MODULE 4: PNEUMATIC POWER SYSTEMS

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

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

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

INTRODUCTION

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

CHOICE OF WORKING MEDIUM:

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

i) When a system needs high speed, medium pressure and less accuracy a pneumatic system is good. If the system requires high pressure and high accuracy, a fluid system with oil is good.

ii) When the power requirements are very high, like in a power press, oil hydraulics is the option.

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

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

CHARACTERISTICS/ADVANTAGES OF COMPRESSED AIR (PNEUMATIC SYSTEMS):

i) Air is available in abundance at all locations.

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

iii) Compressed air can be stored conveniently in a reservoir and used whenever required.

iv) Compressed air is free from explosion and electrical hazard problems.

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

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

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

DISADVANTAGES OF COMPRESSED AIR (PNEUMATIC SYSTEMS):

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

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

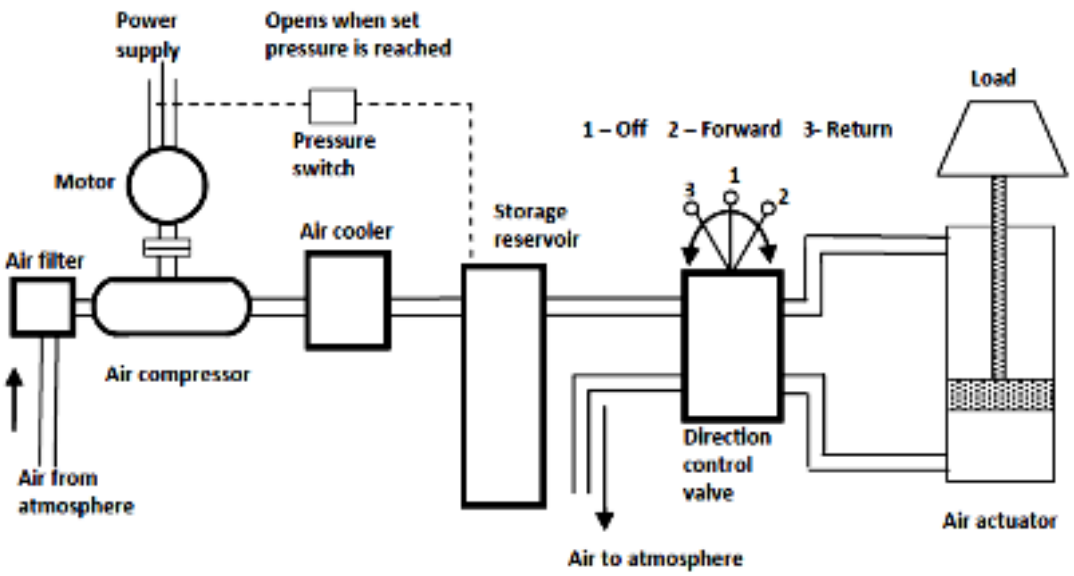
iii) **Heat Dissipation:** Air due to its low conductivity, cannot dissipate heat as much as a hydraulic fluid.

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

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

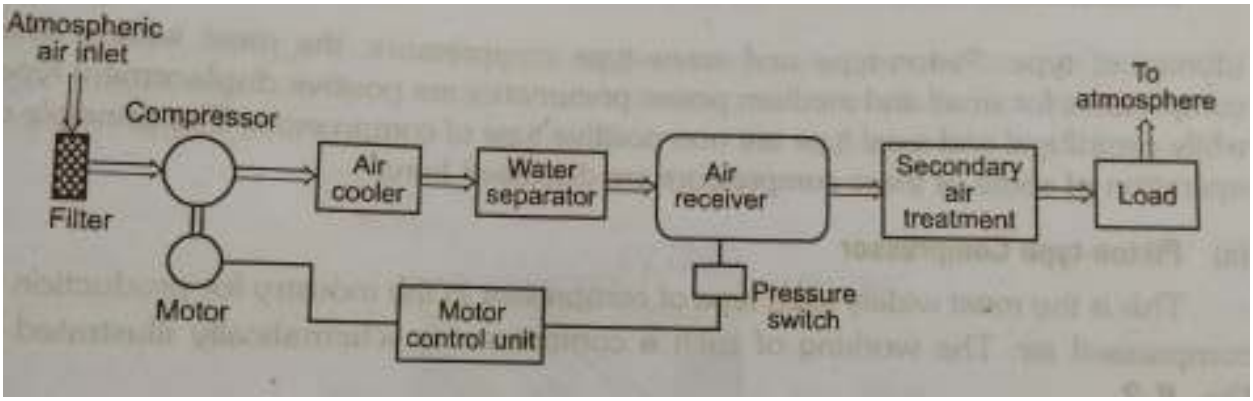
STRUCTURE OF A PNEUMATIC SYSTEM:

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



PRODUCTION OF COMPRESSED AIR:

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



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

switches the compressor-motor off. With usage the pressure drops down, which is again sensed by the pressure switch, and in turn switches the motor on.

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

PERFECT GAS LAWS:

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

Boyle's Law:

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

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

Charles' Law:

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

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

Gay-Lussac's Law:

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

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

General Gas Law:

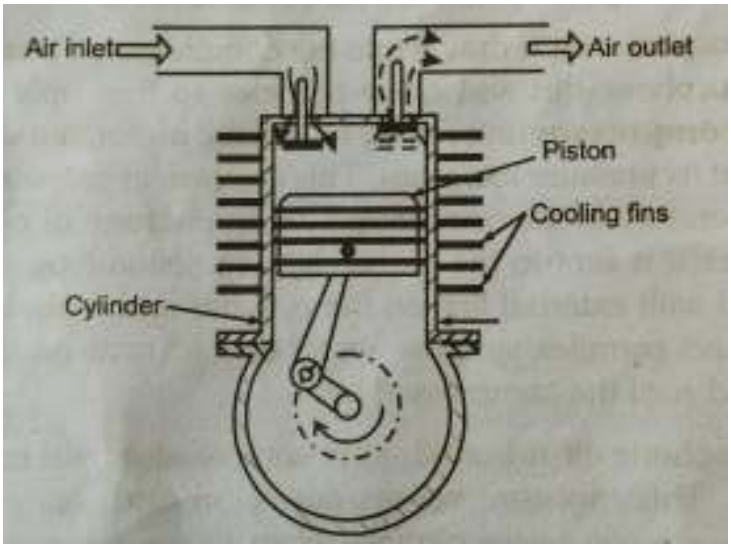
It contains all three gas parameters (pressure, temperature and volume), since none are held constant during a process from state 1 to state 2. It is defined as

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

COMPRESSORS:

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

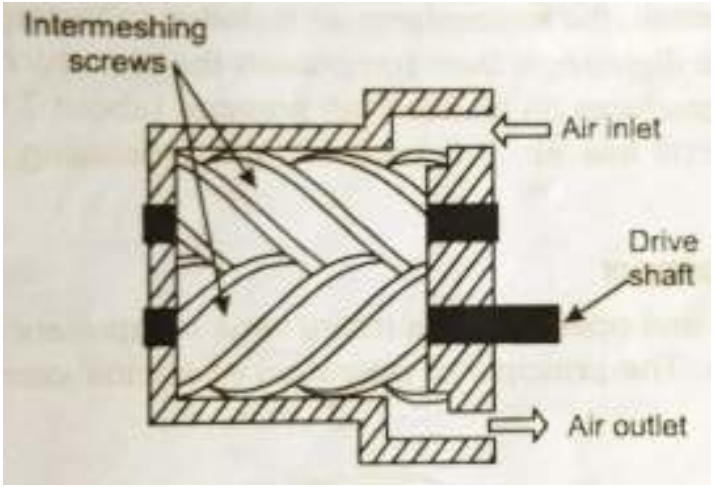
Piston-type Compressor:



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

(the second half revolution of the crank shaft), the inlet valve gets closed, the outlet valve opens and the air is compressed as the piston moves up in the cylinder. The air compression process is accompanied with an increase in temperature. The air is cooled by providing fins around the cylinder.

Screw-type Compressor:



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

FLUID CONDITIONERS:

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

Air Filters:

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

Air Dryer:

The air filter can only remove condensed water particles from air. The vapour passes through the air-filter and causes problems as it condenses at other components. In a compressed air, the relative humidity (RH) and dew point are higher. Both the RH and the dew point are dependent on the temperature and pressure. Whenever the temperature drops and/or the pressure increases the water condenses. This problem can be reduced by keeping the humidity of air below 100%, for which air-dryers are used.

Lubricators:

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

Air Pressure Regulator:

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

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

the required level to maintain the pressure. Similarly, if the supply pressure drops, the regulator increases the flow rate so as to increase the pressure to the required level.

PNEUMATIC ACTUATORS

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

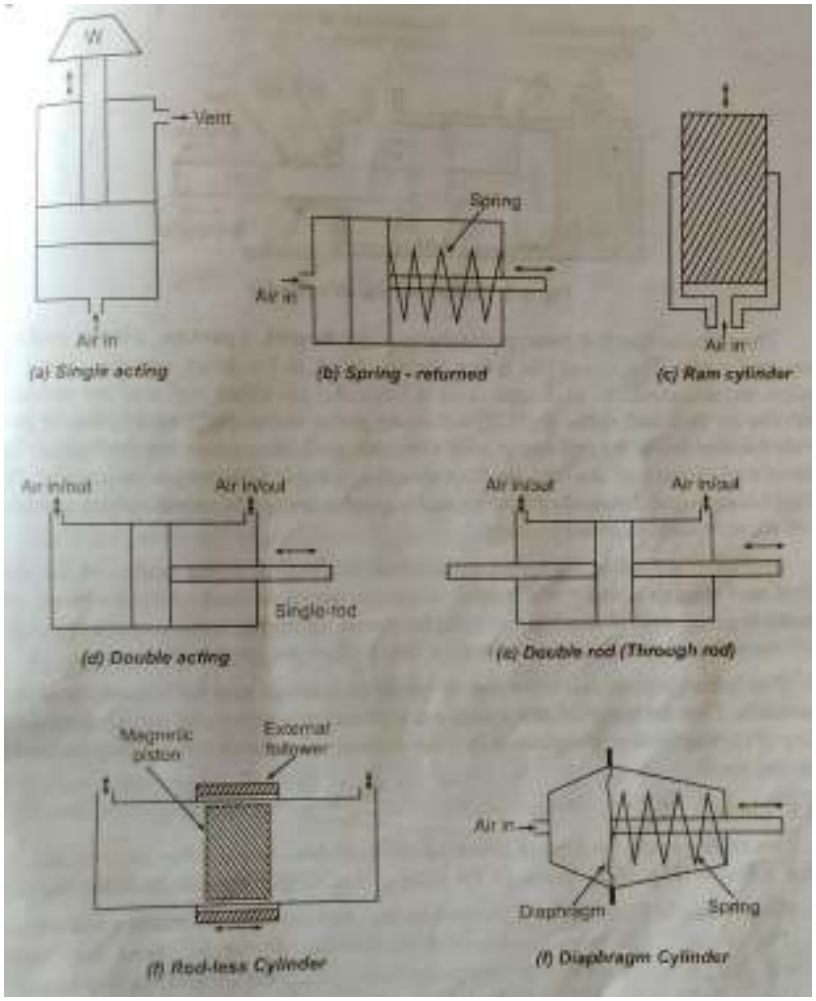
Linear Cylinders:

Classification of Air Cylinders:

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

Pneumatic cylinders are briefly classified as follows:

1) **Single acting cylinder:** It is a cylinder in which air pressure is applied on to the piston side only and extension takes place by the air pressure in one direction. The return stroke is mostly by gravity.
2) **Spring Return Cylinder**: It is a single acting cylinder in which movement in one direction is under air pressure, while the return stroke is accomplished by a spring.
3) **Ram Cylinder:** in this the cylinder rod itself forms the movable element termed as ram. It is usually single acting and return stroke is either under gravity or assisted by return cylinders.



4) **Double acting cylinder:** it is a cylinder in which the ait pressure is applied alternately on either side, so that
5) **Double rod or through-rod cylinder:** In a double-rod or through-rod cylinder, the piston-rod extends/retracts on either end of the cylinder.
6) **Rod-less cylinder:** In this, there is no rod connected to the piston. Usually, the piston is a magnetic type, while an external follower (magnetic) follows the piston due to magnetic coupling.
7) **Diaphragm Cylinder:** For short stroke lengths, small cylinders with a rubber or metal diaphragm is used instead of a piston. The main advantage of such cylinders is that there is no leakage between the inlet and outlet chambers; and there is no frictional loss.

SEALS:

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

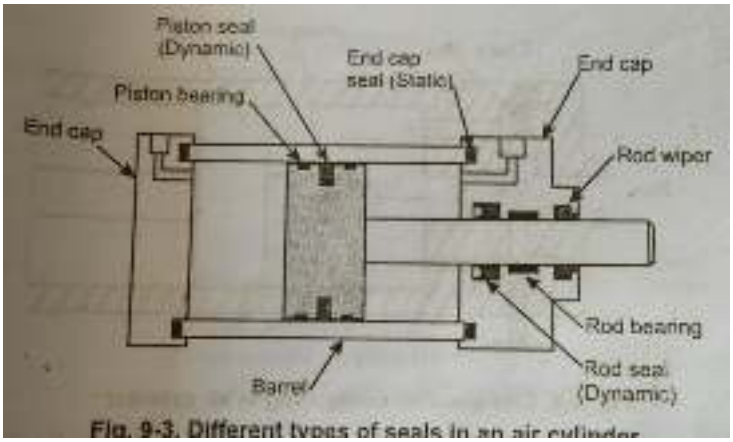


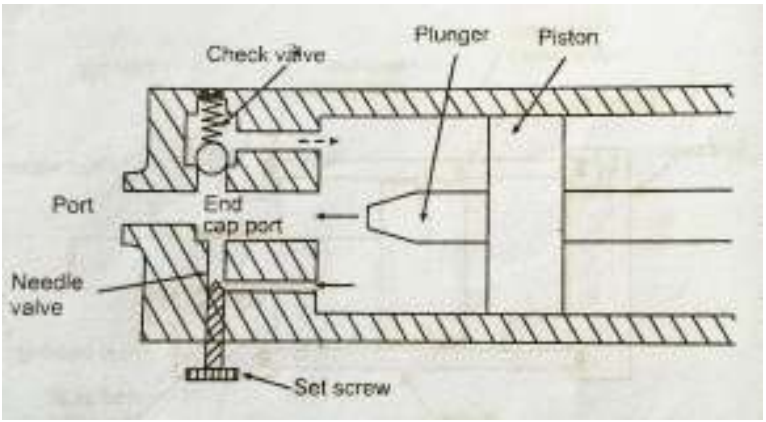
Fig. 9-3. Different types of seals in an air cylinder

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

END POSITION CUSHIONING:

Normal single-acting and double-acting cylinders, while moving heavy loads, may undergo sudden impacts at the end of strokes. This sudden deceleration may cause damage to the load,

or cylinder or to the pneumatic system itself. To avoid this problem, end-position cushioning is provided in cylinders.



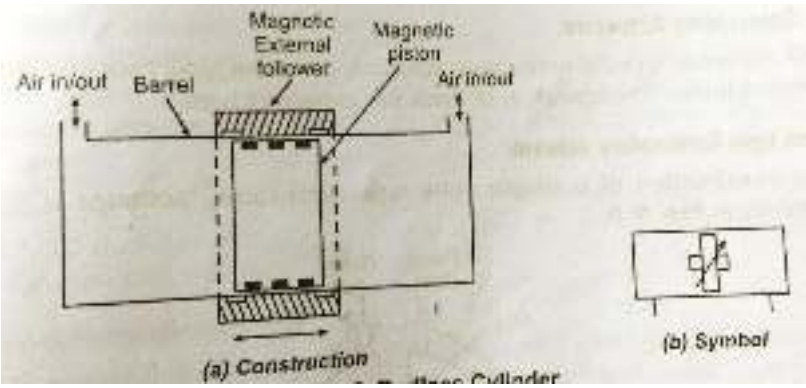
In this, the piston end is provided with a plunger (or a cushioning piston), the air inlet port is such that it matches with the cushioning plunger size. At the end of stroke, the cushioning piston mates with the inlet port and blocks the direct flow path for the air.

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

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

RODLESS CYLIDERS:

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



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

Advantages:

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

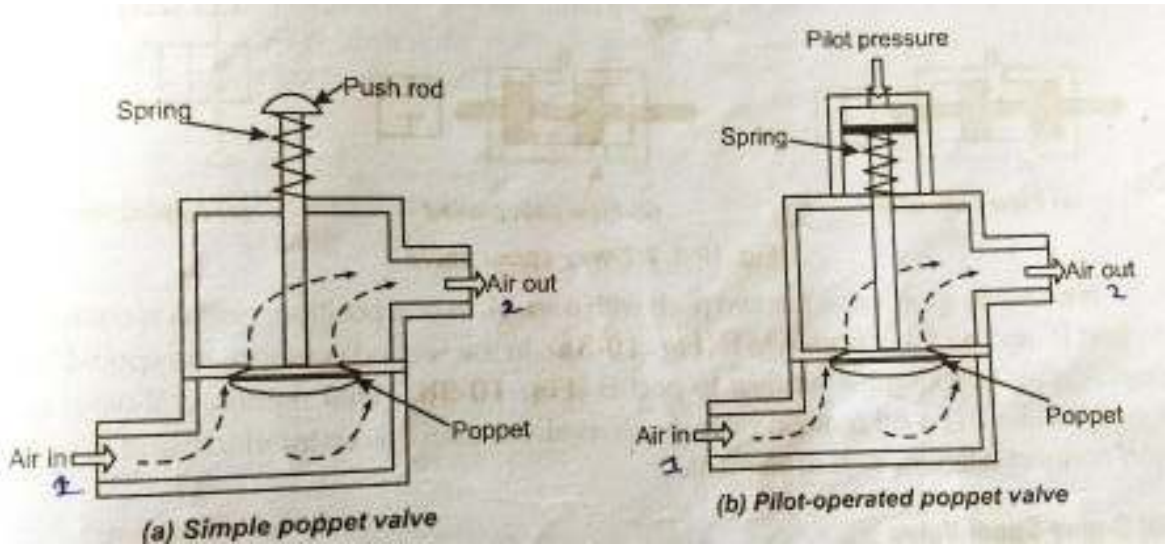
PNEUMATIC CONTROL VALVES

Classification of Pneumatic valves:

1) Direction Control Valves
   a) Poppet Valves
   b) Spool (slide) Valves
2) Flow control Valves
3) Pressure control Valves

4) Non-return Valves
   a) Check Valve
   b) Shuttle Valve
   c) Quick Exhaust Valve

Poppet Valves:

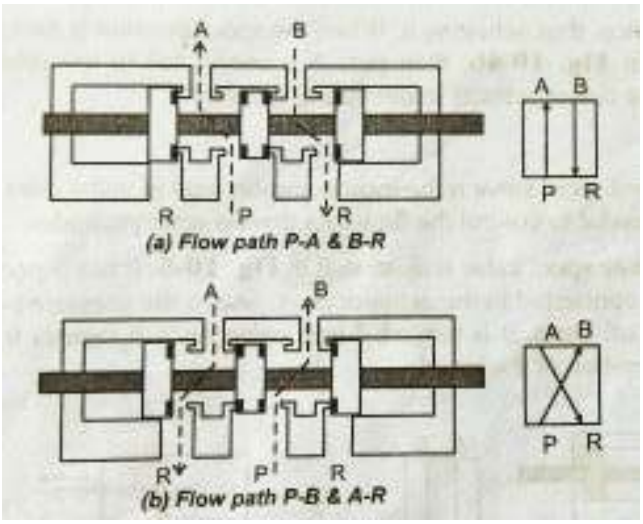


In poppet valves (also termed seat valves) are used to control the air flow. In a simple poppet valve, the poppet is operated manually. It has a cylindrical arrangement with two ports (1 and 2). The ports are separated by a poppet, seated on a valve seat. The poppet is held in a closed position (in the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

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

Suspended Seat type valve:

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

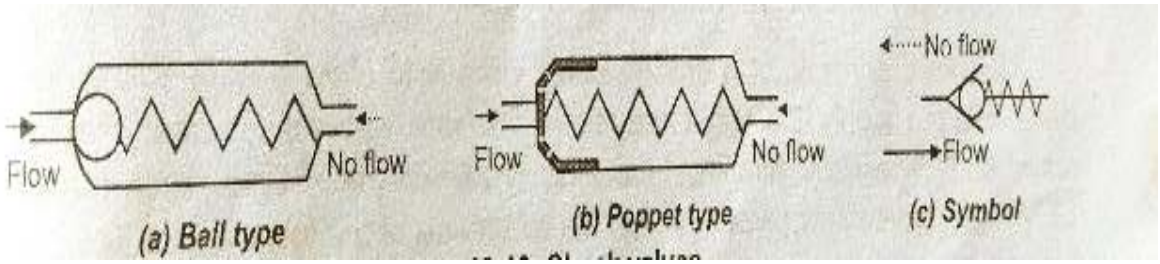


In this the main disc seat seal connects port P to either to port A or port B. The secondary seat discs seal the exhaust port B whichever is not functional. Such valves are generally provided with manual override buttons at each end of the spool to manually move the spool.

NON-RETURN VALVES:

Check valve:

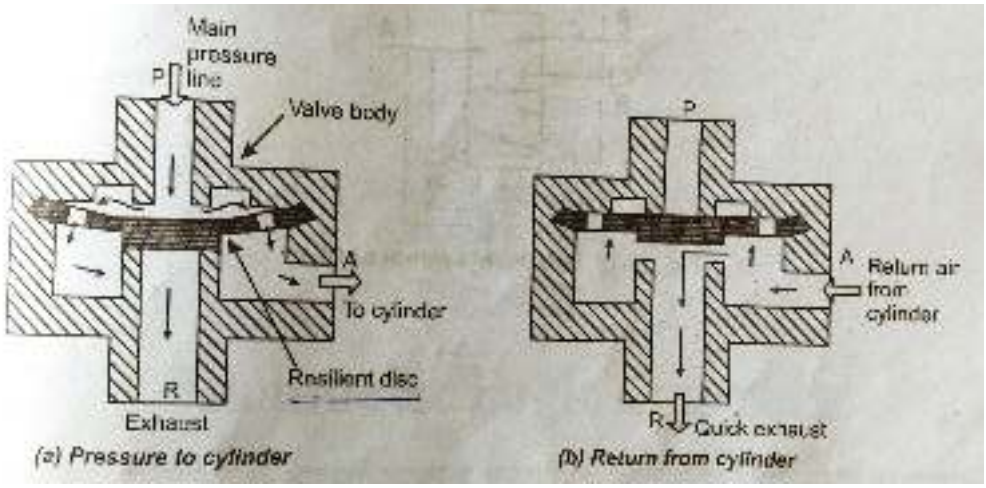
Check valves allow free flow of air in one direction and block any flow in the reverse direction.



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

Quick Exhaust Valve (QEV):

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

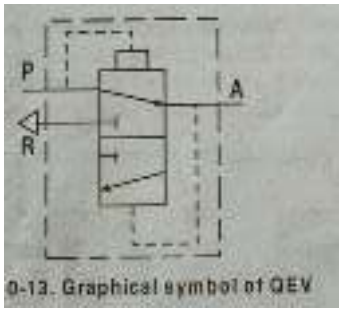


The basic principle of a quick exhaust valve is to allow a normal flow to the cylinder in the supply line, while increase the flowrate (above the normal rate) in the return line. It basically eliminates the entry of return/exhaust air through the usual DCV route, where flow passes through the constraints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

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

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

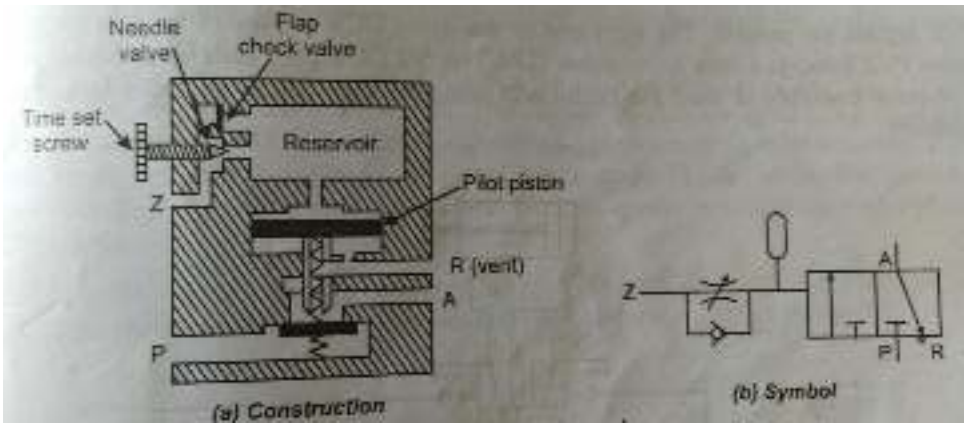
exhausted freely through the valve. Due to this unrestricted excess flow rate the cylinder retracts at a higher speed than the normal design speed.



0-13. Graphical symbol of QEV

Time Delay Valve:

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



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

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

QUESTIONS FROM PREVIOUS YEAR QUESTION PAPERS:

DEC 2015/JAN 2016

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

JUNE/JULY 2016

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

DEC 2016/JAN 2017

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

JUNE/JULY 2017

1) What are the types of pneumatic actuators? With sketch explain the construction and working principle of single acting cylinder.
2) Differentiate hydraulic and pneumatic system.
3) What is cushioning? Sketch and explain the cushioning of cylinder.

4) With a neat sketch and symbol explain 3/2 direction control poppet valve.
5) Explain quick exhaust valve with circuit diagram.
6) Explain the three stages of preparation of compressed air.

DEC 2017/JAN 2018

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

JUNE/JULY 2018

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

CRASH COURSE – MAY 2017

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

ONE TIME EXIT SCHEME – APRIL 2018

1) With a neat sketch explain the structure of pneumatic system.
2) Write a neat sketch explain FRL unit.
3) With a neat sketch explain rod-less cylinder.
4) Explain with a neat sketch:
   i) Time delay valve
   ii) Shuttle valve
   iii) Poppet valve
   iv) Solenoid valve

MODEL QUESTION PAPER – 1

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

MODEL QUESTION PAPER – 2

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