5

Pneumatic Cylinders, Motors and Valves

Contents

5.1 Introduction

Pneumatic actuators are devices used to convert the pressure energy of compressed air into 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. Pressurised air from the compressor is stored in the reservoir from where it is supplied to the pneumatic actuator to do work.

Their chief limitation is that the elastic nature of compressed air makes the actuators unsuitable for powering movement where a constant force or motion is required against a fluctuating load, or where extreme accuracy of the supply is vital. The air cylinder is also inherently limited in thrust output by the relatively low supply pressure, so high output forces can only be produced by large sized cylinders.

5.2 Types of Pneumatic Cylinders

- Pneumatic cylinders are devices that convert air pressure into linear mechanical force and motion. They are used for single purpose applications such as clamping, stamping, transferring, branching, allocating, ejecting, metering, tilting, bending, turning, etc.
- Pneumatic cylinders are classified according to the parameters shown below:

1. Cylinder application
    a) Light duty air cylinders
    b) Medium duty air cylinders
    c) Heavy duty air cylinders
2. Cylinder action
    a) Single acting cylinder
    b) Double acting cylinder
3. Cylinder movement
    a) Rotating air cylinder
    b) Non-rotating air cylinder
4. Cylinder design
    a) Telescopic cylinder
    b) Tandem cylinder
    c) Rod-less cylinder
    d) Impact cylinder
    e) Duplex cylinder
    f) Cylinder with sensors

5.2.1 Single Acting Cylinders

- A single acting cylinder has one working port. Forward motion of the piston is obtained by supplying compressed air to the working port. Return motion of the piston is obtained by the spring placed on the rod side of the cylinder. A schematic diagram of a single acting cylinder is shown in *Fig. 5.1*.
- Single acting cylinders are used in applications such as clamping, feeding, sorting, locking, ejecting, braking etc., where force is required to be exerted only in one direction.
- Single acting cylinders are usually available in short stroke lengths (maximum length up to SO mm) due to the natural length of the spring. They exert force only in one direction and require only about half the air volume consumed by a double acting cylinder for one operating cycle.

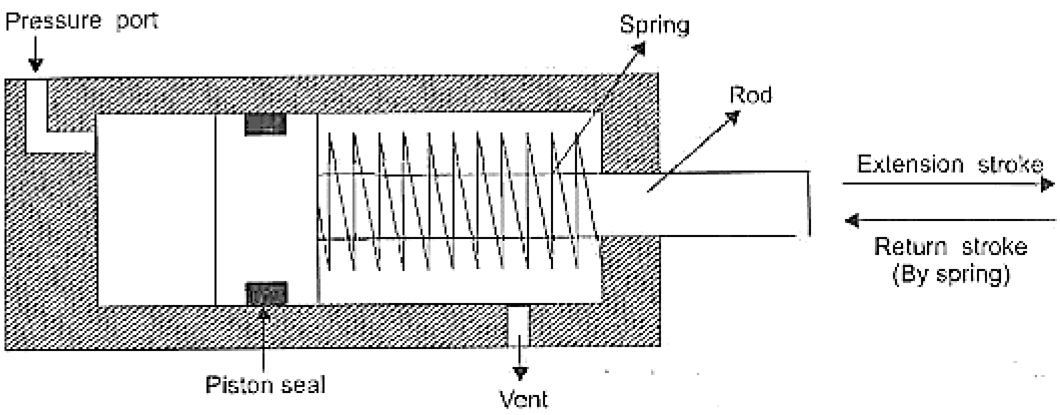

Fig. 5.1 Construction features of a single acting cylinder

- There are varying designs of single acting cylinders including
  a) Diaphragm cylinder
  b) Rolling diaphragm cylinder
  c) Gravity return single acting cylinder
  d) Spring return single acting cylinder

5.2.1.1 Diaphragm Cylinder

- This is the simplest form of a single acting cylinder where the piston is replaced by a diaphragm of hard rubber, plastic or metal clamped between the two halves of a metal casing expanded to form a wide, flat enclosure. A schematic diagram of a diaphragm cylinder is shown in *Fig.5.2*.

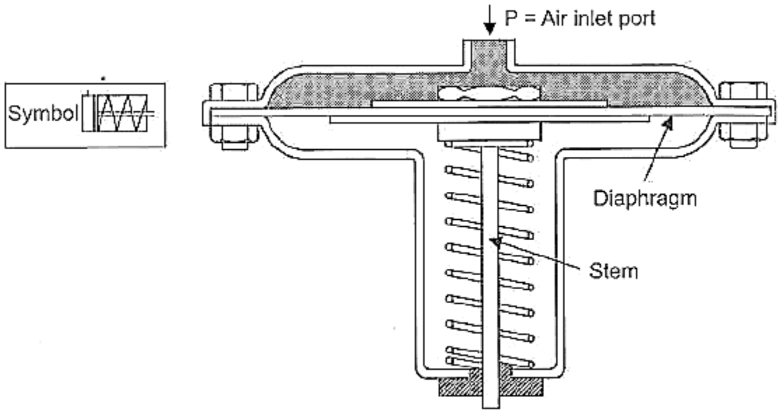

Fig.5.2 Construction features of diaphragm cylinder

- The operating stem which takes the place of the piston rod in a diaphragm cylinder can also be designed as a surface element that acts directly as a clamping surface. Only short operating strokes, up to a maximum of 50 mm, can be executed by a diaphragm cylinder.
- This makes the diaphragm type of the cylinder particularly adaptable to clamping operations. The return stroke is accomplished by a spring built into the assembly or by the tension of diaphragm itself in the case of a very short stroke. Diaphragm cylinders are used for short stroke applications like clamping, riveting, lifting, and embossing.

5.2.1.2 Rolling Diaphragm Cylinder

- These are similar to diaphragm cylinders. A schematic diagram of a rolling diaphragm cylinder is shown in Fig.5.3. It also contains a diaphragm instead of a piston, which in this instance rolls out along the inner walls of the cylinder when air pressure is applied to the device, thereby causing the operating stem to move outwards.

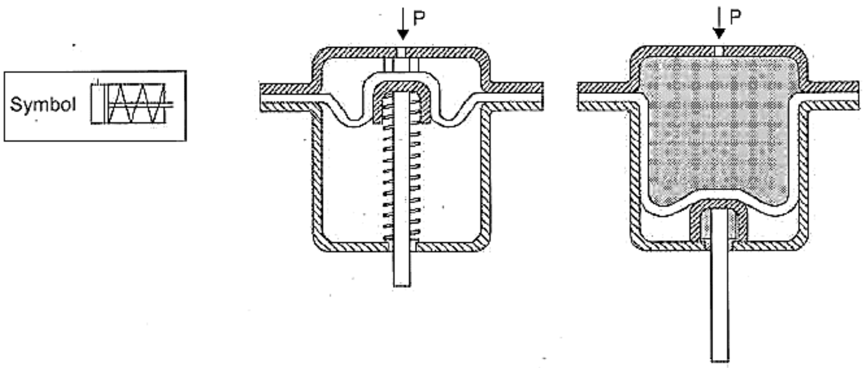

Fig.5.3 Construction features of rolling diaphragm cylinder

- Compared with the standard diaphragm type, a rolling diaphragm cylinder is capable of executing appreciably longer operating strokes (averaging from 50 mm to 800 mm). A separate guide for the stem is not normally provided in these designs, since the component being actuated by the cylinder usually cannot break out of set limits of motion. Any off-centre displacement is countered by the rolling diaphragm with no loss of power.
- Materials used for rolling diaphragms in present-day designs ensure durability under normal operating conditions. This is important because even a small crack or cuts in the diaphragm can lead to early failures once the flexible material undergoes high stress as it unrolls at each stroke.
- If the actuator needs to be dismantled for any reason, it must be inspected carefully for any burrs or sharp edges inside. Metal cuttings also constitute a hazard if they enter the cylinder housing.

5.2.1.3 Gravity Return Single Acting Cylinder

- In push type (a), the cylinder extends to lift a weight against the force of gravity by applying oil pressure at the blank end. The air is passed through the blank end port or the pressure port. The rod end port or vent port is open to the 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 and back into the tank.

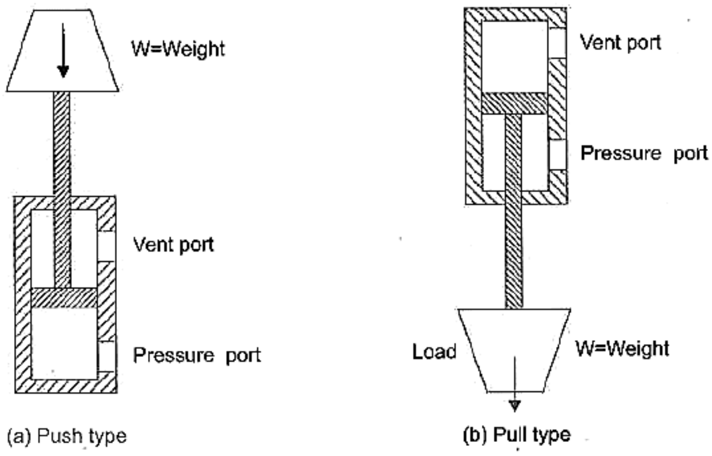

Fig.5.4 Gravity return single acting cylinder

- In the pull type (b), the cylinder lifts the weight by retracting. The blank end port is the pressure port and the blind end port is now the vent port. The cylinder automatically extends whenever the pressure port is connected to the tank.

5.2.1.4 Spring return single acting cylinder

- A spring return single acting cylinder is shown in *Fig.5.5* Part (a) is push type, where the pressure is sent through 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 the atmosphere so that air can flow freely in and out of the rod end of the cylinder.

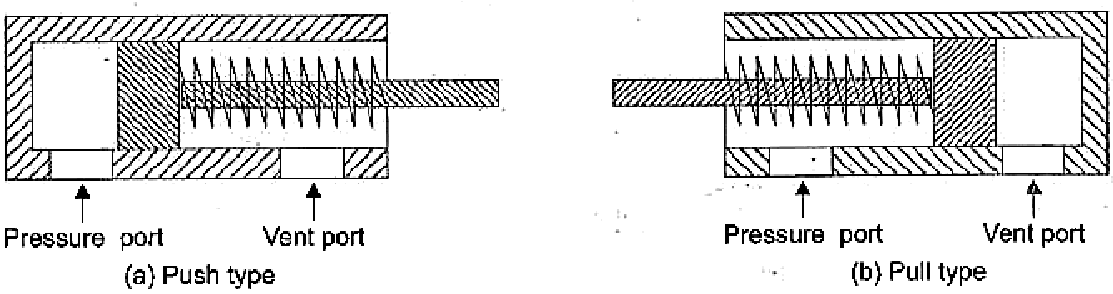

Fig.5.5 Spring return single acting cylinder

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

5.2.2 Double Acting Cylinders

- A schematic diagram of a double acting cylinder is shown in *Fig.5.6*. Double acting cylinders are equipped with two working ports, one on the piston side and the other on the rod side. For forward motion of the cylinder compressed air is admitted on the piston side, and the rod side is connected to the exhaust.
- During the return stroke, air admitted in the rod side while the piston side is connected to the exhaust. Force is exerted by the piston during both forward and return movements of the cylinder. Double acting cylinders are available in diameters ranging from a few millimetres to around 300 mm, and stroke lengths from a few millimetres up to 2 metres (special cylinders).

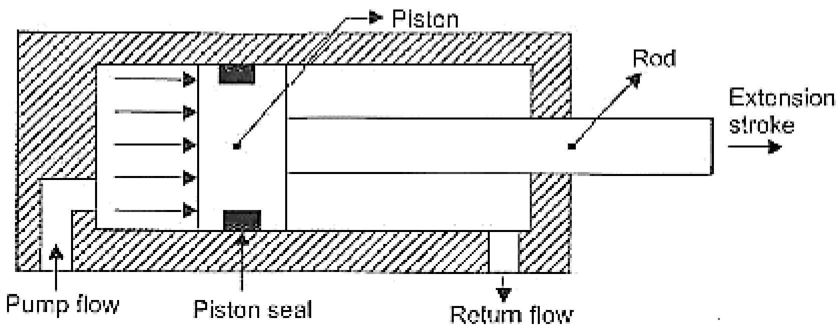

Fig.5.6 Double acting cylinder

- The construction of a double acting cylinder is shown in *Fig.5.7* and is similar to that of a single cylinder except that there is no return spring. In a double acting cylinder, air pressure can be applied to either side (supply or exhaust) of the piston, thereby providing a pneumatic force in both directions. Double acting cylinders are most commonly used in applications where a longer stroke length is required.

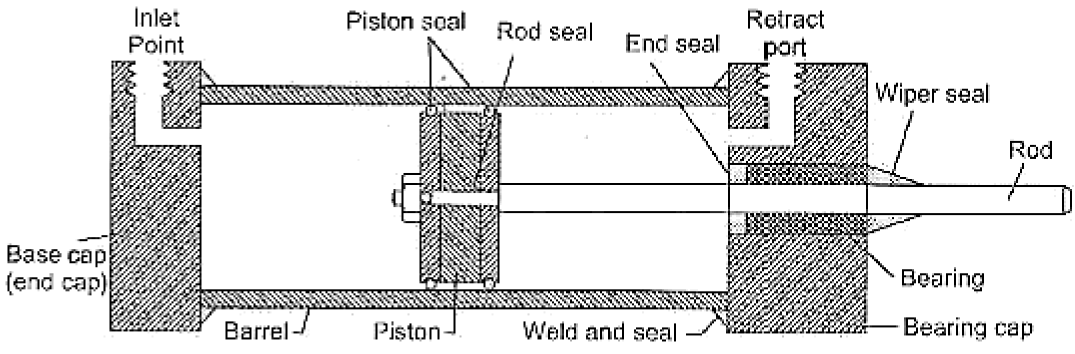

Fig.5.7 Construction features of double acting cylinder

- The seven parts of a double acting cylinder are:
  - Base cap with a port connection
  - Bearing cap with a port connection
  - Cylinder barrel
  - Piston
  - Piston rod
  - Scraper rings
  - Seals
- The base and bearing caps are made of cast aluminium or malleable cast iron. The two caps can be fastened to the cylinder barrel by tie rods, threads or flanges.
- The cylinder barrel is usually made of a seamless drawn steel tube to increase the life of the sealing components, and the bearing surfaces of the cylinder are precision machined. For special applications, the cylinder barrel can be made of aluminium, brass or steel tubes with a hard chromed bearing surface. These special designs are used where operation is infrequent or where there are corrosive influences.
- The piston rod is made preferably from heat treated steel. A certain percentage of chrome in the steel protects against rusting. Generally the threads are rolled to reduce fractures. Piston seals are. provided between the piston and the barrel to avoid leakage. A sealing ring is fitted in the bearing cap to seal the piston rod. The bearing bush guides the piston rod and may be made of sintered bronze or plastic coated metal. In front of this bearing bush is a scraper or wiper ring. It prevents dust and dirt particles from entering the cylinder space. Bellows are therefore not usually required.

5.2.2.1 Double acting cylinder with piston rod on one side

- *Fig.5.8* shows the operation of a double acting cylinder with a piston rod on one side. To extend the cylinder, pump flow is sent to the blank end port as in *Fig.5.8 (a)* and 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 seen in *Fig.5.8* (b).

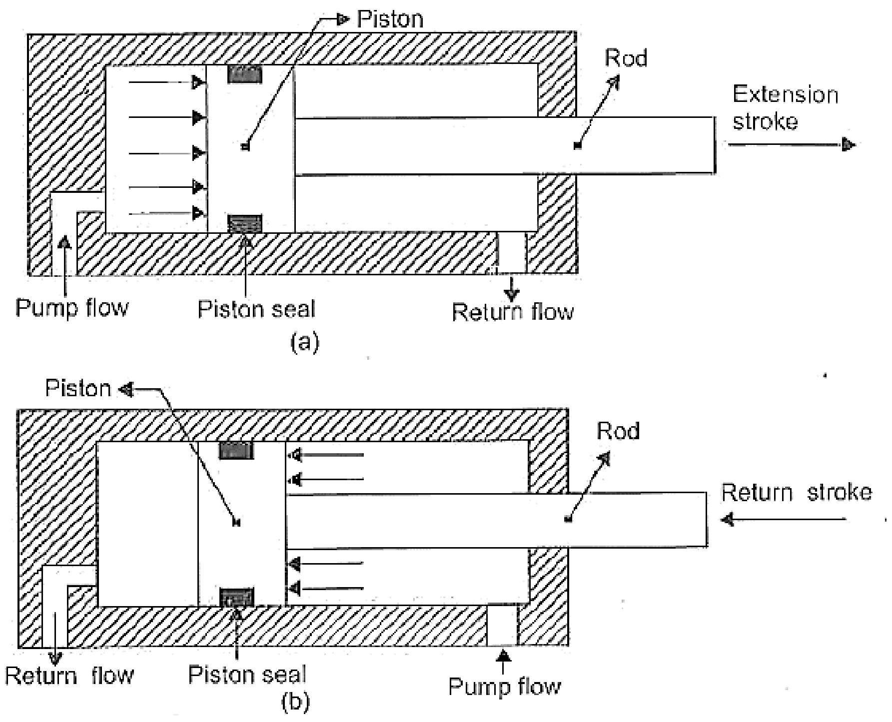

Fig.5.8 Double acting cylinder with piston rod on one side

5.2.2.2 Double acting cylinder with piston rod on both sides

- A double acting cylinder with a piston rod on both sides has a rod extending from both ends. Work can be done by both ends of the cylinder, thereby making it more productive. Double rod cylinders can withstand higher side loads because they have an extra bearing on each rod to withstand the load.
- They are used when there is a bending load and accurate alignment and maximum strength is required. A further advantage is that the rod is precisely located and may be used to guide the machine member coupled to it, dispensing with external guides or bearings in many cases. Most standard production models are available either in single rod or double rod configurations. A disadvantage of the double rod configuration is that there is a reduction in the maximum thrust due to the blanking effect of the rod cross-section on the piston area.

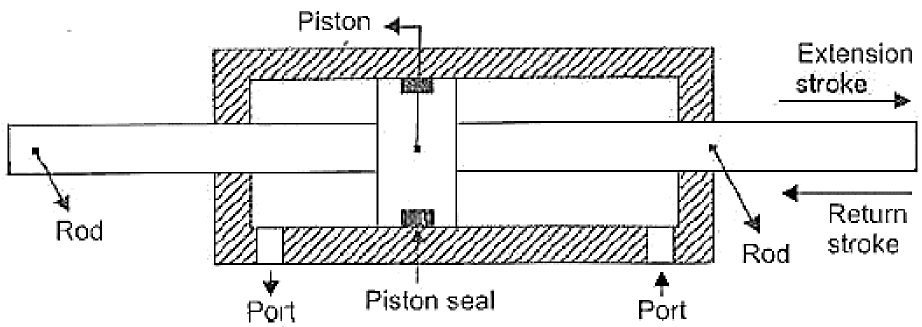

Fig.5.9 Double acting cylinder with piston rod on both side

5.2.3 Classification based on cylinder action

- The rotating type of cylinder is used in applications where the cylinder body is connected to a rotating member, and the air connection to the cylinder is in a stationary housing. They are not widely used.

- Non-rotating cylinders are widely used in industries. The cylinder body is connected to the air connection which is mounted on stationary housing and the piston rod moves inside the cylinder.

5.2.4 Classification based on cylinder design

- In the industry, a distinction is made between specially designed regular cylinders and spe¬cial duty cylinders designed for a specific purpose. Special design cylinders are basically natural variations of single or double acting cylinders, with changes during production to swap indifferent shapes or materials for certain parts.
- Special duty cylinders on the other hand, are designed from the start for non-standard conditions of service or application. The following section deals with some of the commonly used special design and special duty cylinders.

5.2.4.1 Telescopic cylinder

- A telescopic cylinder (shown in *Fig.5.10* (a) and (b)) is used when a long stroke length and a short retracted length are required. It extends in stages, each stage consisting of a sleeve that fits inside the previous stage. *Fig.5.10* (c) shows the construction of a typical double acting telescopic cylinder with two pistons (two stages).

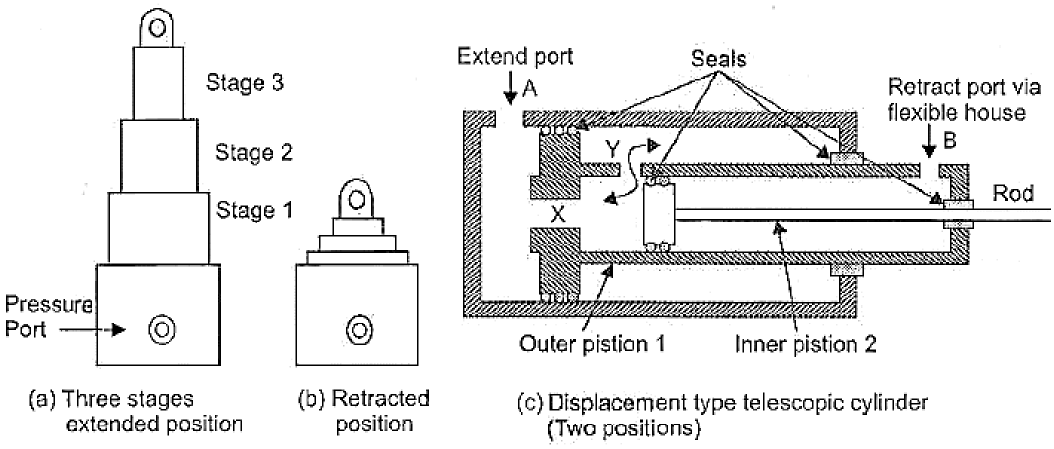

Fig.5.10 Telescopic cylinder

Extension stroke

- When pressure is applied at port A, air flows through ports A and X and pressure is applied on both sides of piston 1. But a difference in the areas causes piston 1 to move to the right. Once piston 1 fully extends, the inner piston 2 extends.

Retraction stroke

- To retract, air is applied to port B. Air pressure acts on the annulus of the inner piston 2 and moves it to the left. This starts to close port A whereupon air from port B goes to the annular side of piston 1 and pushes piston I to the left.

5.2.4.2 Tandem cylinder

- A schematic diagram of a tandem cylinder is shown in *Fig.5.11*. Tandem cylinders are two separate double acting air cylinders arranged in line as one cylinder body, so that the power generated by them works in combination approximately doubling the piston output.
- A tandem cylinder is used in applications where a large amount of force is required from a small diameter cylinder.
- Basically, a tandem cylinder is simply two or more separate cylinders stacked end to end in a unit, with all the pistons mounted on a common piston rod. Pressure is applied to both pistons, resulting in an increased force because of the larger working area.

- The drawback is that these cylinders must be longer than a standard cylinder to achieve equal speed, because the flow must go to both pistons.

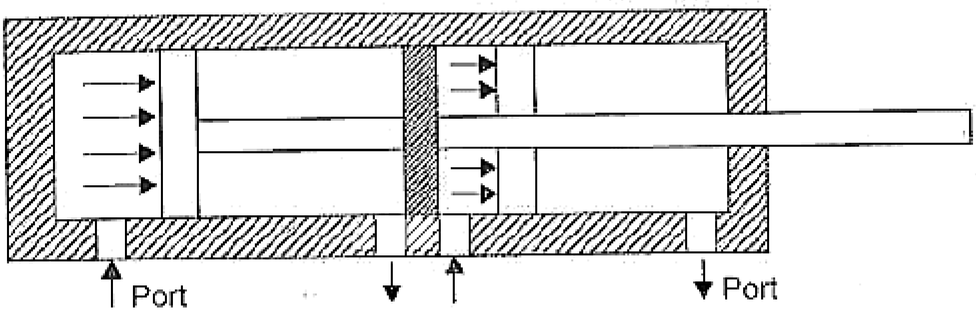

Fig.5.11 Tandem cylinder

5.3 Cylinder Mountings

- The way in which the cylinder is mounted affects the service life, maintenance frequency and the success of the entire installation. Poor mounting design can cause excessive side loads and stresses which bring about early failure of vital components. There are three main categories of cylinder mountings. The selection of these mountings depends on the application and the machine configuration. *Fig.5.12* shows all three cylinder mountings.
- Fixed centreline mountings
- Pivoted centreline mountings

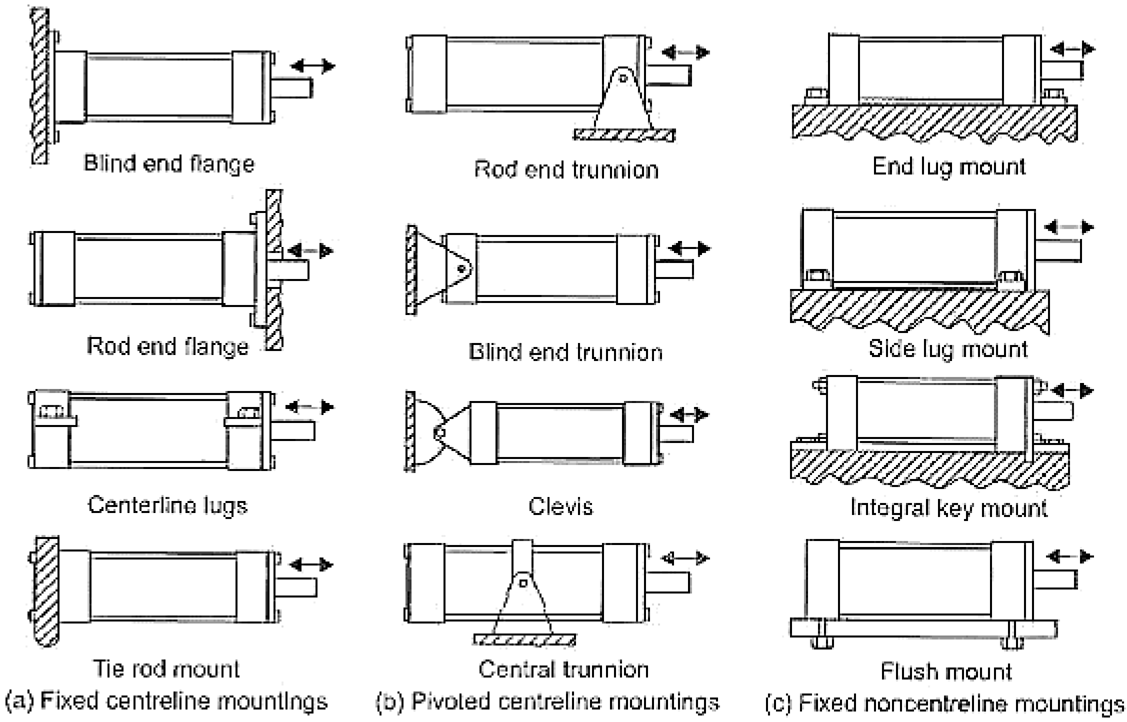

Fig.5.12 Types of Mountings

5.4 Air Motors

- Air motors are high power, high weight, compact and dependable units requiring little maintenance over long periods of use.

Advantages of air motors

- Completely'safe in conditions where electric motors might create a risk of fire or explosion.
- Can be readily be adjusted for speed by varying the pressure of the air supply via a regulator.
- Air motors cannot be damaged by overload; they simply slow down or stop before damage occurs.
- Many types of air motors are reversible

The principle advantages of an air motor drive applicable to all air motors

- Air motors are very safe, with all parts (including the motor supply) being completely flame proof. Safety is of particular importance on construction sites, ship building yards, etc., where temporary supplies are used under severe conditions.
- Motors can be overloaded and stalled without damage.
- Simple design and construction, easily maintained and overhauled.
- Operates satisfactorily in adverse conditions, such as heat, moisture, dirt, etc.
- Emergency supplies can be easily stored.

5.4.1 Types of air motors

a) Vane air motor
b) Piston air motor
c) Diaphragm air motor
d) Turbine motor
e) Gear motor

5.4.1.1 Vane motor

- The vane type motor is produced in a variety of power outputs, varying from fractional to approximately 15 kW. The fractional kilowatt units are used extensively in portable tools such as drills, grinders, chippers etc., and also in multiple tool mass production assemblies like nut and stud runners. The large kilowatt motors are frequently used to power pumps, valves, hoists, winches, soot blowers etc.

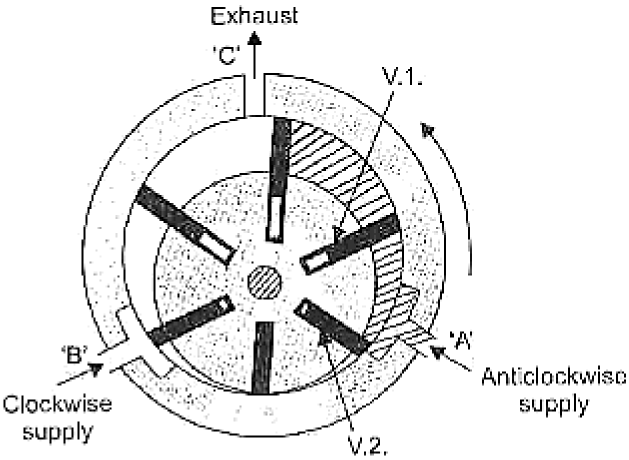

Fig.5.13 Vane motor

- *Fig.5.13* illustrates the operational principle of a reversible internal vane motor. A rotor shaft carrying vanes is mounted eccentrically in the power chamber with the vanes arranged to slide radially to seal against the power chamber wall.
- The vanes are usually mechanically or pneumatically sprung against the casting to provide sealing force for starting; this force is increased by centrifugal action when the motor speed rises. Air is supplied to the rotor chamber via either port A or port B, depending on the direction required.

5.4.1.2 Piston motor

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- Many applications require a motor that is capable of large power outputs combined with good torque characteristics at low speeds. The piston type motor possesses these char¬acteristics and is manufactured in a wide range, from fractional to approximately 20 kW. The smaller types of motors sometimes use gearing to increase the torque. The gearing is usually an integral part of the motor, and the complete assembly forms a very compact unit. The two most common cylinders are:
  a) Vee type radial piston motor
  b) Radial piston motor

5.4.1.2.1 Vee type radial piston motor

- The vee type units have four cylinders arranged in two banks at 90° to each other. Drop forged two-throw crank shafts are normally used, with two connecting rods on each crank pin. Rotary or oscillating distribution valves are located between the cylinders and operated either by gearing or by eccentric cams.
- The valve timing can be controlled to provide equal power in both directions, or alternatively, may be biased to provide increased power in one direction with a corresponding decrease in the opposite direction. *Fig.5.14* shows a typical arrangement of a vee motor.

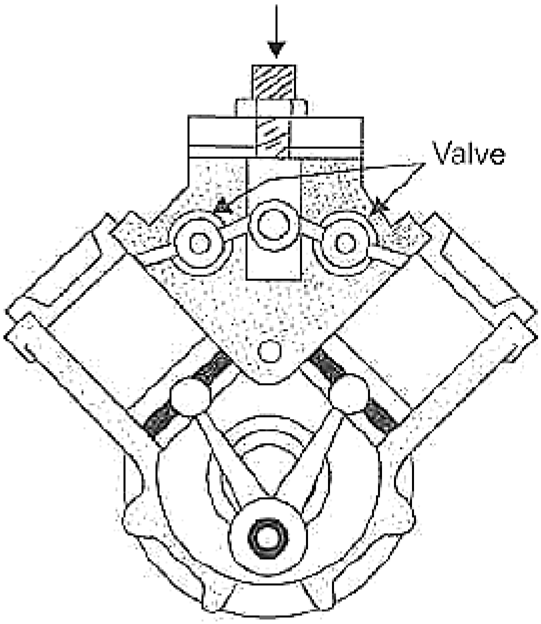

Fig.5.14 Vee type motor

5.4.1.2.2 Radial piston motor

- The radial design is frequently adopted on the large kilowatt motors and three, four, five, or six cylinder models are produced. A schematic diagram of a piston type radial motor is shown in *Fig.5.15*.
- All connecting rods operate on a common crank pin as found in a standard radial motor practice. The power and exhaust strokes are controlled by rotary distributing valves and a two-stage exhaust is frequently adopted.
- The inlet valve opens at top dead centre and remains open for approximately 160 degrees. The inlet valve then closes and the large primary exhaust port opens quickly to release the high pressure air into the atmosphere. At approximately 200 degrees, the primary exhaust valve closes and a secondary exhaust port opens to evacuate the remaining air. A reversal of direction is obtained by interchanging the inlet and secondary exhaust directions.

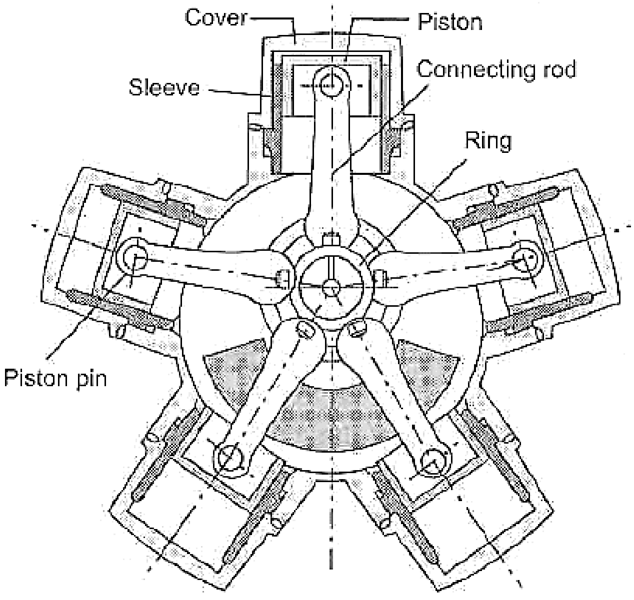

Fig.5.15 Radial piston motor

- Piston type motors are suitable for control applications due to their robust and variable speed and torque characteristics.

5.4.1.2.3 Diaphragm air motor

- The schematic diagram of a diaphragm air motor is shown in *Fig.5.16*. Diaphragm air motors are used when high torque at very low speeds is required. This motor operates directly on the valve shaft via a ratchet and foot wheel mechanism. The motor contains a diaphragm to produce the necessary thrust, and a snap-over valve mechanism operated by the motor shaft alternately admits air to the power chamber and then vents it. This produces continuous oscillations of the motor shaft and hence rotations of the valve spindle.

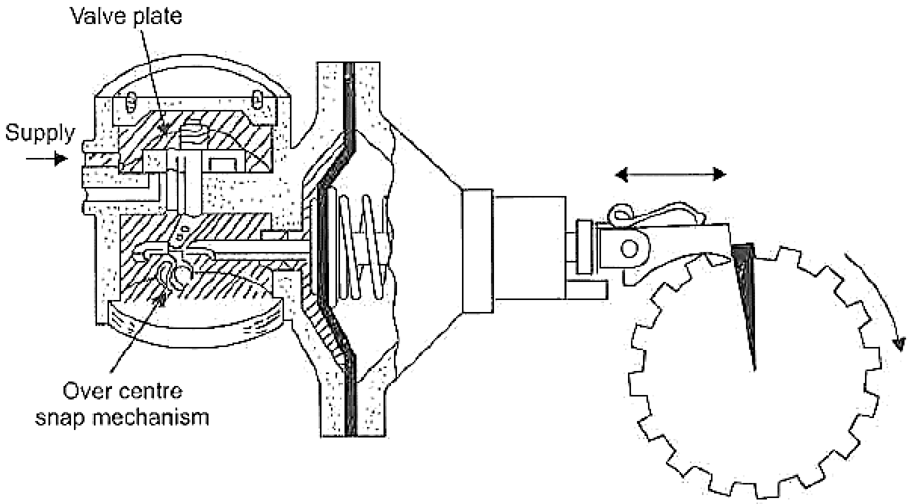

Fig.5.16 Diaphragm air motor

5.4.1.2.4 Turbine motor

- These high speed motors generate only a small torque. In fact, when stalled, the torque is practically negligible. Speeds are limited to between 50,000 RPM to 80,000 RPM and the torque is the highest in the middle of this range.
- Application is limited to where high speeds combined with light loads are required, e.g., high-speed pencil grinders and dental drills. Stalling does not damage a turbine motor. Turbine motors can be fitted with me¬chanical governors to limit the maximum speed and the motors operate without sliding or rubbing (except for the bearings).
- Bearing friction is therefore the only limiting factor for speed. Only the bearings require lubrication, otherwise turbines can process dry air with no lubrication.

5.4.1.2.5 Gear motor

- These motors are categorised as dynamic motors. The mating gears are of three types: straight, helical or double helical. These are pure displacement motors, i.e., they don't use the expansion properties of compressed air and have low volumetric efficiency. Gear motors are used in heavy industrial applications requiring power capacities up to or higher than 30 kW.

Advantages of gear motors

- Very high speeds are possible.
- The motor is oil free.
- There is no wear.
- They arc suitable for continuous operation.

5.5 Valves

- Valve are defined as devices to control or regulate the commencement, termination and direction and also the pressure or rate of flow of a fluid under pressure which is delivered by a compressor or vacuum pump or is stored in a vessel.
- Values of one sort or another, perform three main function in pneumatic installation
- They control the supply of air to power units, example cylinders
- They provide signal which govern the sequence of operation
- They act as interlock and safety devices
- The type of valve used is of little importance in a pneumatic control for most part. What is important is the function that can be initiated with the valves, its mode of actuation and line connection size, the last named characteristics also determining the flow size of the valve.
- Valves used in pneumatics mainly have a control function that is when they act on some process, operation or quantity to be stopped. A control function requires control energy, it being desirable to achieve the greatest possible effect with the least effort. The form of control energy will be dictated by the valve's mode of actuation and may be manual, mechanical, electrical hydraulic or pneumatic.
- Valve available for pneumatic control can be classified into four principal groups according to their function:
    a) Direction control valve (Same as used in hydraulics. Range of working pressure is less)
    b) Non return valves
    c) Flow control valves (Same as used in hydraulics. Range of working pressure is less)
    d) Pressure control valves (Same as used in hydraulics. Range of working pressure is less)

5.5.1 Non return valves

- Non return valves permit flow of air in one direction only, the other direction through the valve being at all times blocked to the air flow. Mostly the valves are designed so that the check is additionally loaded by the downstream air pressure, thus supporting the non-return action.
- Among the various types of non-return valves available, those preferentially employed in pneumatic controls are as follows

a) Check valve
b) Shuttle valve
c) Quick exhaust valve
d) Two pressure valve
e) Restrictor check valve
f) Pilot Operated Check Valve

5.5.1.1 Check valve

- The simplest type of non-return valve is the check valve which completely blocks air flow in one direction while permitting flow in the opposite direction with minimum pressure loss across the valve.

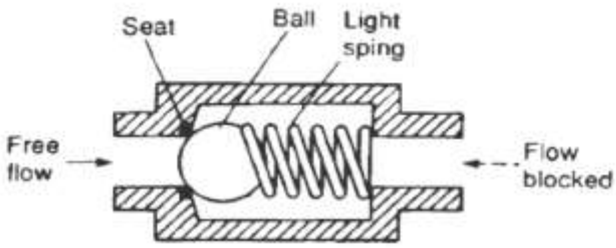

Fig.5.17 Check valve

- As soon as the inlet pressure in the direction of free flow develops a force greater than that of the internal spring, the check is lifted clear of the valve seat. The check in such valve may be plug, ball, plate or diaphragm.

5.5.1.2 Shuttle valve

- It is also known as a double control valve or double check valve. A shuttle valve has two inlets and one outlet. At any one time, flow is shut off in the direction of whichever inlet is unloaded and is open from the loaded inlet to the outlet.
- A shuttle valve may be installed, for example, when a power unit (cylinder) or control unit (valve) is to be actuated from two points, which may be remote from one other.

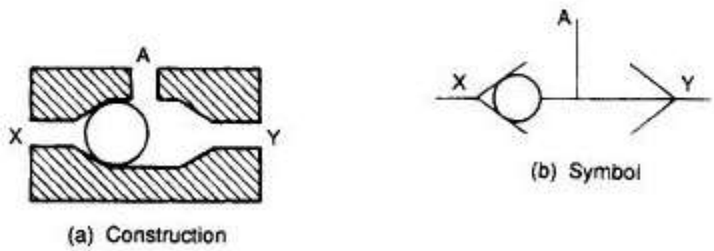

Fig.5.18 Shuttle valve

5.5.1.3 Quick Exhaust Valves

- A quick exhaust valve is a typical shuttle valve. The quick exhaust valve is used to exhaust the cylinder air quickly to atmosphere. Schematic diagram of quick exhaust valve is shown in *Fig.5.19*. In many applications especially with single acting cylinders, it is a common practice to increase the piston speed during retraction of the cylinder to save the cycle time.
- The higher speed of the piston is possible by reducing the resistance to flow of the exhausting air during the motion of cylinder. The resistance can be reduced by expelling the exhausting air to the atmosphere quickly by using Quick exhaust valve.

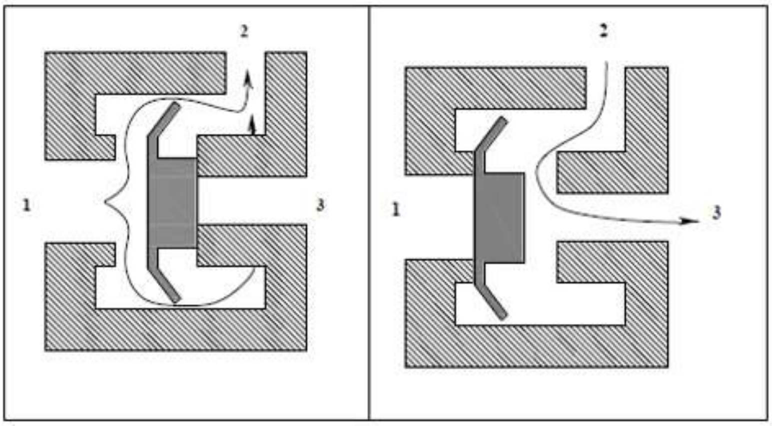

Fig.5.19 Quick exhaust valves

- The construction and operation of a quick exhaust valve is shown in *Fig.5.19*. It consist of a movable disc (also called flexible ring) and three ports namely, Supply port 1, which is connected to the output of the final control element (Directional control valve). The Output port, 2 of this valve is directly fitted on to the working port of cylinder. The exhaust port, 3 is left open to the atmosphere.

Forward Motion:

- During forward movement of piston, compressed air is directly admitted behind the piston through ports 1 and 2 Port 3 is closed due to the supply pressure acting on the diaphragm. Port 3 is usually provided with a silencer to minimise the noise due to exhaust.

Return Motion:

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

5.5.1.4 Two Pressure Valve

- This valve is the pneumatic AND valve. It is also derivate of Non Return Valve. A two pressure valve requires two pressurised inputs to allow an output from itself. The cross sectional views of two pressure valve in two positions are given in *Fig.5.20*.
- As shown in the *Fig.5.20*, this valve has two inputs 12 and 14 and one output 2. If the compressed air is applied to either 12 or input 14, the spool moves to block the flow, and no signal appears at output 2. If signals are applied to both the inputs 12 and 14, the compressed air flows through the valve, and the signal appears at output 2.

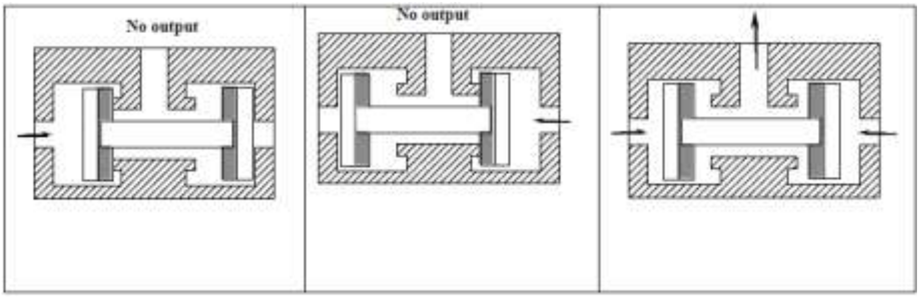

Fig.5.20 Two pressure valve

5.5.1.5 Restriction Check Valve or Throttle Relief Valve

- Some valves are meant for an application where free flow is required in one direction and restricted flow required in another direction. These types of valves are called as restriction check valve.
- These valves are used when a direction sensitive flow rate is required. For example, the different actuator speeds are required in both the directions. The flow adjustment screw can be used to set the discharge (flow rate) in the restricted direction.

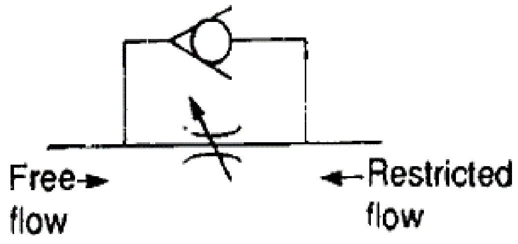

Fig.5.21

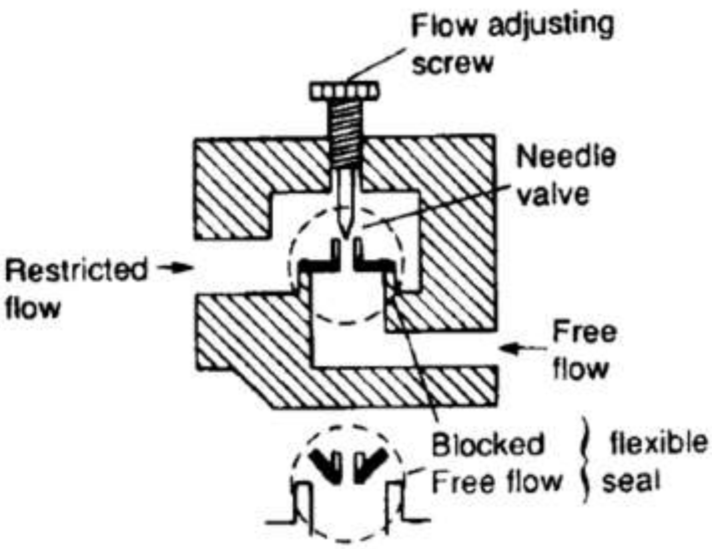

Fig.5.22 Restriction Check Valve

5.5.1.6 Pilot Operated Check Valve

- A pilot-operated check is similar to a basic check valve but can be held open permanently by application of an external pilot pressure signal.

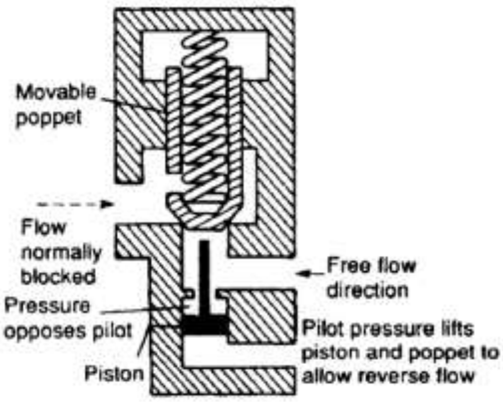

Fig.5.23 Pilot Operated check valve

5.5.1.7 Time Delay Valve

- The time delay valve shown in Fig. consists of an in-built air reservoir, an in-built non-return flow control valve and a pilot controlled spring return 3 way 2 position direction control valve. This valve is used in the pneumatic system to initiate a delayed signal.
- When the compressed air is supplied to the port 'P' of the valve, it is prevented from flowing to port 'A' from 'P' as this is blocked by the spring actuated spool. Air is accumulated in an in-built reservoir of the valve from the pilot control port 'Z', the control passage of the same being controlled by the needle of the in-built throttle valve. Pressure starts building up here.

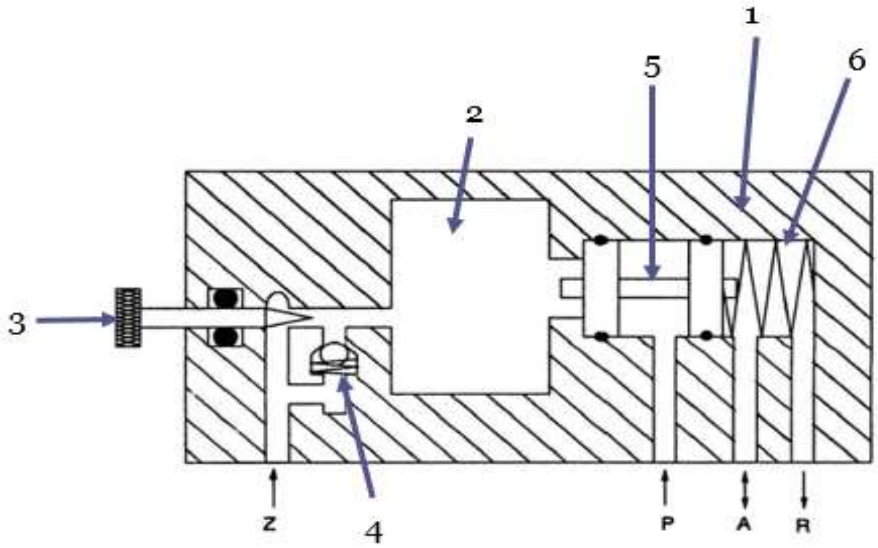

Fig.5.24 Time Delay Valve

1. Valve Body 2. Air Chamber 3. Adjusting Screw 4. Openings- P, A, R, Z 5. Non Return Valve 5. Valve Spool 6. Spring

- When the pressure needed to push the spool is built-up in the reservoir, the pilot spool of the 3/2 direction control valve shifts, thus opening port 'P' of the main valve to 'A' and closing the port 'R'.
- The time required to build-up the pressure in the reservoir, is the amount of delay time offered by the time delay valve.
- With further increase of pressure, the inbuilt check valve opens, the air from the reservoir gets exhausted and the valve spool returns to its original position.

5.6 Reference Books

1. Basic Pneumatic Systems, Principle and Maintenance by S R Majumdar, McGraw-Hill
2. Pneumatics Concepts, Design and Applications by Jagadeesha T
3. Fluid Power with Applications by Anthony Esposito, Pearson