (frequency transformer), check the reference value setting. |
| | The impeller diameter is too large. | Use a smaller impeller. |
| | The density and/or viscosity of the pumped liquid is too high. | Seek assistance. |
| | The shaft seal is worn. | Replace the mechanical seal. |
| | | Check the sealing, flushing, and cooling pipe (pressure). |
| | | Avoid running the pump dry. |
| | There is not enough sealing. | Tighten the screws. |
| | | Replace the mechanical seal. |
| | The discharge pressure is too low. | Increase the minimum amount being carried. Open the control valves and bypass piping. |
| | There is not enough hydraulic thrust balance. | Clean the relief holes in the impeller. |
| | | Replace the worn impeller and wear rings. |
| The pump is not running quietly. | The pump and/or pipes are not completely filled with liquid. | Fill with liquid |
| | | Vent the pump and/or pipes. |
| | The NPSH is too low. | Increase the liquid level. |
| | | Increase the suction pressure. |
| | | Reduce the resistance in the intake/suction pipe. Change the course and pipe size, open the shutoff valves, and clean the filters. |
| | The inner components are suffering from wear. | Replace the worn parts. |
| | Forces in the pipeline are too high and the pump is under strain. | Change the position of the support pipes and use compensators. |
| | | Check that the foundation plate and frame are properly cast and in place. |
| | There is too much, not enough, or the wrong type of lubricant. | Change the lubricant. |
| | The electrical supply is incorrect. | Check the voltage of all phases (2-phase running). |
| | | Check the cable connections. |
| | | Check the fuses. |
| | The sealing is insufficient. | Tighten the screws. |
| | | Replace the mechanical seal. |
| | There is not enough hydraulic thrust balance. | Clean the relief holes in the impeller. |
| | | Replace the worn impeller and wear rings. |
| | There is system-related vibration (resonance). | Seek assistance. |
| The pump casing becomes warm during operation. | The pump or suction/intake pipe is blocked | Clean the pump and pipes. |
| | The NPSH is too low. | Increase the liquid level. |
| | | Increase the suction pressure. |
| | | Reduce the resistance in the intake/suction pipe. Change the path and pipe size, open the shutoff valves, and clean the filters. |
| | The inner components are suffering from wear. | Replace the worn parts. |
| | There is system-related vibration (resonance). | Seek assistance. |

| Symptom | Cause | Remedy |
|---|---|---|
| The temperature in the shaft sealing area is too high. | The shaft seal is worn. | Replace the mechanical seal. |
| | | Check the sealing, flushing, and cooling pipe (pressure). |
| | | Do not run the pump dry. |
| | There are lines and rough spots on the shaft or shaft sleeve. | Replace the worn parts. |
| | There are deposits on the mechanical seal. | Clean the mechanical seal. |
| | | Replace the mechanical seal if necessary. |
| | | Provide additional rinsing or quench. |
| | The coupling is not aligned. | Align the pump. |
| The temperature at the bearing is too high. | The back pressure is too high. | Open the discharge valve more. |
| | | Reduce resistance in the discharge pipe. Clean the filter if necessary. |
| | | Use a larger impeller. Make sure to note the available motor power. |
| | The back pressure and the discharge pressure are too low. | Throttle the discharge valve. |
| | The speed is too high. | Reduce the speed. |
| | | Compare the speed of the motor with the specified pump speed. See the rating plate. |
| | | When you adjust the speed (frequency transformer), check the reference value setting. |
| | The inner components are suffering from wear. | Replace the worn parts. |
| | The forces in the pipeline are too high and the pump is under strain. | Change the position of the support pipes and use compensators. |
| | | Check that the foundation plate and frame are properly cast and in place. |
| | There is either too much, too little, or the wrong type of lubricant. | Change the lubricant. |
| | The electrical supply is not correct. | Check the voltage of all phases (2-phase running). |
| | | Check the cable connections. |
| | | Check the fuses. |
| | There is not enough sealing. | Tighten the screws. |
| | | Replace the mechanical seal. |
| | The bearing is damaged. | Replace the bearing. |
| | | Check the lubricant and bearing space for pollutants. Rinse the oil area. |
| | There is not enough hydraulic thrust balance. | Clean the relief holes in the impeller. |
| | | Replace the worn impeller and wear rings. |
| | There is system-related vibration (resonance). | Seek assistance. |
| The pump is leaking. | There is not enough sealing. | Tighten the screws. |
| | | Replace the mechanical seal. |
| | The discharge pressure is too high. | Reduce the amount of pressure that is carried. Throttle the control valve. |

| Symptom | Cause | Remedy |
|---|---|---|
| There are leaks at the shaft seal. | The shaft seal is worn. | Replace the mechanical seal. |
| | | Check the sealing, flushing, and cooling pipes (pressure). |
| | | Do not run the pump dry. |
| | There are deposits on the mechanical seal. | Clean the mechanical seal. |
| | | Replace the mechanical seal if neces-sary. |
| | | Provide additional rinsing or quench if necessary. |
| | The impeller is out of balance. | Remove any blocks or deposits. |
| | | Replace the impeller is it is broken or unevenly worn. |
| | | Check the shafts to make sure that they are running true. |
| | The coupling is not aligned. | Align the pump. |
| | The coupling distance is too small. | Correct this. |
| | Forces in the pipeline are too high and the pump unit is under strain. | Change the position of the support pipes and use compensators. |
| | | Check that the foundation plate and frame are properly cast and in place. |
| | There is not enough sealing. | Tighten the screws. |
| | | Replace the mechanical seal. |

## TOPIC 4: Fixing/adjusting/replacing the faulty device

Good maintenance and repair procedures contribute significantly to the safety of the maintenance crew as well as that of machine operators. The variety and complexity of machines to be serviced, the hazards associated with their power sources, the special dangers that may be present during machine breakdown, and the severe time constraints often placed on maintenance personnel all make safe maintenance and repair work difficult.

Training and aptitude of people assigned to these jobs should make them alert for the intermittent electrical failure, the worn part, the inappropriate noise, the cracks or other signs that warn of impending breakage or that a safeguard has been damaged, altered, or removed. By observing machine operators at their tasks and listening to their comments, maintenance personnel may learn where potential trouble spots are and give them early attention before they develop into sources of accidents and injury.

Sometimes all that is needed to keep things running smoothly and safely is machine lubrication or adjustment. Any damage observed or suspected should be reported to the supervisor; if the condition impairs safe operation, the machine should be out of service for repair.

Safeguards that are missing, altered, or damaged also should be reported so appropriate action can be taken to insure against worker injury. If possible, machine design should permit routine lubrication and adjustment without removal of safeguards. But when safeguards must be removed, and the machine serviced, the lockout procedure of 29 CFR 1910.147 must be adhered to. The maintenance and repair crew must never fail to replace the guards before the job is considered finished and the machine released from lockout..

Is it necessary to oil machine parts while a machine is running? If so, special safeguarding equipment may be needed solely to protect the oiler from exposure to hazardous moving parts. Maintenance personnel must know which machines can be serviced while running and which cannot. "If in doubt, lock it out." Obviously, the danger of accident or injury is reduced by shutting off and locking out all sources of energy.

In situations where the maintenance or repair worker would necessarily be exposed to electrical elements or hazardous moving machine parts in the performance of the job, there is no question that all power sources must be shut off and locked out before work begins. Warning signs or tags are inadequate insurance against the untimely energizing of mechanical equipment. Thus, one of the first procedures for the maintenance person is to disconnect and lock out the machine from all of its power sources, whether the source is electrical, mechanical, pneumatic, hydraulic, or a combination of these.

Energy accumulation devices must be "bled down."

**Electrical:** Unexpected energizing of any electrical equipment that can be started by automatic or manual remote control may cause electric shock or other serious injuries to the machine operator, the maintenance worker, or others operating adjacent machines controlled by the same circuit. For this reason, when maintenance personnel must repair electrically powered equipment, they should open the circuit at the switch box and padlock the switch (lock it out) in the "off" position.

## TOPIC 5: After repair testing

### System testing methods

#### Tee testing

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

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

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

**Pump test**

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

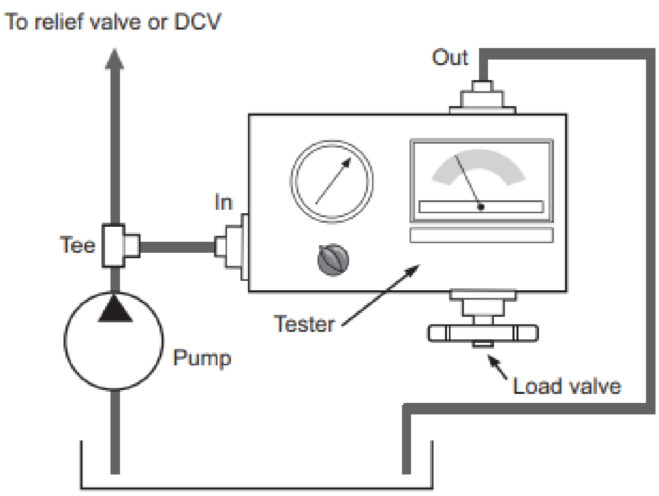



Figure1: Pump test

The manufacturer's specifications or pump-commissioning data provide a reference against which any future flow readings are compared. This comparison enables a pump's efficiency to be determined.

To evaluate a pump's output, the tester is installed in the circuit between the pump outlet and the inlet to the directional control valve or before the relief valve, as illustrated in Figure 1.
The system is run until normal operating temperature is reached.

The tester's loading valve is fully opened to allow full flow at zero pressure. The valve is then progressively closed through a series of predetermined pressure 'steps' and the flow and pressure readings are recorded. The level of decrease in flow between the minimum and maximum pressure settings will indicate the pump's condition.

A typically worn or damaged pump will lose 20–30 per cent flow capability. Low flow at both minimum and maximum pressure indicates inlet problems.

**Relief valve test**

To test a relief valve, the tester is installed in the circuit after the relief valve, with the outlet of the tester connected to the reservoir. When the loading valve on the tester is fully opened, the pump's flow passes through the tester and back to the reservoir, bypassing the control circuit. The loading valve is then slowly closed while pressure and flow readings are observed.

The pressure will increase until the relief valve opens and diverts the flow back to the reservoir via the relief valve. When the relief valve's operating pressure setting is reached, there should be a zero reading on the tester's flow meter.

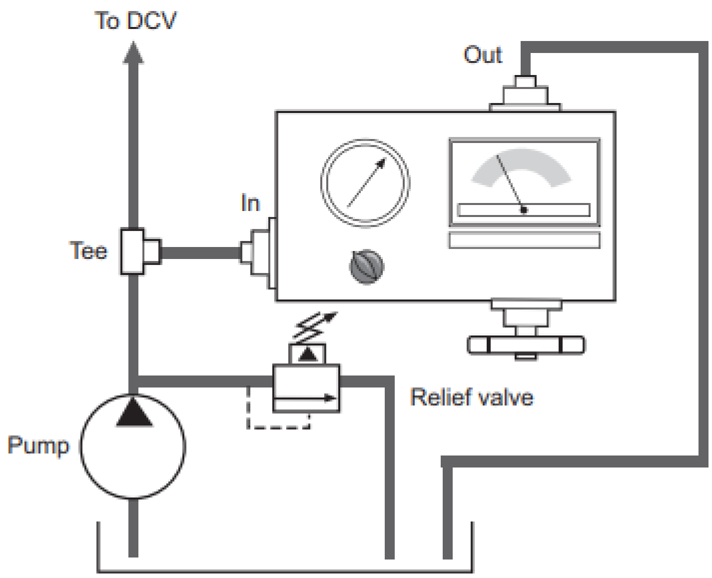



Figure2: Relief valve test

The pressure setting should be recorded and adjusted if it is incorrect. It is not unusual for a relief valve to start opening below the maximum pressure setting, causing considerable leakage and loss of machine performance.

Direct-acting relief valves are prone to this problem; pilot-operated relief valves are not – and are preferred. The cracking pressure can be checked by slowly increasing the pressure until the flow through the tester starts to fall away.

## Tee testing for leakage in control valves and cylinders

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

The leakage test for a directional control valve (DCV) is conducted by closing the tester's loading valve and monitoring the flow and pressure readings. Leakage is determined by subtracting flow readings on the tester from the system flow readings determined during the pump test.

If the flow readings of the valve equal the pump test flow readings, the valve is in good condition. If all valve leakage readings are similar, the tests indicate the component is functioning correctly even if test readings are somewhat below the flow readings of the pump test. The manufacturer's recommendations and the application will determine whether any leakage can be tolerated.

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

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

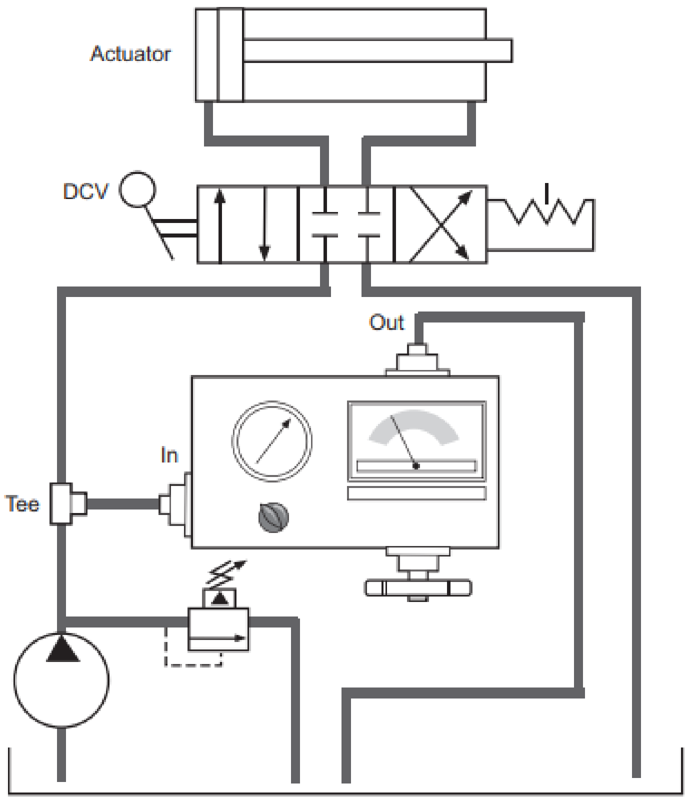



Figure: Tee testing control valves and cylinders

### Motor in-line testing

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

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

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

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

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

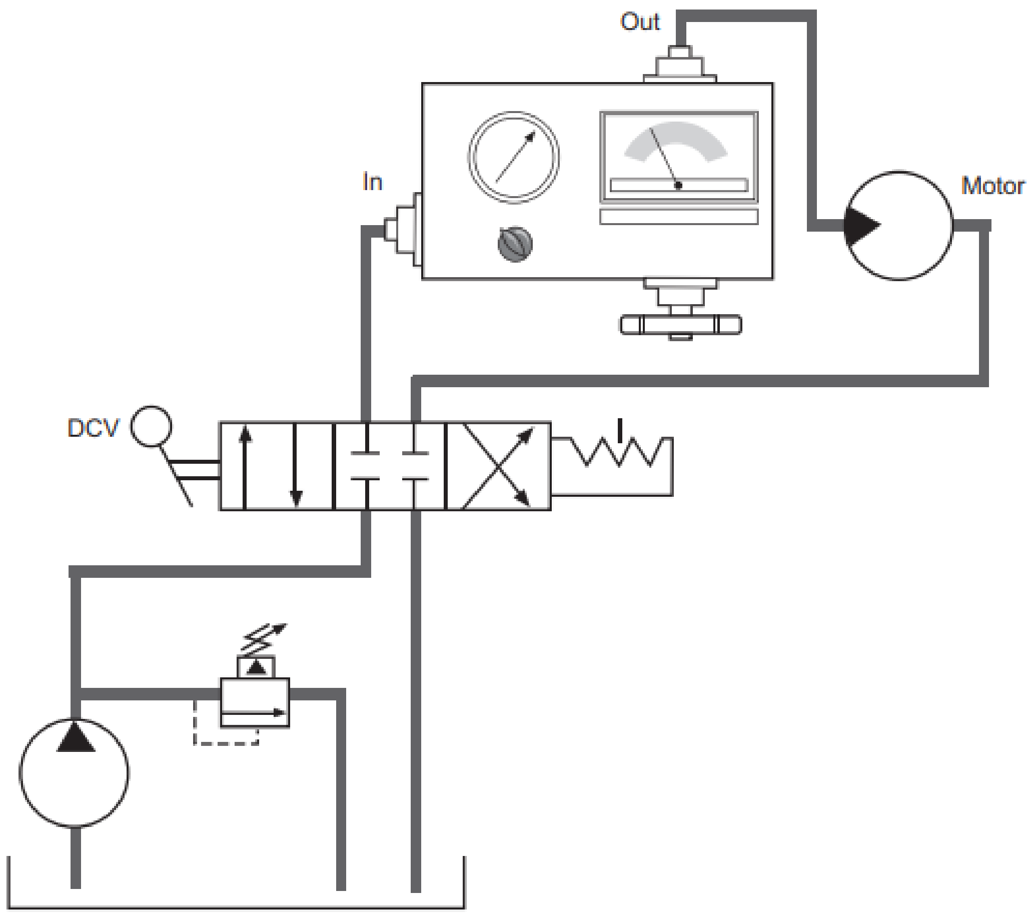



Figure 4: Motor test

**LEARNING OUTCOME 4.4: Clean the workplace**

- **Topic 1: Collection of measurement and fault detectors instruments and tools**

During collection of instruments and tools trainer must arrange them according to their types, reused and waste as example:

| Measuring Instruments To be Reused | Tools To be Reused | Faults tools | Faults measuring instruments |
|---|---|---|---|

- **Topic 2: Arrangement of non- used materials**

When arranging materials, the stored materials must not create a hazard for employees. Employers should make workers aware of such factors as the materials' height and weight, how accessible the stored materials are to the user, and the condition of the containers where the materials are being stored when stacking and piling materials. To prevent creating hazards when storing materials, employers must do the following:

- ✓ Keep storage areas free from accumulated materials that cause tripping, fires, or explosions, or that may contribute to the harboring of rats and other pests;
- ✓ Place stored materials inside buildings that are under construction and at least 6 feet from hoist ways, or inside floor openings and at least 10 feet away from exterior walls;
- ✓ Separate non-compatible material; and
- ✓ Equip employees who work on stored grain in silos, hoppers, or tanks, with lifelines and safety belts.
- ✓ In addition, workers should consider placing bound material on racks, and secure it by stacking, blocking, or interlocking to prevent it from sliding, falling, or collapsing.

What safeguards must workers follow when stacking materials?

- Stacking materials can be dangerous if workers do not follow safety guidelines. Falling materials and collapsing loads can crush or pin workers, causing injuries or death. To help prevent injuries when stacking materials, workers must do the following:
- Stack lumber no more than 16 feet high if it is handled manually, and no more than 20 feet if using a forklift;
- Remove all nails from used lumber before stacking;
- Stack and level lumber on solidly supported bracing;
- Ensure that stacks are stable and self-supporting;
- Do not store pipes and bars in racks that face main aisles to avoid creating a hazard to passersby when removing supplies;
- Stack bags and bundles in interlocking rows to keep them secure; and
- Stack bagged material by stepping back the layers and cross-keying the bags at least every ten layers (to remove bags from the stack, start from the top row first).

- **<u>Topic 3: Cleaning of tools and working area</u>**

- Before starting cleaning the workplace, Trainer must instruct his/her trainees how to perform the activity as shown in example

  - How to use cleaning equipment
  - How to use the cleaning chemicals
  - How to report faults in machinery
  - How to report general maintenance issues

- Trainer explain the types of soil for the purpose of general cleaning

## Types of soil

For the purpose of general cleaning, this is how soil is categorised:

- Litter
- Dust
- Dirt
- Staining
- Tarnishing

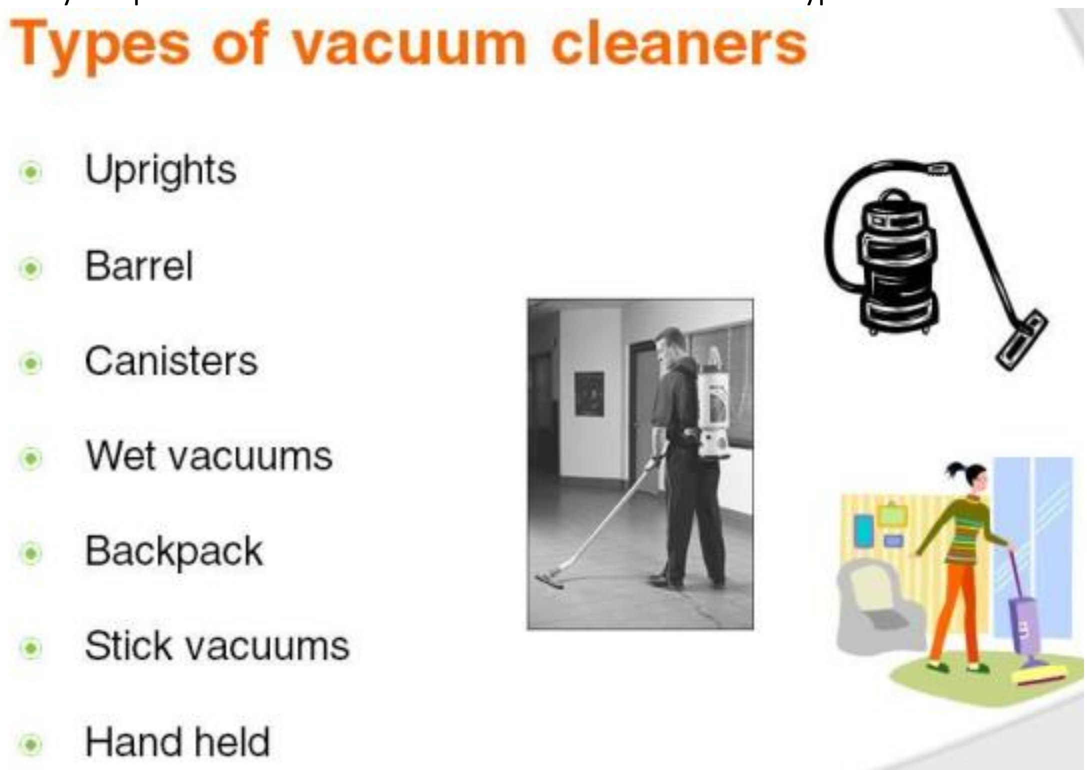
- Trainer to explain that cleaning is a science which is constantly evolving. A good knowledge of machinery, chemicals and cleaning techniques is vital Most cleaning methods involve a combination of mechanical action either human or machine and chemicals Heat is used for sterilization.

## How Do We Clean ?

- Mechanical
- Chemical
- Combination of Both
- Heat

- Trainer should discuss in detail the operation of each machine. The use of these includes mechanical action. If possible demonstrate one of each machine to students.


- Trainer to discuss that the vacuum cleaner is the most important piece of electrical equipment used by the professional cleaner and should be well cared for. Types of vacuum cleaners




- Trainer to explain that scrubbers are usually classified as slow rotation machines (approximately 150 rpm-300 rpm).
- Polishers can vary from 150 rpm to 2500 rpm
- The latter (2500 rpm) are classified as burnishers which are **only used** to polish floors
- The slower rotating machines can be used to scrub, strip floors (remove polish), polish and buff floors (Buffing is a maintenance method of cleaning the floors between strip and polish procedures)
- Buffing may be done daily or weekly where strip and polish is done as needed, depending on the amount of foot traffic. Maybe every 3 or 6 months.

## Types of other electrical cleaning equipment

- Scrubbers
- Polishers
- Carpet cleaning machines
- Upholstery cleaning machines
- High pressure washers
- Steam cleaners
- Portable dryers
- Blowers

- Trainer to discuss the different types of sweepers (manual, battery driven and ride on).
- Trainer should get brochure samples or pictures of different styles of cleaners trolleys and discuss what items should be placed on them and how they should be stacked neatly and in clean condition.

## Non-electrical heavy equipment

- Sweepers
- Carpet sweepers
- Trolleys

- Dustpans may also include lobby pans which are the long handled style. These are for cleaning areas where there is always litter particles .It prevents the cleaner from having to bend all the time.

## Other cleaning equipment (1)

- Mops and Buckets
- Brooms and brushes
- Dustpans
- Feather Dusters
- Wet floor signs

- Types of cleaning chemicals

- Acids
- Alkalis
- Abrasives
- Detergents
- Bleaches
- Disinfectants and Sanitisers
- Polishes
- Solvents

- Trainer reminds the students that chemicals should NEVER be mixed.
  i. One may render the other inactive but also can cause a chemical reaction which can give off fatal gases
  ii. Always follow the instructions for use and know the purpose of each one
  iii. Refer to the general precautions in the Trainee Manual.

## Safe Handling of Chemicals

- NEVER mix any chemicals
- Follow manufacturer's instructions re dilution rates/uses
- Wear protective clothing
- Correct labeling
- Clean up spillages promptly

- Trainer to hold a general discussion on what to wear and when.
  If possible have some examples to show the students.

## Protective Clothing and Equipment

Always wear and use the correct protective clothing and equipment for the task you are performing.

- Decanting chemicals
- Cleaning bathrooms
- High pressure washing
- Carpet cleaning
- Using noisy equipment (blowers)

- Trainer to explain that disposal of waste is a very important task. Explain that if waste is not disposed of correctly; it may attract vermin and pests and generate bad odors.


- Trainer to discuss these issues explaining that good teamwork between cleaners will make their tasks easier for the next day as the cleaners store will be neat and tidy, all equipment in working order and everything in its place will save time and effort.


After cleaning, use an all-purpose oil, such as WD-40® to lubricate tools with adjustable parts. Lightly spray other metal tool parts as well (avoid getting oil on handles), such as screwdrivers and bladed lawn and garden tools. Wipe away any excess with a rag before storing. This will help fight corrosion and rust.

If your tools already show signs of rust, there are a number of rust removers available at True Value, such as Evapo-Rust Rust Remover. You can also try spraying tools with WD-40® and then scrubbing them with steel wool or a stiff wire brush.

Afterwards, wash them with warm, soapy water and scrub them again with a cloth or rag until all signs of rust are gone. Then dry them thoroughly with a clean, dry rag. Apply a light coat of WD-40® and wipe away excess oil before storing.

**Safety Alert**

You should wear heavy gloves when cleaning or removing rust from tools that can cut. Wear safety goggles when using a wire brush to remove rust.

Smooth weathered, rough wooden handles with a medium-grit emery cloth. Handles should be smooth enough to slide your hand along. If the wood is very rough, first sand across the grain in a shoe-shine fashion. Finish by sanding with the grain. Wipe a dry handle down with a heavy coat of linseed oil to rejuvenate and protect the wood.

Use files to sharpen digging tools and to sharpen nicked or dull cutting tools. For digging tools, file the working edge to a 45-degree bevel with a coarse file. Hone and maintain the sharp edge of all cutting tools with a medium-grit sharpening stone. For faster cutting, wet the stone with water or lubricate it with honing oil depending on the type of stone you have.

A proper storage system is a must for hand tools. A toolbox, storage container, shelving unit, or a combination of all of these can be used to keep your tools protected and in peak condition. Ideally, your storage units should be kept somewhere with minimal exposure to moisture and temperature changes. Remember to keep tools in their respective places or hung on designated hangers when a job has been completed.

**Helpful Tips**

Use a small tool bag for the tools you often used in workplace. The rest of your tool arsenal can remain in your main toolbox.

You should have a space where you can inspect your tools and perform necessary maintenance tasks, such as a worktable. Cover it with newspaper or plastic sheeting to protect the table and make it easier to clean up after you're done with the job.

**POWER TOOLS**

Power tools such as electric drills, saws, sanders and nailers need routine maintenance just like your hand tools. Because of their mechanical and electrical parts, power tools are more susceptible to problems caused by poor maintenance, dust and debris accumulation and general malfunction. The following are some helpful tips on how to clean and properly store your tools.

- **Topic 4: Management of waste materials**

What is waste?

Waste is any scrap materials, effluent or unwanted surplus substance and any substance which require to be disposed of as being broken, worn out, contaminated or otherwise spoiled.

There are four categories of potential waste.

- Worn but functioning
- Useable otherwise than by means of specialised waste recovery
- Useable only by specialised waste recovery establishments
- Unwanted , and which requires collection

Waste management or waste disposal is all the activities and actions required to manage waste from its inception to its final disposal. This includes amongst other things, Collection, transport, treatment and disposal of waste together with monitoring and regulations.


- **Waste Hierarchy**

The Waste Hierarchy must be considered when deciding what the best option is to manage a waste stream. This is a mandatory requirement of the Waste (England & Wales) Regulations 2011. It places more emphasis on waste prevention, and requires organisations to consider preparing waste for reuse, then opportunities for recycling, before options such as energy recovery. By law, we need to apply the Waste Hierarchy to ensure we minimise the impacts of our waste activities.


Figure: Waste Hierarchy Triangle

The Regulations stipulate that materials such as paper, metal, plastic and glass must be collected separately if it is necessary to encourage high quality of the recycling of the material.

**Waste Segregation and Disposal**

All waste prior to reuse, recycling or disposal should be held in secure, designated areas. All waste must be pre-treated (where required), segregated, clearly labelled and held in areas to prevent escape. Storage facilities for waste must be:

- ✓ Safe and secure from unauthorised entry
- ✓ Robust
- ✓ Covered and locked


Figure: Waste management

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