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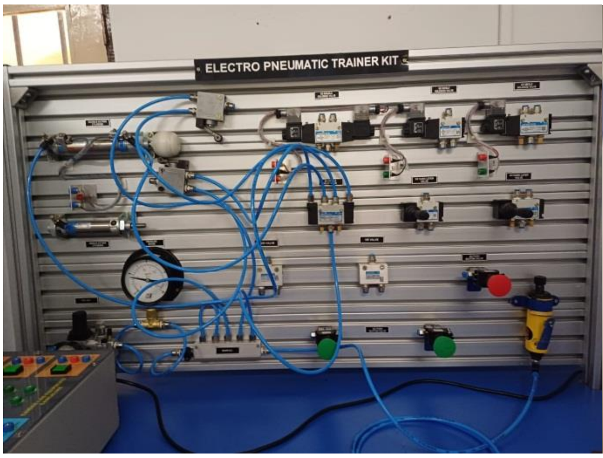

DRIVE SYSTEMS FOR ROBOTICS (22RI34)

UNIT 3: NOTES

PNEUMATIC DRIVES

III SEMESTER, B.E.

DEPARTMENT OF ROBOTICS AND ARTIFICIAL INTELLIGENCE

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Introduction:

The working concept of Pneumatic system is similar to that of a Hydraulic power system. A pneumatic system is a system that uses compressed air to transmit power. Usually, a centrally located compressor provides power to cylinders, rotary actuators, and other pneumatic devices through a system of tanks, pipes and valves. Pneumatic system use pressurized gas, mostly air, to transmit motion and power. A **pneumatic system** is a system that uses compressed air or gas to perform work. Pneumatic systems are commonly used in industrial applications, machinery, and tools due to their reliability, simplicity, and efficiency. These systems are found in various industries, including manufacturing, automation, automotive, and construction.

The concept of **Pascal's law** also holds good for Pneumatic systems. Since a confined air behaves same as a confined fluid with respect to pressure, the force can be calculated using pressure and area on which it is acting **(i.e F=p.A).** Also many components used in Pneumatics such as control valves, filters, actuators, motors have same constructional features.

Choice of Working Medium:

- When a system needs high speed, medium pressure and less accuracy, a pneumatic (air) is good. If a system requires high pressure and high accuracy then fluid system with oil is good.
- Whenever the power requirements are very high, power press like oil hydraulics is the best option.
- Location of the system also plays the vital role in selection of the working medium. Location with Sevier temperature variations oil hydraulics systems will do better. Where air systems will lead to Sevier condensations problems.
- Another selection issue is that of air is that of fire/electrical hazards, air being non-explosion in nature it is preferred for fire and electric hazards are expected. Oil is more prove to fire/electric hazards.

Structure or Components of Pneumatic Power Systems:

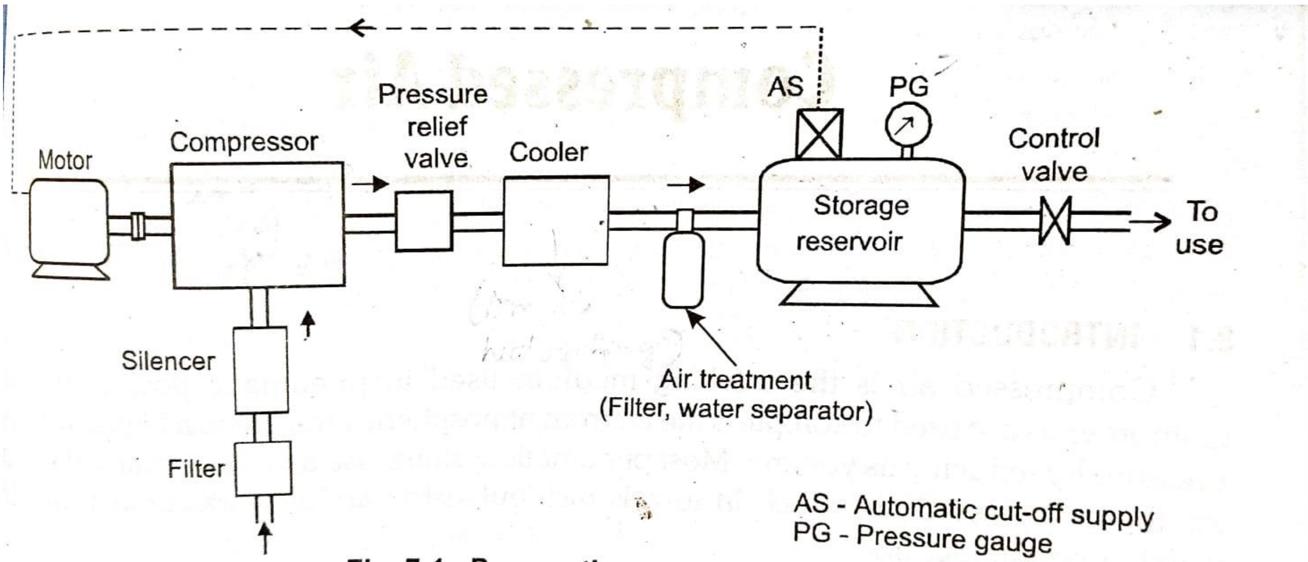


Fig. 7-1. Pneumatic power system

In this system, an electric motor drives an air compressor. The atmospheric air is sucked by the compressor (in its suction stroke) through a filter and a silencer. The purpose of filter is to separate air from suspended and other dust particles, while the silencer is used to reduce the noise level of the air while passing through the system lines. The compressor line is provided with a safety valve (pressure relief valve), to protect the system pressure rising beyond the safe level. Since the compression process increases the temperature of the compressed air, the air is passed through a small heat exchanger, to cool the air to environmental condition. The compressed air then passes through a filter and water trap to remove any escaped dust particle and to remove any condensate. 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. A pressure gauge is provided on the container to monitor the pressure of the air. Also an automatic switch is provided which stops the electric motor supply once the air reaches a set pressure.

Production of Compressed Air:

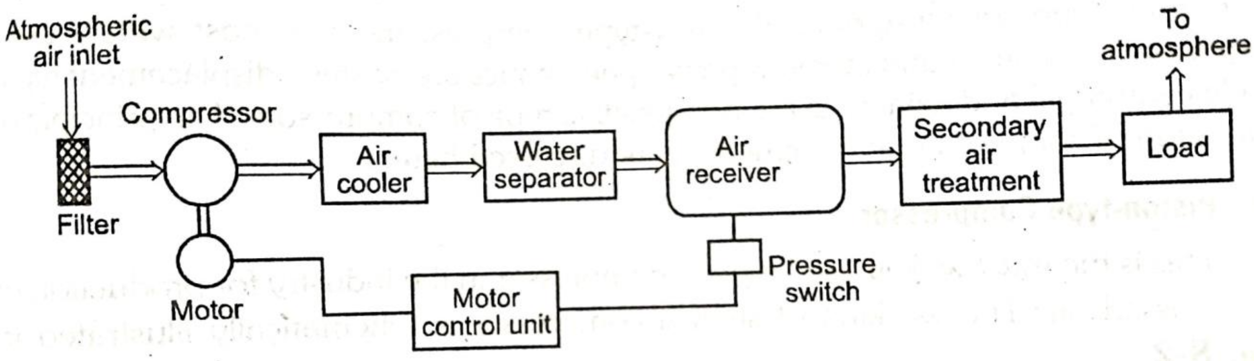


Fig. 8-1. Production of compressed air

Compressed air is produced using compressors and stored in an air receiver (the reservoir). The atmospheric air is drawn-in by the compressor and compressed to a higher pressure and sent to the receiver. The process of increasing the pressure takes place by reducing the volume of the air. The production of compressed air for pneumatic applications involves a number of stages such as filtering, compressing, cooling, moisture separation, and so on. The process is schematically shown in **Fig. 8-1**.

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 enter 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. Some form of **coolers** are required to cool the air before it is sent to the air receiver. In piston-type of compressors, it is commonly provided with external fins on the cylinder and a fan blows air to remove the heat. In large and complex systems, water cooled heat exchangers are used to remove the heat and cool the compressed air.

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 **air receiver**. An air receiver is a pressure vessel that stores the compressed air. Once the receiver is filled with compressed air and the 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 process of adding oil mist, filtering and separation after the air receiver is termed ***secondary air treatment***. This treated air is then sent to the control valves and to the actuators to do the work. The used air is then let out to the atmosphere.

Compressor:

Similar to hydraulic pumps, compressors are the source of pneumatic power. These can also be classified into two categories: Positive displacement and non-positive displacement (dynamic type). Piston type and Screw type compressors the most commonly used compressors for small and medium power pneumatics are positive displacement type. While centrifugal axial type is non-positive displacement type of compressors.

Rotary Vane compressor:

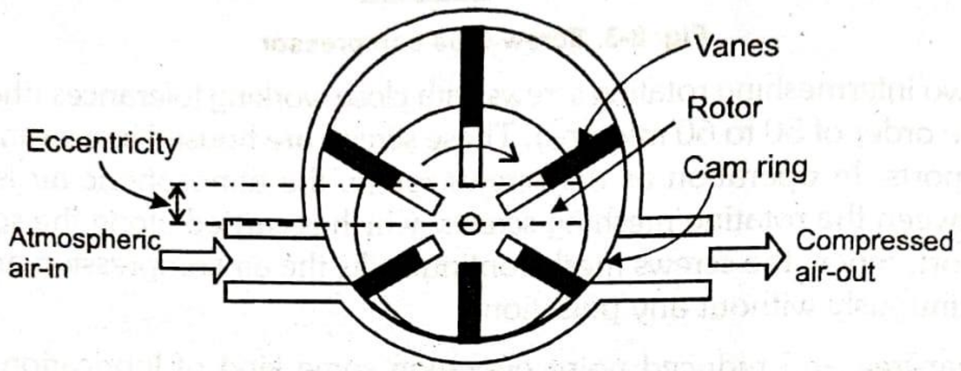


Fig. 8-5. Rotary vane compressor

It consists of a rotor mounted eccentrically in a cylindrical casing. There are slots in the rotor in which rectangular blades or vanes are located. The vanes are free to slide outward from the centre of the rotor. The vanes are held in contact with the inner surface of the casing under spring pressure, which is also assisted by the centrifugal force while running.

As the rotor rotates (in the left half of the compressor) the atmospheric air is drawn-in with the vanes gradually increasing in volume (forming moving chamber between vanes). In the right half of the rotor-casing the vanes start moving inward, thereby reducing the volume of the moving chambers, thus compressing the air, which is delivered to the outlet port. A mist of oil is injected into the compressor, which acts as seal between the sliding surfaces (vane ends and the inner surface of the casing).

A single stage vane compressor can compress up to 3 bar, which is much lower than the piston type compressor. For higher pressures, about 10 bar, a two stage vane compressor is suitable. Many instruments and laboratory equipments use rotary vane compressor for their operation.

Pneumatic Air Pressure Regulators:

In pneumatic systems the flow velocities are quite high, which may lead to considerable pressure drops between the air receiver (reservoir) and the loading point. Hence it is common practice to maintain the higher pressure in air receiver than that is required in 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 the pressure-reducing valves used in hydraulic systems. Air pressure regulators in pneumatic systems are used to adjust the supply of air to the required level of the load irrespective of the air flow, to maintain the 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 are the equivalent of hydraulic actuators. Pneumatic actuators convert the air pressure into linear or rotary motion depending upon their design. Similar to hydraulic actuators, pneumatic cylinders are also used for gripping/moving of objects in various industrial applications.

Pneumatic actuators which are designed to produce linear motion are termed linear **air cylinders**. These can be conventional **rod-type cylinders** or **rod-less cylinders**. Actuators which are designed to produce rotary motion are termed **rotary cylinders** or more popularly **air motors**.

These actuators can be classified as light, medium and heavy duty type, depending upon the load to be handled by them. The principle of operation of some pneumatic actuators is discussed in the subsequent sections.

Classifications of Air cylinder:

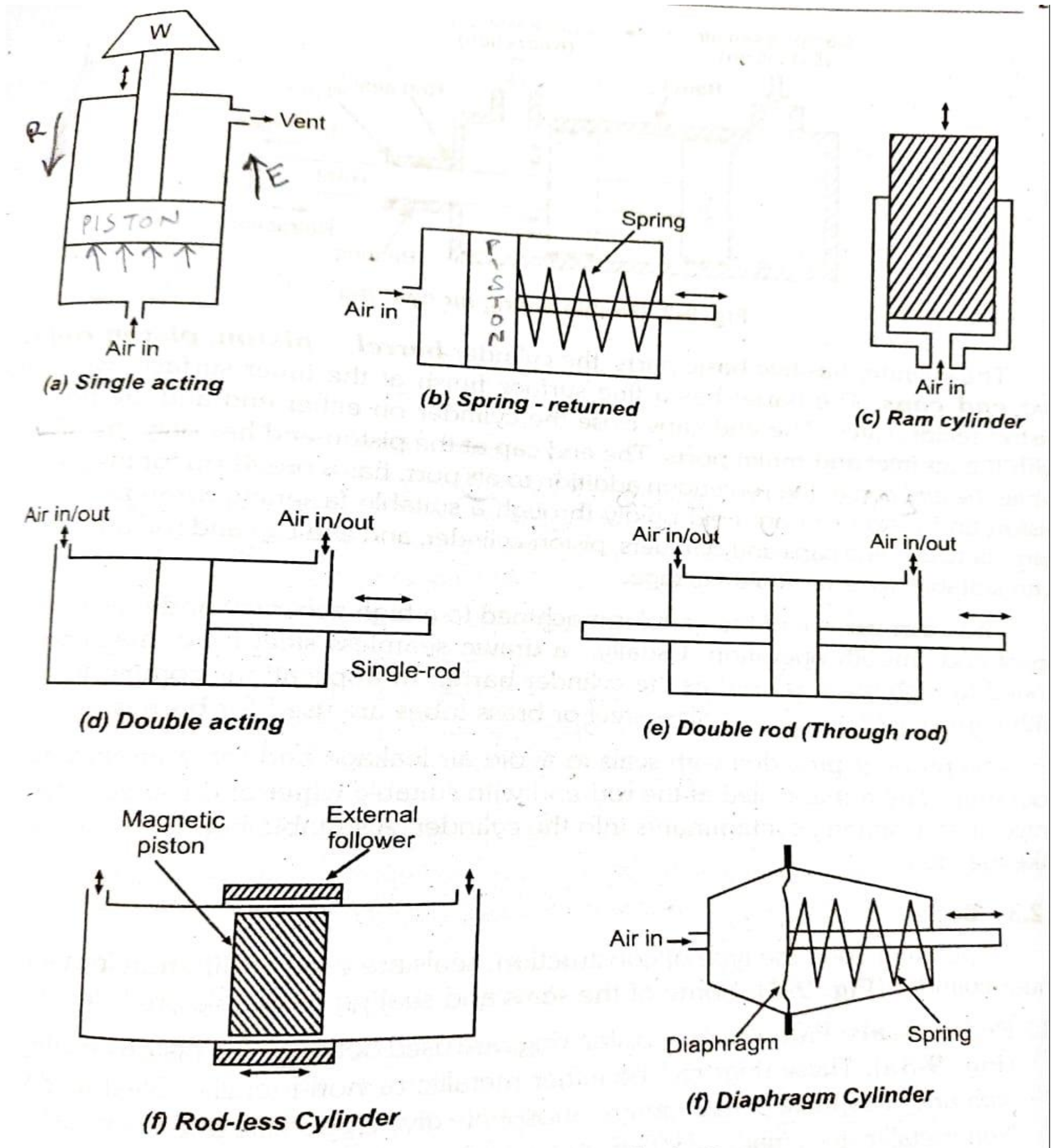
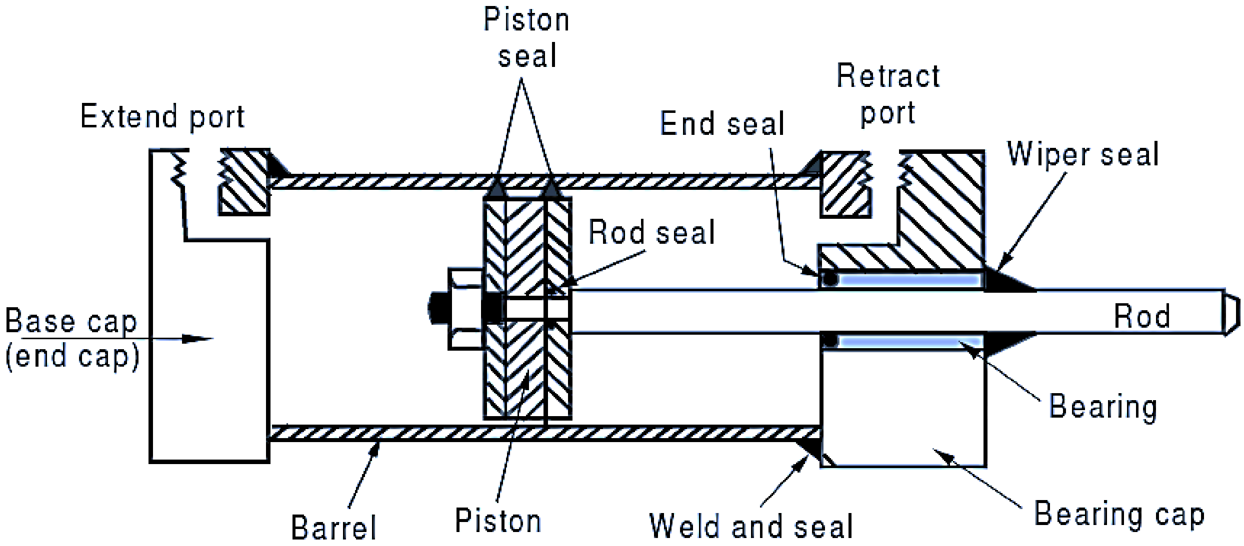


Fig. 9-1. Types of air cylinders

A brief classification of air or pneumatic cylinders with their schematic representations is given below.

1. **Single Acting Cylinder (Fig. 9-1a):** It is a cylinder in which air pressure is applied on to the piston in only side, and the extension takes place by the air pressure in one direction. The return stroke is mostly by gravity.
2. **Spring Return Cylinder (Fig. 9-1b):** 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 (Fig. 9-1c):** In this the cylinder rod itself forms the movable element, termed the *ram*. It is usually single acting, and return stroke is either under gravity or assisted by return cylinders.
4. **Double-acting cylinder (Fig. 9-1d):** It is a cylinder in which the air pressure is applied alternately on either side, so that both the forward and return stroke are controlled by the air pressure.
5. **Single rod cylinder:** In this, the piston rod extends from one side of the cylinder. The most common single and double acting cylinders are single rod type, in which actuation is possible on a single side.
6. **Double rod or through-rod cylinder (Fig. 9-1e):** In a double-rod or through-rod cylinder, the piston-rod extends/retracts on either end of the cylinder.
7. **Rod-less cylinder (Fig. 9-1f):** 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.
8. **Diaphragm Cylinder (Fig. 9-1g):** 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.

Construction of Double acting Cylinders:



The cylinder has five basic parts: the cylinder ***barrel***, a ***piston***, ***piston rod*** and two ***end caps***. The barrel has a fine surface finish at the inner surface, where the piston reciprocates. The end caps close the cylinder on either end and are provided with the air inlet and outlet ports. The end cap at the piston-end has only the air port, while the end cap at the rod end in addition to air port, has a provision for the rod. The piston and piston rod are held rigidly through a suitable fastening arrangement. The joints between end caps and cylinders, piston-cylinder, and end cap and rod are provided with suitable seals to avoid leakage.

The inner surface of the barrel is machined to a high accuracy and finish for leak-proof and smooth operation. Usually, a drawn seamless steel tube, machined and honed to high finish is used as the cylinder barrel. In applications coming in contact with corrosive materials, stainless steel or brass tubes are used for barrels.

The piston is provided with seals to avoid air leakage and for smooth, wear free operation. The rod is sealed at the rod-end with suitable wiper and rod-seals to avoid entry of atmospheric contaminants into the cylinder. A suitable bearing is provided to take the loads.

Rotary actuators:

Vane type air motor:

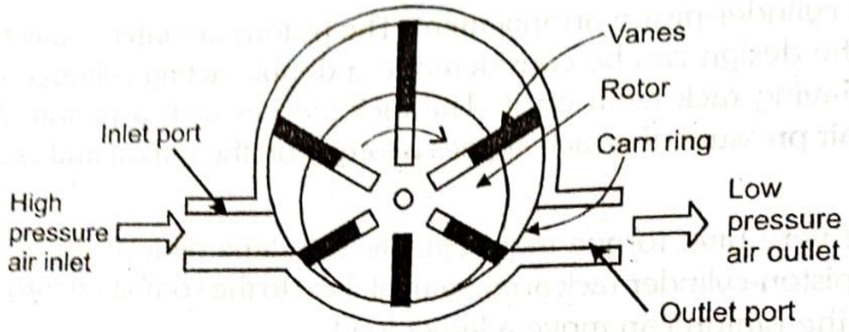


Fig. 9-9. Vane type air motor

The construction is similar to that of a hydraulic vane motor. It has a rotor with slots in which vanes can slide. The vanes are held against the smooth inner surface of a casing. The vanes are assisted with spring pressure to press against the inner surface so as to minimise air leakage. The rotor centre and the casing centres are off-set so as to cause a difference in the inlet and outlet chambers. This results in a pressure imbalance at the inlet and outlet, causing the rotation of the rotor. The high pressure air at the inlet acts on the unequal areas of the vanes, which in turn apply a torque on the rotor and causes its rotation.

Turbine type:

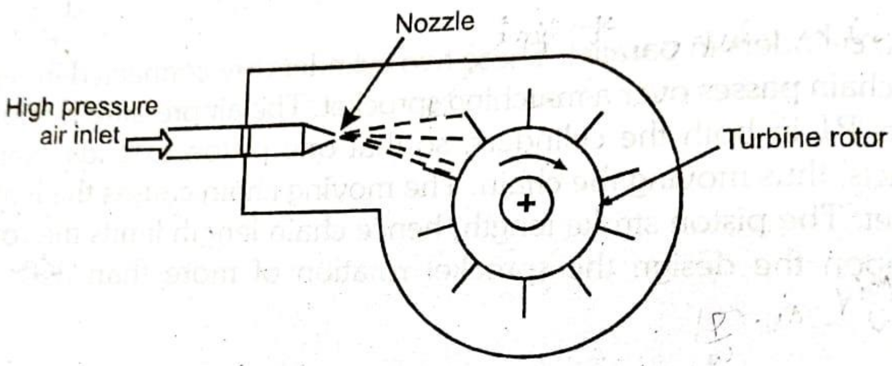


Fig. 9-10. Turbine type air motor

It has a turbine rotor with blades around it. A high pressure jet of air is made to impinge on the turbine blades. The kinetic energy of the air is converted into rotational motion of the rotor. Such motors have a high power-to-weight ratio than the vane motors. However, they work at very high speeds, and hence are suitable for grinding or routing type of high speed operations.

Design Parameters:

1) Size, weight and compactness
2) Speed selection
3) Overload protection
4) Direction Reversal
5) Environmental protection
6) Maintenance.

a) **Size, weight and compactness:** Higher the size, the motor becomes bulkier to handle. Large size motors are suitable for stationary applications, while small compact motors are used for mobile applications.

b) **Speed selection:** The provision of speed regulation helps in using the same motor for different applications.

c) **Overload protection:** The design of a motor to protect from overloads helps minimise damage to motor and to the work.

d) **Direction Reversal:** It is convenient to provide direction reversal option so that the motor can be run in either direction to meet the operational requirements.

e) **Environmental Protection:** Basically air motors are designed to be insensitive to environmental contaminants like dust, water, and heat. This makes the operation trouble-free.

f) **Maintenance:** The motor design should cater for low and/or ease of maintenance of the components. This reduces the down time and improves productivity.

Advantages of Air motors:

- Light and compact
- High power to weight ratio.
- Reversible motors
- Variable speed
- No over heating
- Cool running
- Cleanliness
- Lower pressures.

Pneumatic Control Valves:

- Pneumatic control valves are essential system to control the pneumatic components.
- They determine how much air passes through and in which direction.
- This means that they can be used as control valves, but also as safety valves that shut off the air supply in dangerous situations or that depressurise the system.
- The valves used are flow control, pressure control and direction control type.

Classification of Pneumatic Control Valves:

Pneumatic control valves are designed to perform, different functions. Based on their functions Pneumatic control valves are classified.

1. Directional Control Valves (DCV)
(a)Poppet valves
(b)Spool (Slide) Valve
2. Flow control valves
4. Non-return valves
(a)Check valve
(b)Shuttle valve
(c)Quick Exhaust valve

Direction Control Valves (DCV):

- **Direction control valves (DCVs)** are fundamental components in pneumatic systems, used to control the direction of airflow, thereby determining the movement of actuators like cylinders or motors.
- It is used to direct the flow path of air in pneumatic circuits.
- The valves used to direct the flow of air in pneumatic circuits is termed as Directional Control Valves (DCV).
- Basically DCV consists of body with ports that are connected to flow passages, theses passages, the direction of flow are controlled by movable parts like spool or poppet.
- Apart from directing the flow of air it is also used for allow or block the air flow, to control the speed, sequence of operation.
- They are also used to select between low or high pressure in pneumatic systems.

Functions of Direction Control Valves

1. **Start, stop, or change the direction** of airflow in the system.
2. Regulate the path the compressed air follows to power pneumatic components.
3. Allow or block the exhaust of air for precise motion control.

Classification of DCVs

Direction control valves are classified based on various factors:

1. By Number of Ports (Ways)

- **2/2 Valve:** Two ports, two positions (open/closed); often used as simple on/off switches.
- **3/2 Valve:** Three ports, two positions; common in single-acting cylinders.
- **4/2 Valve:** Four ports, two positions; standard for double-acting cylinders.
- **5/2 Valve:** Five ports, two positions; used in double-acting cylinders with more complex control.
- **5/3 Valve:** Five ports, three positions; adds a mid-position for specialized control like hold or exhaust.

2. By Number of Positions

- **Two-position:** Simple switch between two states.
- **Three-position:** Adds a neutral or intermediate state.

3. By Actuation Method

- **Manual:** Actuated by levers, pushbuttons, or pedals.
- **Mechanical:** Actuated by rollers or cams.
- **Pneumatic:** Actuated by air pressure signals.
- **Electrical (solenoid):** Actuated by electrical signals.
- **Combination:** Multiple actuation modes for redundancy or flexibility.

4. By Type of Construction

- **Spool Valves:** Use a sliding spool to open and close paths; suitable for high flow rates.

- **Poppet Valves:** Use a poppet to seal openings; known for low leakage and fast switching.
- **Rotary Valves:** Use rotating elements to change flow paths; compact but less common.

5. By Mounting Style

- **Inline:** Standalone valves installed directly on the line.
- **Manifold:** Mounted together in a block for compact systems.
- **Sub-base:** Valves mounted on a sub-base for easy replacement or servicing.

Symbols of DCVs in Pneumatics

DCVs are represented in pneumatic circuit diagrams using standard symbols that show:

- Number of ports and positions.
- Flow paths for each position.
- Actuation method (e.g., solenoid, lever).

Ports and position representation:

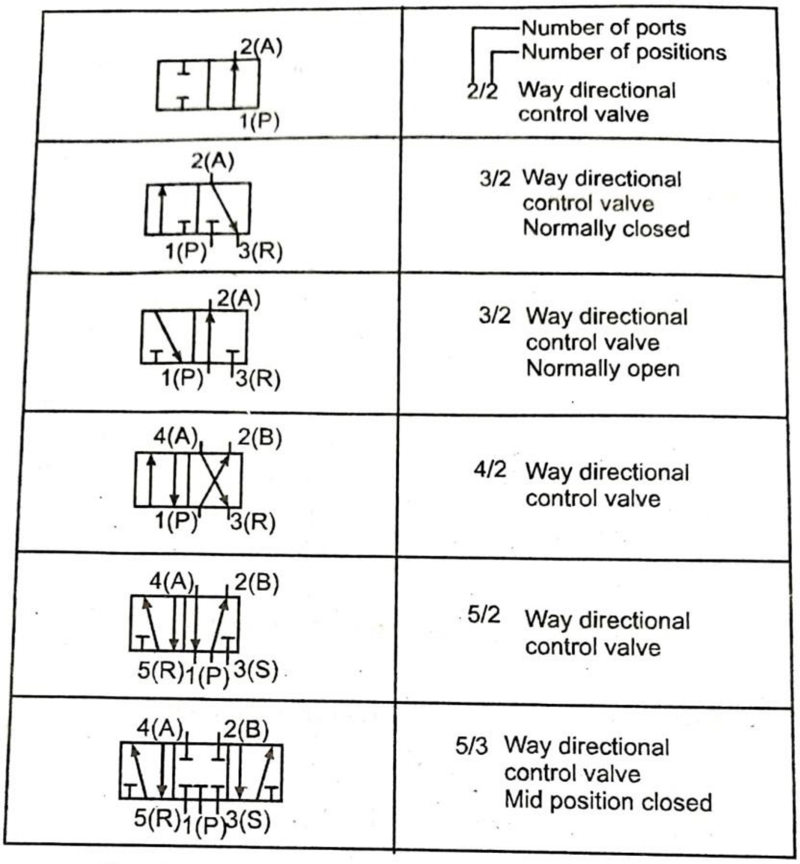
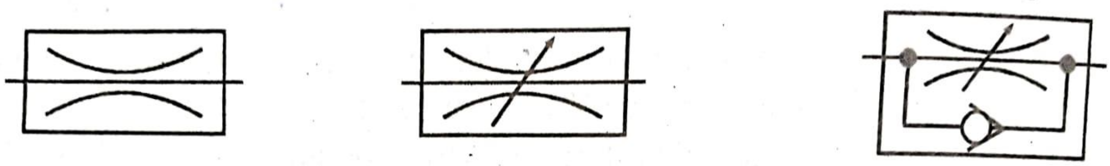


Fig. 10-1. Port and position description of DCV

Flow Control Valve (FCV):

- The flow control valves are used to reduce the flow rate of air in the line and inturn control the speed of the actuator.
- The FCV acts as restriction (similar to orifice) to the flow of air by reducing the area of opening.
- Opening can be varied hence the flow can also be varied.
- Most of FCV is adjustable type, so that flow rate can be manipulated during the operation.
- The FCV is also provided with by-pass check valve so that flow is restricted in one direction only; free flow exists in reverse direction.

Graphical representation of Flow Control Valve:



(a) Fixed area type (b) Adjustable area type (c) One-way (check valve) type

Fig. 10-7. Graphical symbols of FCV

Types of Flow Control Valves:

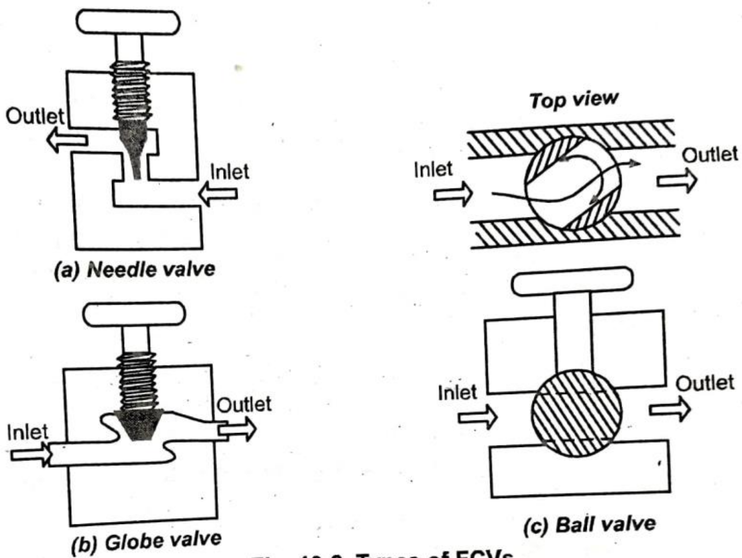


Fig. 10-8. Types of FCVs

Pressure Control Valve:

- The pressure control valve is also termed as pressure regulators, it is essential components of all pneumatic systems.
- It is important to supply the pressure of air in pneumatic systems so that there will be no fluctuations at actuators or electro pneumatic devices.
- The PCV is provided at two locations one is at receiver tank and other is loading circuit.
- The pressure regulators provides safety measures against over pressure build up during the line.
- The main advantage is that it care during pressure drop during air utilization and fluctuations in the flow velocities.
- The pressure regulator maintains the required pressure in the downstream.

Operation:

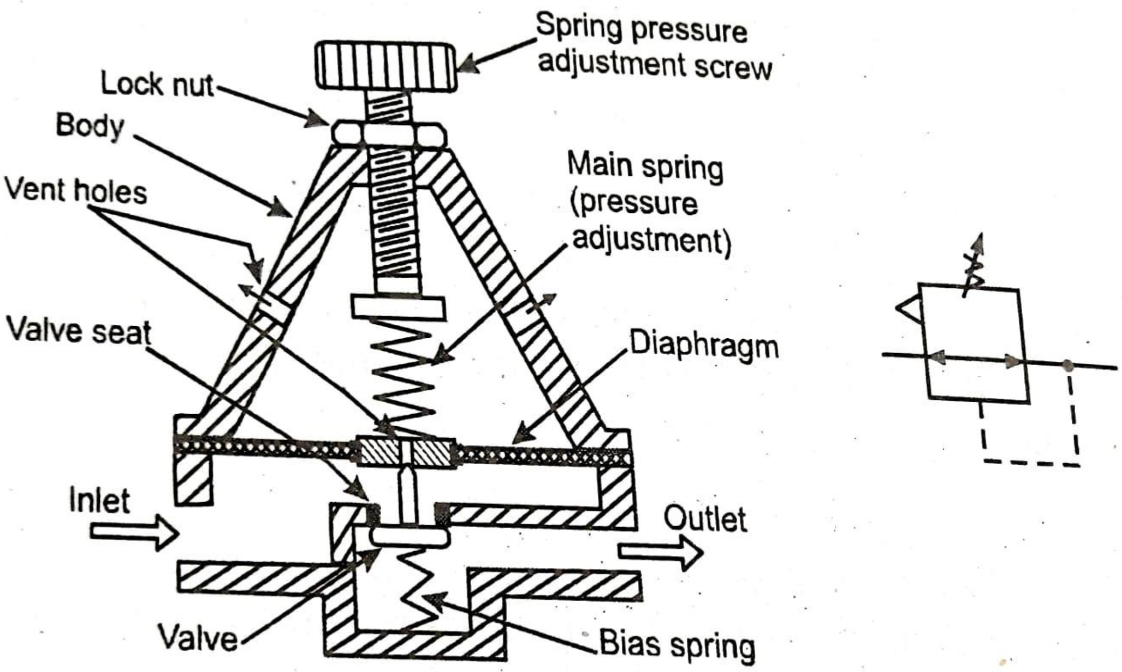


Fig. 10-9. Pressure regulator

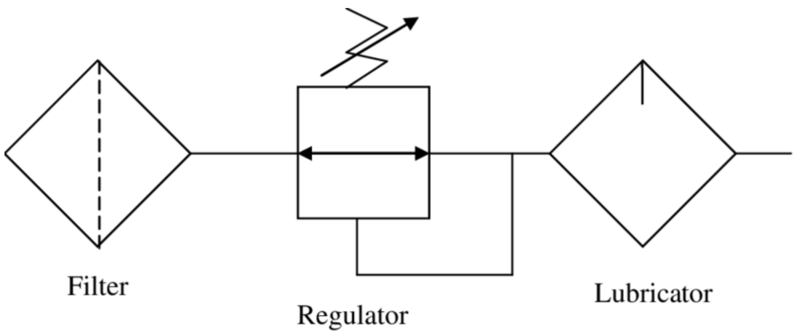
The metal body is also provided with vent holes connecting the downstream area through the vent hole in the diaphragm metal portion. The diaphragm stiffness can be varied and set by the main tension spring. This pressure setting acting on the valve decides the valve opening and the flow.

In operation, the diaphragm area is exposed to the downstream pressure and fluctuates according to the downstream pressure variations. When the compressed air is utilised in the downstream and there is a pressure drop, the diaphragm moves down under spring pressure (due to reduction in pressure acting on its downstream side). As a result, the valve linked to the diaphragm opens more, thus allowing more air flow to the downstream and hence increase the pressure there.

Similarly, whenever there is a pressure build up in the downstream, it acts against the main spring force, leading to the movement of the diaphragm upwards. This results in the complete closure of the valve (under bias spring force). With further deflection in the diaphragm, the valve being fully closed, the vent hole in the diaphragm centre is exposed to the downstream area. As the vent hole at the centre is open, the air from the downstream area flows though it and escapes to the atmosphere though the vent holes in the metal body, thus reducing the pressure in the downstream line. Once the pressure is stabilised, the diaphragm moves down and closes the vent with the valve stem, thereby regulating the pressure.

Filter Regulator Lubricator:

Filter Regulator Lubricator (FRL) consists of three elements - a filter (F) to, generally, remove particles above 40 micron in size and water, a regulator (R), which controls pressure and a lubricator (L), to provide a controlled quantity of oil into the system.

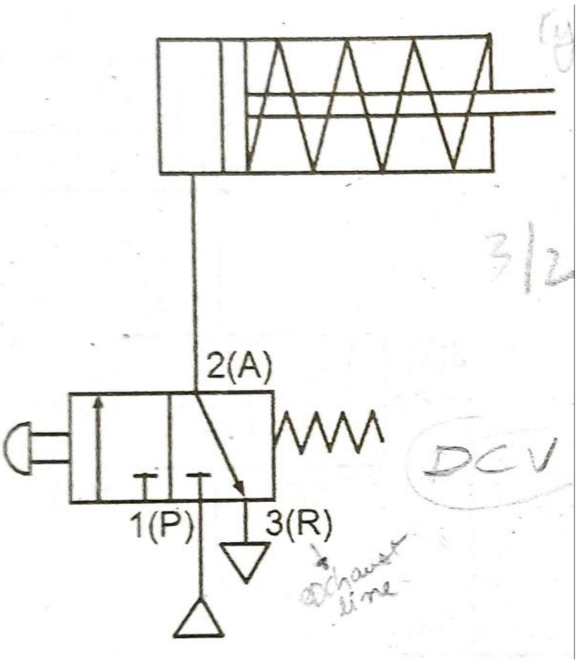


Filter: The filter body has a construction that creates a cyclonic action for the incoming air. The air to be filtered is allowed downward with a swirling motion that forces the moisture and the heavier particles to fall down. The deflector used in the filter mechanically separates the contaminants before they pass through the cartridge filter. The filter cartridge provides a random zig-zag passage for the airflow.

Regulator: The control knob works against a spring which, in turn, places load against a diaphragm assembly. The diaphragm pushes down on a valve pin connected to the valve seat and the seat drops. 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.

Lubricator: A lubricator is designed to introduce a controlled quantity of oil into the downstream air flow. The function of an air lubricator is to add a controlled amount of 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, packings used in air cylinders, etc

Design of Direct actuation of Cylinder:



In a direct actuation cylinder, the cylinder operation is controlled directly by the operation of the DCV. The DCV is directly linked to the cylinder and the DCV in turn is operated by some actuation means like pedal or button. A typical pneumatic circuit involving direct actuation of a cylinder is illustrated in **Fig. 12-1**.

It has a spring returned single-acting cylinder, connected to a 3/2 NC (normally closed) directional control valve. The DCV in its unactuated position, connects the cylinder port to the exhaust so that the cylinder remains in retracted position. Thus, the operation of the DCV directly helps in actuating the cylinder.

In operation, when the 3/2 NC DCV is actuated, high pressure air flows from port 1 (P) to port 2 (A), keeping the exhaust port in blocked condition. Due to this, the cylinder extends. When the DCV is de-actuated (released), the cylinder port 2 (A) is directed to the exhaust line 3 (R), keeping the 1 (P) pressure port in blocked condition. The cylinder retracts under spring pressure.

Design of Indirect actuation of Cylinder:

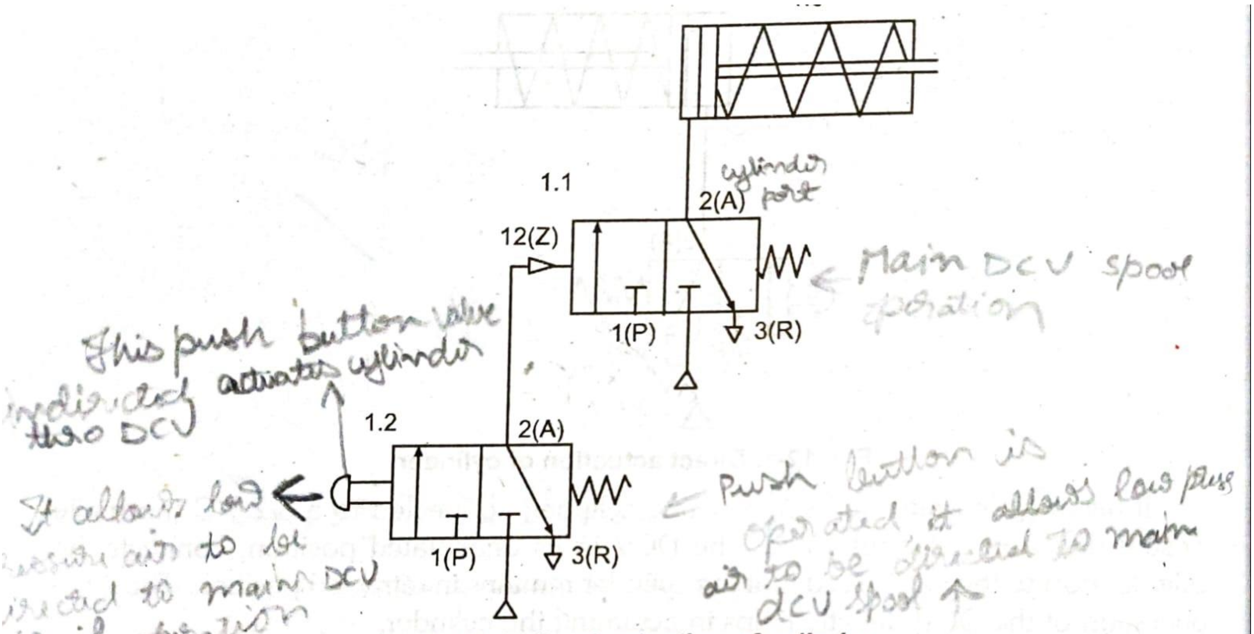


Fig. 12-2. Indirect actuation of cylinder

In this case, the DCV is operated (piloted) by another button operated DCV. The advantage is that small manual force is enough to operate the pilot valve, which in turn actuates a large size DCV; hence a large size cylinder can be actuated. Since the cylinder actuation takes place due to the indirect operation of the DCV it is termed ***indirect actuation***.

A typical pneumatic circuit with the use of two 3/2 valves for the indirect actuation of a single acting cylinder is illustrated in **Fig. 12-2**.

It has a spring-returned single acting cylinder connected through a 3-position 2-way (3/2) pilot operated DCV. This valve in turn is operated (piloted) through a push button 3/2 DCV. This push button valve indirectly actuates the cylinder through the DCV.

In operation, when the 3/2 NC push button valve is operated, it allows a low pressure air to be directed to the main DCV spool operation. When the spool in the valve operates the spool, the high pressure air line 1(P) is connected to the cylinder port 2(A). This causes the extension of the cylinder.

When the push button is released, the pilot valve returns, thus closing the low pressure line and opening the exhaust. Due to this, the spool valve under spring pressure closes the high pressure line and opens up the exhaust port. Because of this, the cylinder retracts under spring pressure.

Principle of Cascade systems:

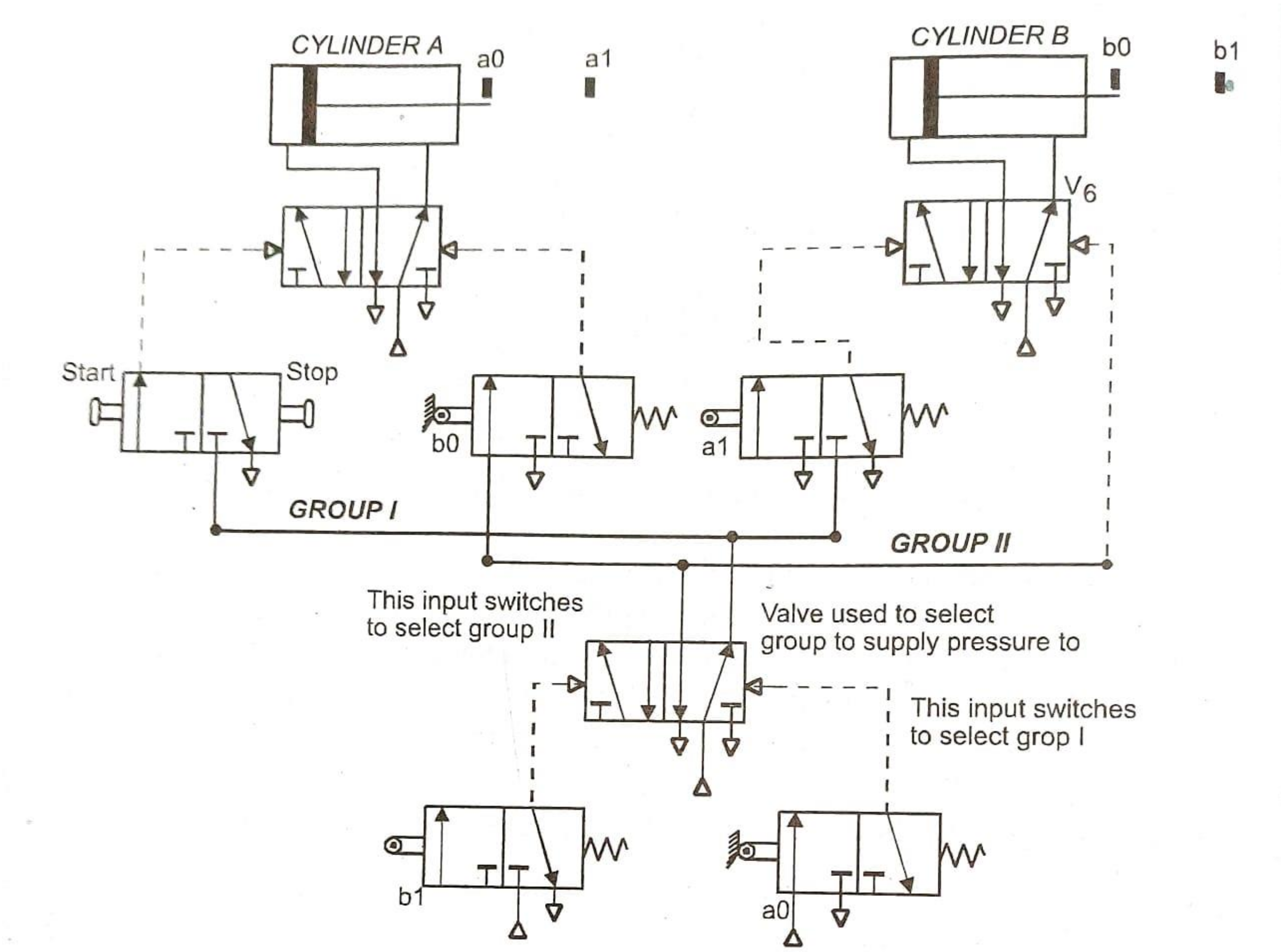


Fig. 13-8. Cascade control action

In the previous sequencing operation, the maintained and trapped signals were eliminated with the use of pulsed signals. Another simple and most effective method to eliminate the maintained and trapped signals is the use of **cascade control action**. In a cascade system, the circuit is divided into different zones (called **groups**) in which the air supply is latched by additional DCV. The principle of a cascade system is as follows:

1. Follow a simple design procedure to determine the minimum number of **groups** in the circuit. To eliminate the **trapped signals**, allocate the signal valves (i.e., limit switches) between these groups.
2. Unlike the previous circuits where a single *supply bus bar* was used to carry the main supply pressure to all components, in a cascade system a separate **supply bus bar** is provided to each group.
3. Provide a conventional arrangement of selector valves to direct the supply only to the active groups.

The main advantages of a cascade system are that it is simple and reliable, uses conventional components, and hence economical.

Advantages of Pneumatic systems:

- Air is available in abundance at all locations.
- Air can be transported from the source to the point of utilization very conveniently through piping layout and there is no limitation of the distances.
- Most components of the air systems are simple, easy handling and compact in designs.
- Compressed air is free from explosions and electrical hazards problems.
- Pneumatic systems are lightweight and compact.
- It is free from fire hazards.
- More power in a smaller and lighter unit compared to most other technology systems.
- It is a cleaner technology.
- Comparatively cheaper in cost.

Disadvantages:

- Power
- Lubrication
- Heat dissipation
- Sealing
- Noise and Condensation.

Applications:

- Pneumatic systems are used in almost every industrial and manufacturing setting, such as: Automotive manufacturing.
- Here, compressed air is used to fill tires.
- Fabrication equipment
- Packing machinery
- Paint spraying equipment
- Filling equipment
- Robotic end of arm tooling.
- Material handling machines
- Presses
- Air-powered tools
- Many other applications in a wide range of industries.

Applications towards Robotics:

- Pneumatics are often used to move a robot arm or for end-of-arm tooling on a robot.
- Using pneumatics for robotics provides many benefits, including lower maintenance and installation costs.
- It can provide the speed and force required of many applications as well, with pick and place being a common application.
- Power caused by the motion and control of gas, such as air, under pressure.
- Pneumatic power systems convert energy from pressurized gas into mechanical motion.
- End effector/Gripper / tools actuations with pneumatics is possible.