

Module 6: Pneumatic Systems

Lecture 1

Pneumatic system

Pneumatic technology deals with the study of behavior and applications of compressed air in our daily life in general and manufacturing automation in particular. Pneumatic systems use air as the medium which is abundantly available and can be exhausted into the atmosphere after completion of the assigned task.

1. Basic Components of Pneumatic System:

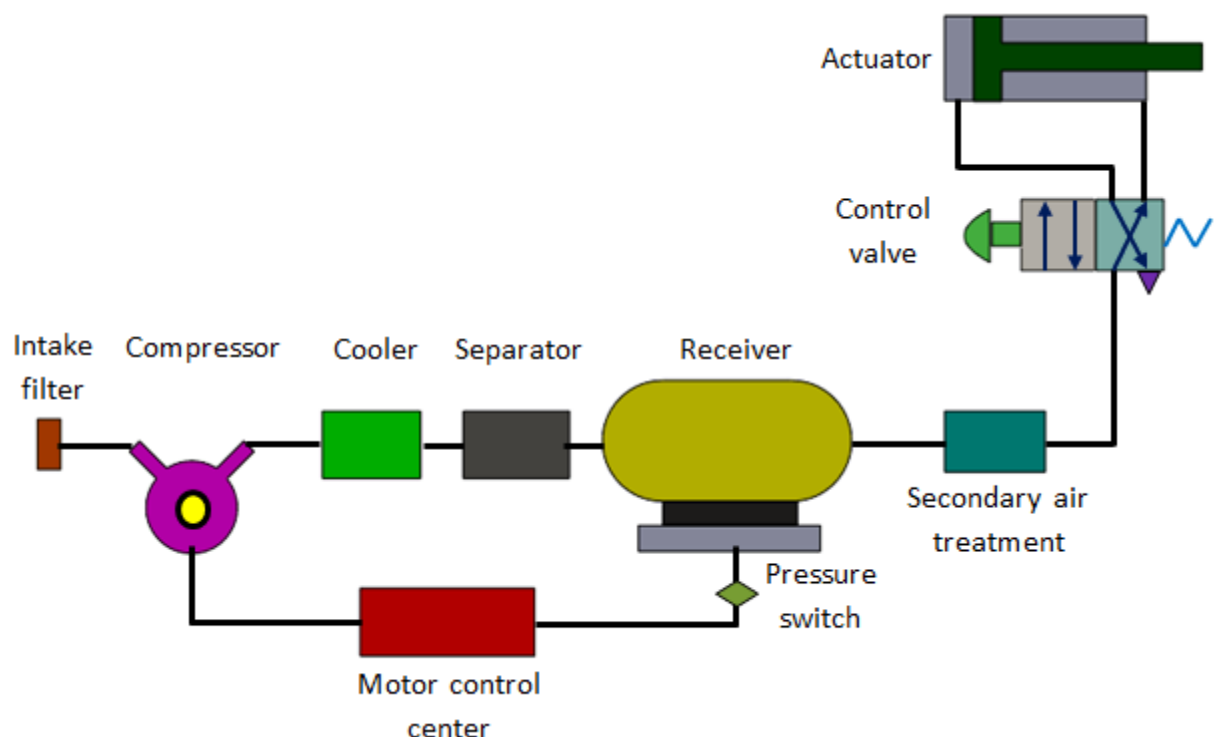


Fig. 6.1.1 Components of a pneumatic system

Important components of a pneumatic system are shown in fig.6.1.1.

- a) **Air filters:** These are used to filter out the contaminants from the air.
- b) **Compressor:** Compressed air is generated by using air compressors. Air compressors are either diesel or electrically operated. Based on the requirement of compressed air, suitable capacity compressors may be used.
- c) **Air cooler:** During compression operation, air temperature increases. Therefore coolers are used to reduce the temperature of the compressed air.
- d) **Dryer:** The water vapor or moisture in the air is separated from the air by using a dryer.
- e) **Control Valves:** Control valves are used to regulate, control and monitor for control of direction flow, pressure etc.
- f) **Air Actuator:** Air cylinders and motors are used to obtain the required movements of mechanical elements of pneumatic system.

- g) **Electric Motor:** Transforms electrical energy into mechanical energy. It is used to drive the compressor.
- h) **Receiver tank:** The compressed air coming from the compressor is stored in the air receiver.

These components of the pneumatic system are explained in detail on the next pages.

2. Receiver tank

The air is compressed slowly in the compressor. But since the pneumatic system needs continuous supply of air, this compressed air has to be stored. The compressed air is stored in an air receiver as shown in Figure 6.1.2. The air receiver smoothens the pulsating flow from the compressor. It also helps the air to cool and condense the moisture present. The air receiver should be large enough to hold all the air delivered by the compressor. The pressure in the receiver is held higher than the system operating pressure to compensate pressure loss in the pipes. Also the large surface area of the receiver helps in dissipating the heat from the compressed air. Generally the size of receiver depends on,

- Delivery volume of compressor.
- Air consumption.
- Pipeline network
- Type and nature of on-off regulation
- Permissible pressure difference in the pipelines

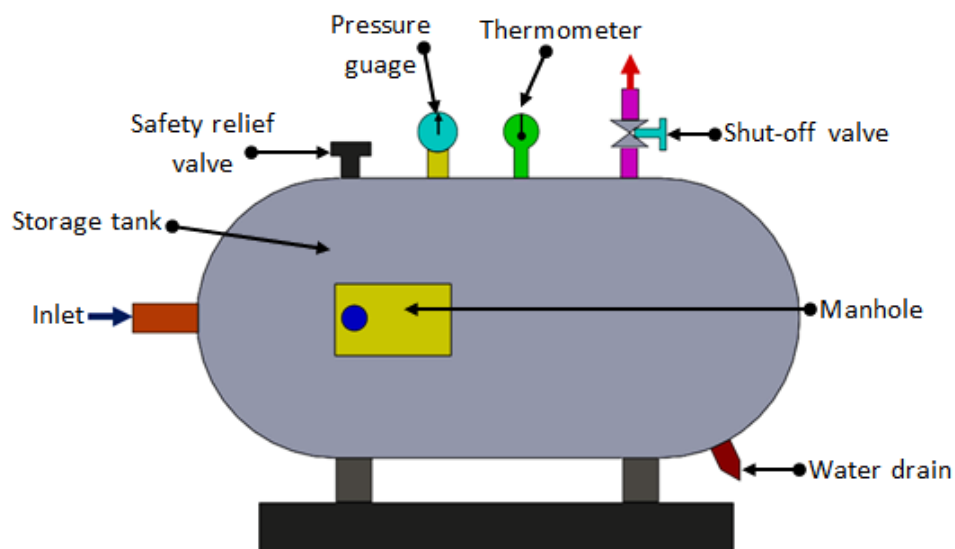


Fig.6.1.2 Air receiver

3. Compressor:

It is a mechanical device which converts mechanical energy into fluid energy. The compressor increases the air pressure by reducing its volume which also increases the temperature of the compressed air. The compressor is selected based on the pressure it needs to operate and the delivery volume.

The compressor can be classified into two main types

- a. Positive displacement compressors and
- b. Dynamic displacement compressor

Positive displacement compressors include piston type, vane type, diaphragm type and screw type.

3.1 Piston compressors

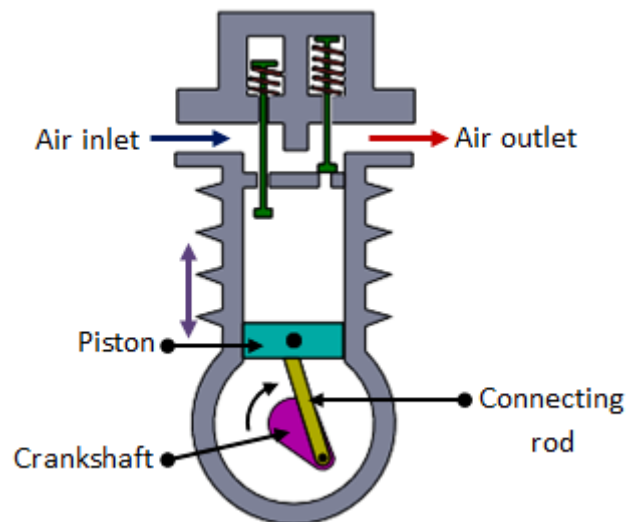


Fig. 6.1.3 Single acting piston compressor

Piston compressors are commonly used in pneumatic systems. The simplest form is single cylinder compressor (Fig. 6.1.3). It produces one pulse of air per piston stroke. As the piston moves down during the inlet stroke the inlet valve opens and air is drawn into the cylinder. As the piston moves up the inlet valve closes and the exhaust valve opens which allows the air to be expelled. The valves are spring loaded. The single cylinder compressor gives significant amount of pressure pulses at the outlet port. The pressure developed is about 3-40 bar.

3.2 Double acting compressor

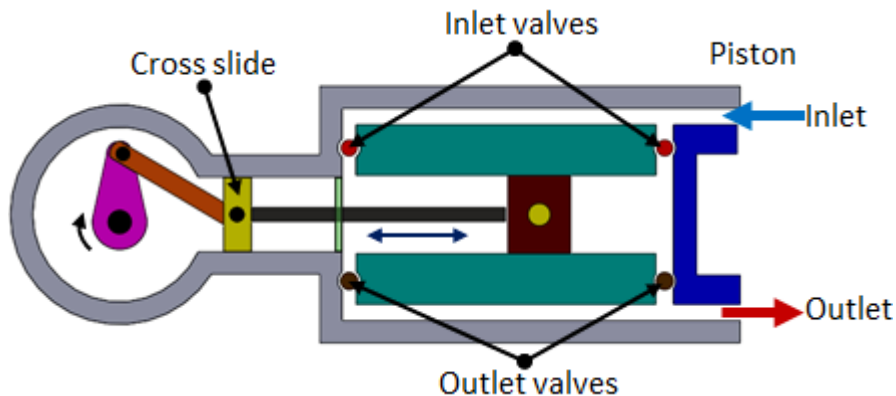


Fig. 6.1.4 Double acting piston compressor

The pulsation of air can be reduced by using double acting compressor as shown in Figure 6.1.4. It has two sets of valves and a crosshead. As the piston moves, the air is compressed on one side whilst on the other side of the piston, the air is sucked in. Due to the reciprocating action of the piston, the air is compressed and delivered twice in one piston stroke. Pressure higher than 30bar can be produced.

3.3 Multistage compressor

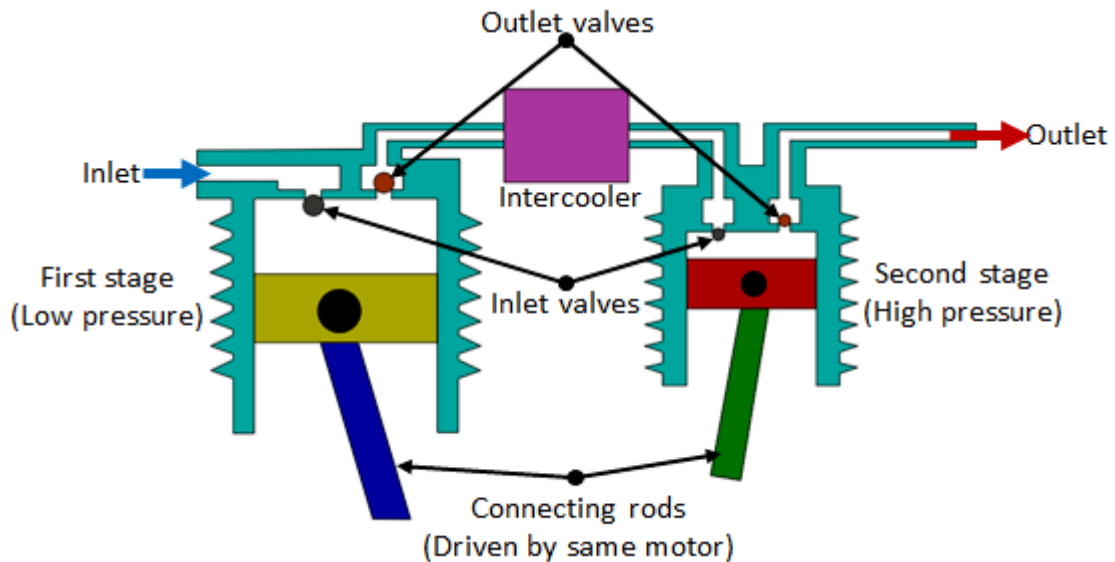


Fig. 6.1.5 Multi-stage compressor

As the pressure of the air increases, its temperature rises. It is essential to reduce the air temperature to avoid damage of compressor and other mechanical elements. The multistage compressor with intercooler in-between is shown in Figure 6.1.5. It is used to reduce the temperature of compressed air during the compression stages. The intercooling reduces the volume of air which used to increase due to heat. The compressed air from the first stage enters the intercooler where it is cooled. This air is given as input to the second stage where it is compressed again. The multistage compressor can develop a pressure of around 50bar.

3.4 Combined two stage compressors

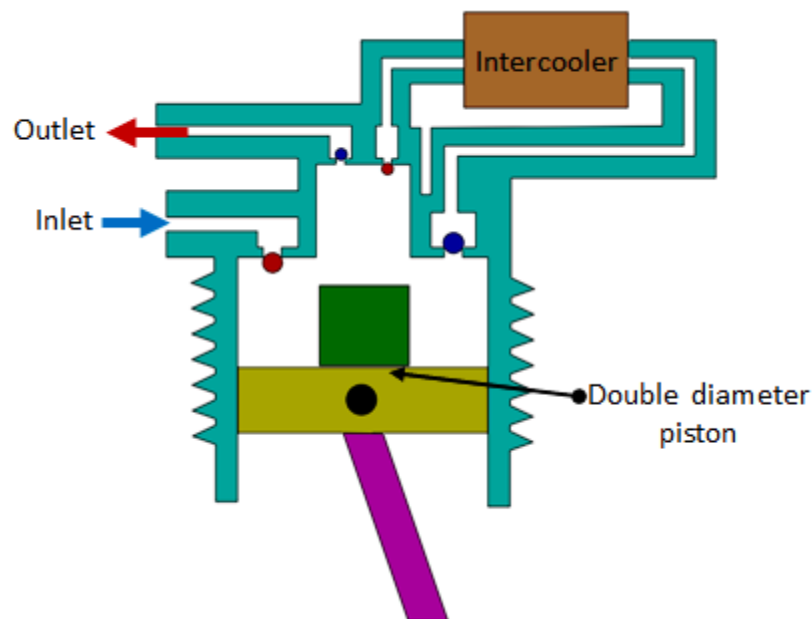


Fig. 6.1.6 Combined two stage compressor

In this type, two-stage compression is carried out by using the same piston (Fig. 6.1.6). Initially when the piston moves down, air is sucked in through the inlet valve. During the compression process, the air moves out of the exhaust valve into the intercooler. As the piston moves further the stepped head provided on the piston moves into the cavity thus causing the compression of air. Then, this is let out by the exhaust port.

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Lecture 2

Compressors

1. Diaphragm compressor

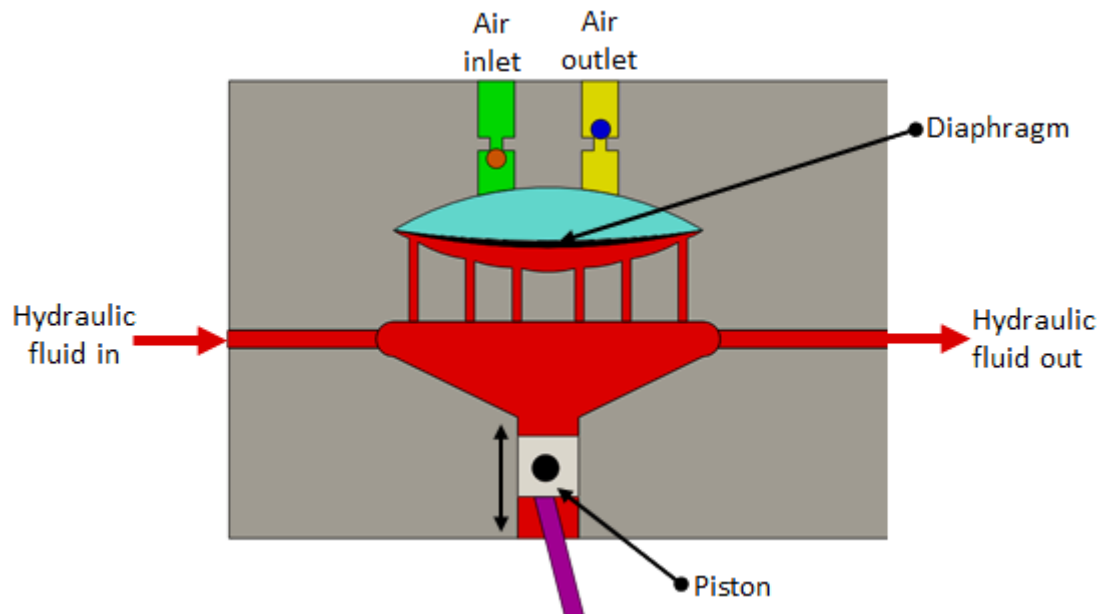


Fig. 6.2.1 Diaphragm compressor

These are small capacity compressors. In piston compressors the lubricating oil from the pistons walls may contaminate the compressed air. The contamination is undesirable in food, pharmaceutical and chemical industries. For such applications diaphragm type compressor can be used. Figure 6.2.1 shows the construction of Diaphragm compressor. The piston reciprocates by a motor driven crankshaft. As the piston moves down it pulls the hydraulic fluid down causing the diaphragm to move along and the air is sucked in. When the piston moves up the fluid pushes the diaphragm up causing the ejection of air from the outlet port. Since the flexible diaphragm is placed in between the piston and the air no contamination takes place.

2. Screw compressor

Piston compressors are used when high pressures and relatively low volume of air is needed. The system is complex as it has many moving parts. For medium flow and pressure applications, screw compressor can be used. It is simple in construction with less number of moving parts. The air delivered is steady with no pressure pulsation. It has two meshing screws. The air from the inlet is trapped between the meshing screws and is compressed. The contact between the two meshing surface is minimum, hence no cooling is required. These systems are quite in operation compared to piston type. The screws are synchronized by using external timing gears.

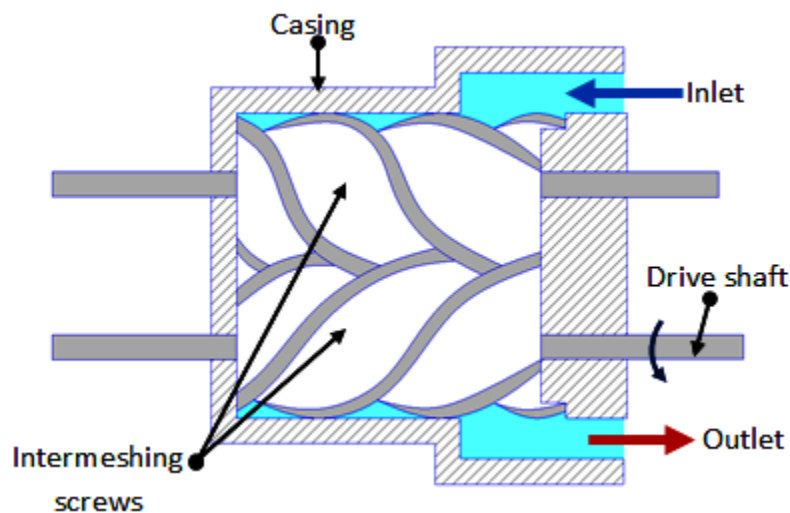


Fig. 6.2.2 Screw compressor

3. Rotary vane compressors

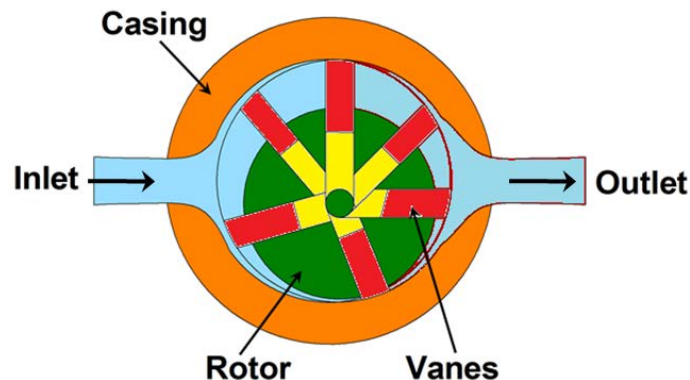


Fig. 6.2.3 Rotary vane compressor

The principle of operation of vane compressor is similar to the hydraulic vane pump. Figure 6.2.3 shows the working principle of Rotary vane compressor. The unbalanced vane compressor consists of spring loaded vanes seating in the slots of the rotor. The pumping action occurs due to movement of the vanes along a cam ring. The rotor is eccentric to the cam ring. As the rotor rotates, the vanes follow the inner surface of the cam ring. The space between the vanes decreases near the outlet due to the eccentricity. This causes compression of the air. These compressors are free from pulsation. If the eccentricity is zero no flow takes place.

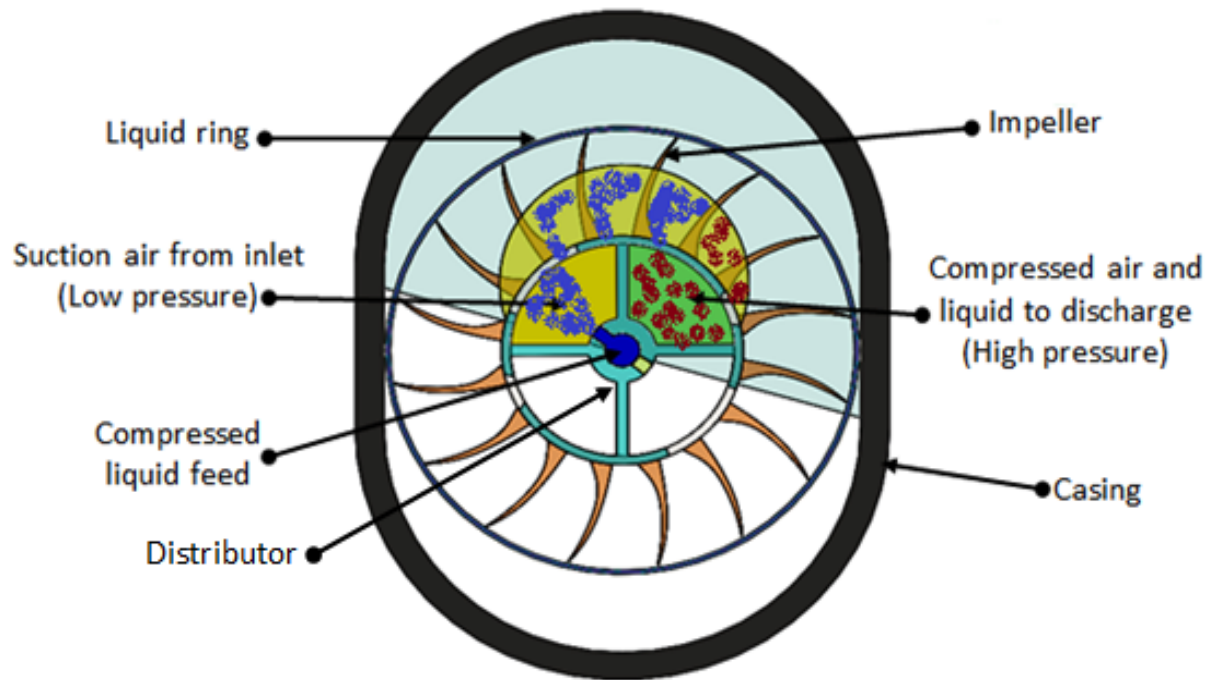


Fig. 6.2.4 Liquid ring compressor

Liquid ring vane compressor is a variation of vane compressors. Figure 6.2.4 shows the construction of Liquid ring compressor. The casing is filled with liquid up to rotor center. The air enters the compressor through the distributor fixed to the compressor. During the impeller rotation, the liquid will be centrifuged along the inner ring of the casing to form the liquid ring. There are two suction and discharge ports provided in the distributor. During the first quarter of cycle, the air is sucked in both suction chambers of the casing and during the second quarter of the cycle, the air is compressed and pushed out through the two discharge ports. During the third and fourth quarters of the cycle, the process is repeated. This type of compressor has no leakage and has minimal friction. For smooth operation, the rotation speed should be about 3000 rpm. The delivery pressure is low (about 5 bar).

4. *Lobe compressor*

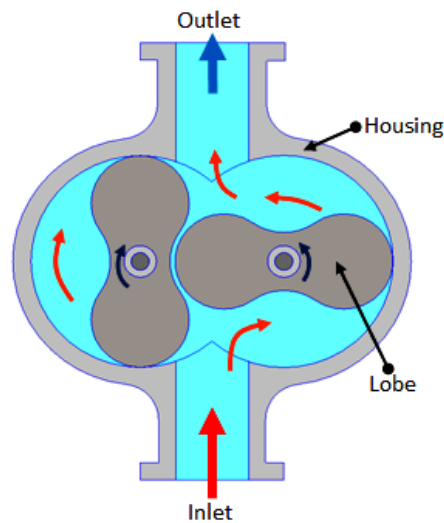


Fig. 6.2.5 Lobe compressor

The lobe compressor is used when high delivery volume but low pressure is needed. It consists of two lobes with one being driven and the other driving. Figure 6.2.5 shows the construction and working of Lobe compressor. It is similar to the Lobe pump used in hydraulic systems. The operating pressure is limited by leakage between rotors and housing. As the wear increases during the operation, the efficiency falls rapidly.

5. *Dynamic compressors*

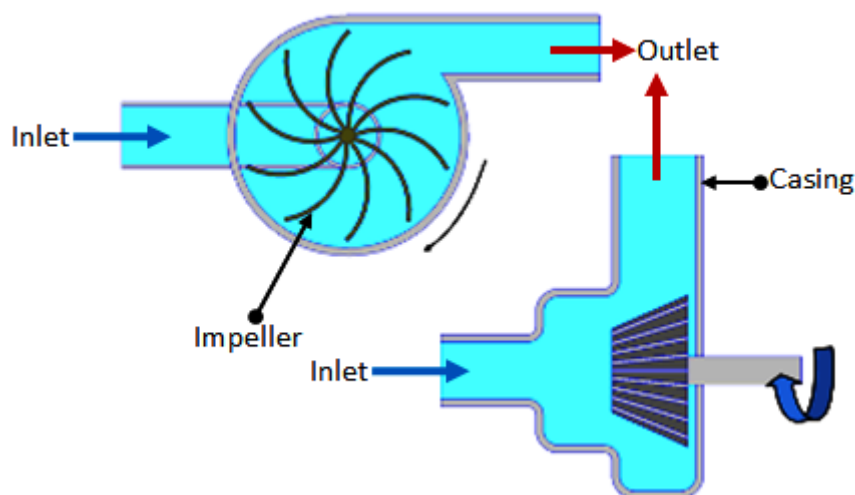


Fig. 6.2.6 Blower (Centrifugal type)

When very large volume of compressed air is required in applications such as ventilators, combustion system and pneumatic powder blower conveyors, the dynamic compressor can be used. The pressure needed is very low in such applications. Figure 6.2.6 shows a typical Centrifugal type blower. The impeller rotates at a high speed. Large volume of low pressure air can be provided by blowers. The blowers draw the air in and the impeller flings it out due to centrifugal force. Positive displacement

compressors need oil to lubricate the moving parts, whereas the dynamic compressors have no such need. The efficiency of these compressors is better than that of reciprocating types.

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Lecture 3

Air Treatment and Pressure Regulation

1. Air treatment stages

For satisfactory operation of the pneumatic system the compressed air needs to be cleaned and dried. Atmospheric air is contaminated with dust, smoke and is humid. These particles can cause wear of the system components and presence of moisture may cause corrosion. Hence it is essential to treat the air to get rid of these impurities. The air treatment can be divided into three stages as shown in Figure 6.3.1.

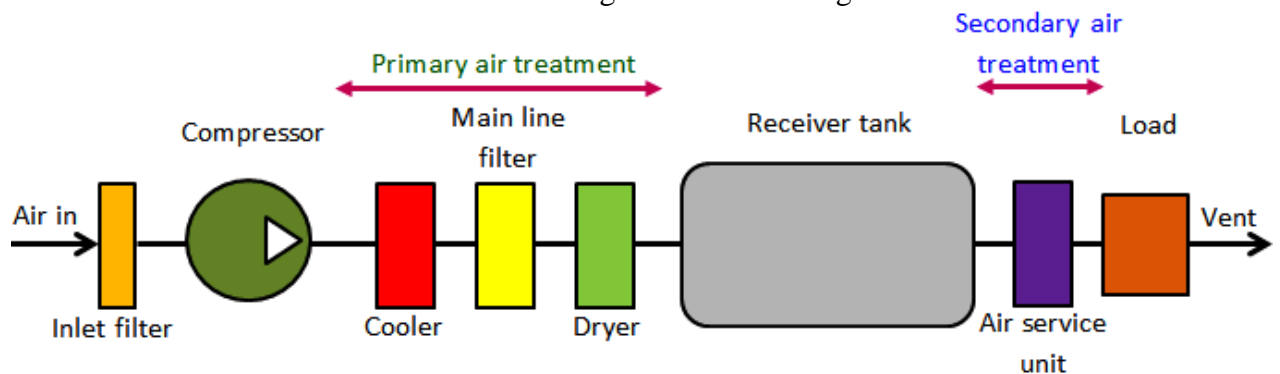


Fig. 6.3.1 Stages of air treatment

In the first stage, the large sized particles are prevented from entering the compressor by an intake filter. The air leaving the compressor may be humid and may be at high temperature. The air from the compressor is treated in the second stage. In this stage temperature of the compressed air is lowered using a cooler and the air is dried using a dryer. Also an inline filter is provided to remove any contaminant particles present. This treatment is called primary air treatment. In the third stage which is the secondary air treatment process, further filtering is carried out. A lubricator introduces a fine mist of oil into the compressed air. This will help in lubrication of the moving components of the system to which the compressed air will be applied.

1.1 Filters

To prevent any damage to the compressor, the contaminants present in the air need to be filtered out. This is done by using inlet filters. These can be dry or wet filters. Dry filters use disposable cartridges. In the wet filter, the incoming air is passed through an oil bath and then through a fine wire mesh filter. Dirt particles cling to the oil drops during bubbling and are removed by wire mesh as they pass through it. In the dry filter the cartridges are replaced during servicing. The wet filters are cleaned using detergent solution.

1.2 Cooler

As the air is compressed, the temperature of the air increases. Therefore the air needs to be cooled. This is done by using a cooler. It is a type of heat exchanger. There are two types of coolers commonly employed viz. air cooled and water cooled. In the air cooled type, ambient air is used to cool the high temperature compressed air, whereas in the water cooled type, water is used as cooling medium. These are counter flow type coolers where the cooling medium flows in the direction opposite to the compressed air. During cooling, the water vapor present will condense which can be drained away later.

2. Main line filter

These filters are used to remove the water vapors or solid contaminants present in the pneumatic systems main lines. These filters are discussed in detail as follows.

2.1 Air filter and water trap

Air filter and water trap is used to

- prevent any solid contaminants from entering in the system.
- condense and remove water vapor that is present in the compressed air.

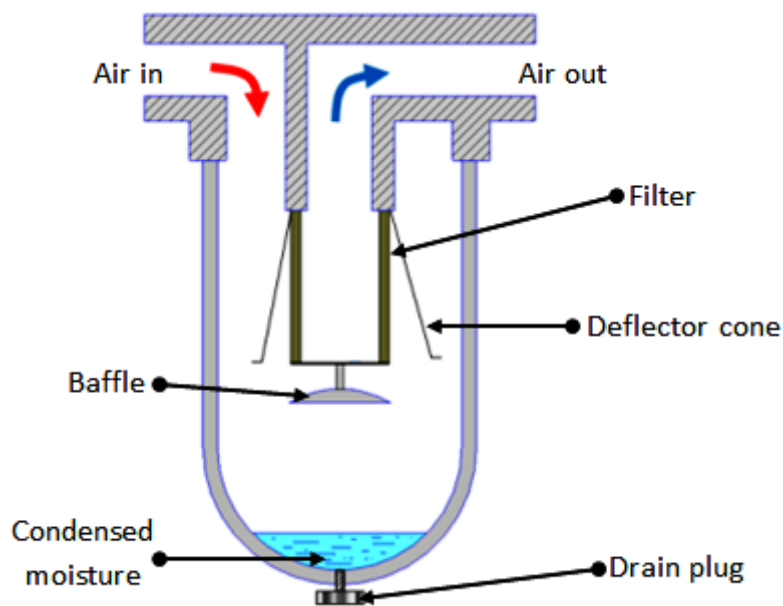


Fig. 6.3.2 Air filter and water trap

The filter cartridge is made of sintered brass. The schematic of the filter is shown in Fig. 6.3.2. The thickness of sintered cartridge provides random zigzag passage for the air to flow-in which helps in arresting the solid particles. The air entering the filter swirls around due to the deflector cone. The centrifugal action causes the large contaminants and water vapor to be flung out, which hit the glass bowl and get collected at the bottom. A baffle plate is provided to prevent the turbulent air from splashing the water into the filter cartridge. At the bottom of the filter bowl there is a drain plug which can be opened manually to drain off the settled water and solid particles.

2.2 Refrigerated dryers

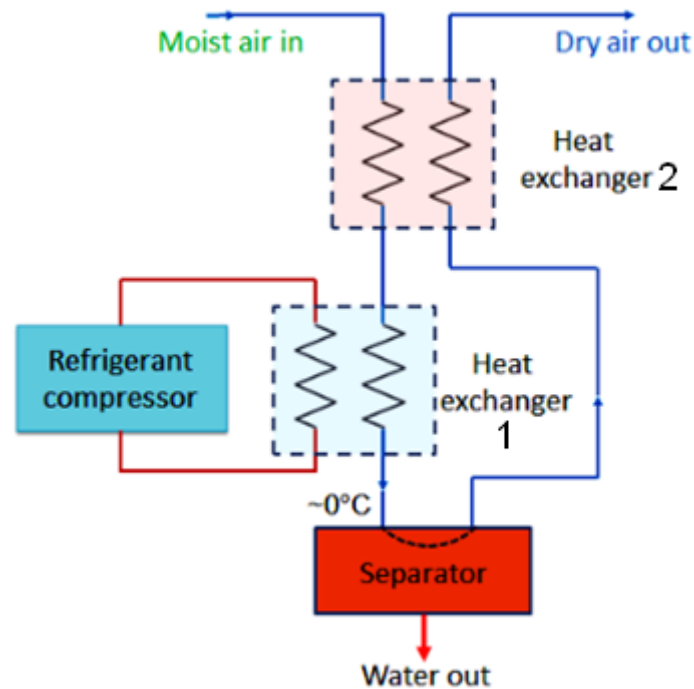


Fig. 6.3.3 Refrigerated dryers

It consists of two heat exchangers, refrigerant compressor and a separator. The system circuitry is shown in Figure 6.3.3. The dryer chills the air just above 0 °C which condenses the water vapor. The condensate is collected by the separator. However such low temperature air may not be needed at the application. Therefore this chilled air is used to cool the high temperature air coming out from the compressor at heat exchanger 2. The moderate temperature dry air coming out from the heat exchanger 2 is then used for actual application; whilst the reduced temperature air from compressor will further be cooled at heat exchanger 1. Thus, the efficiency of the system is increased by employing a second heat exchanger.

2.3 Chemical dryers

When absolute dry air is needed chemical dryers are used. These dryers are of two types viz. adsorption dryer and absorption dryer.

2.3.1 Adsorption dryers

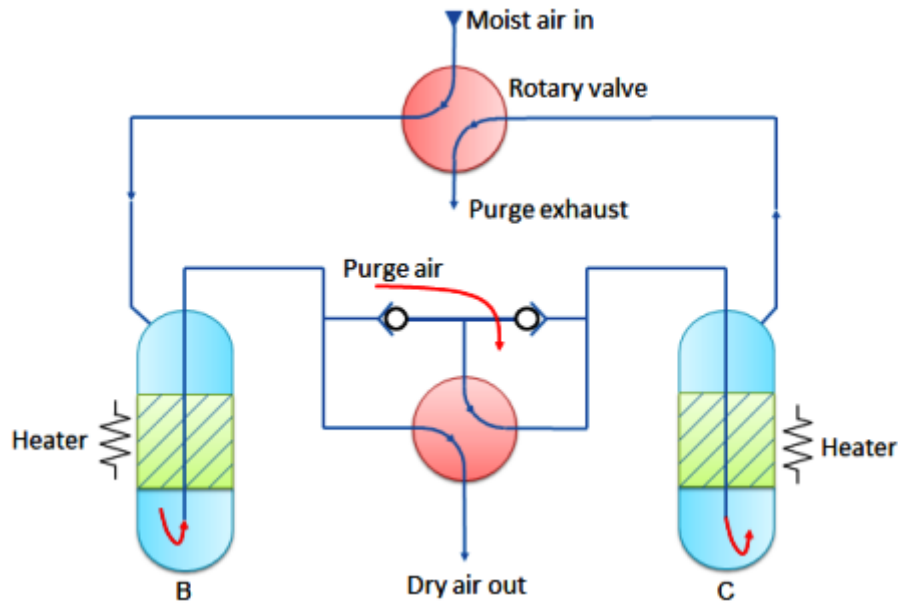


Fig. 6.3.4 Adsorption dryer

In Adsorption dryers, the moisture collects on the sharp edges of the granular material. The adsorbing materials can be silicon dioxide (silica gel) or other materials which exist in hydrated and dehydrated state (copper sulphate, activated alumina). Moisture from the adsorbing material can be released by heating in the column as shown in Fig. 6.3.4. At a given time, one column will dry the air while the other column will regenerate the adsorption material by heating and passing low purge air. The column B dries the air and column C regenerates. The rotary valves are opened using time clock at regular interval to reverse the process. These dryers are also called regenerative dryers.

2.3.2 Absorption dryers

These are also called as deliquescent dryers. Figure 6.3.5 shows a schematic of the same. It uses chemical agents like phosphoric pentoxide or calcium chloride as drying agents. The moisture in the compressed air chemically reacts with the drying agent. The agent dissolves to form a liquid compound which collects at the bottom of the dryer where it can be drained out. The deliquescent agent has to be replenished regularly as it gets consumed during the drying process.

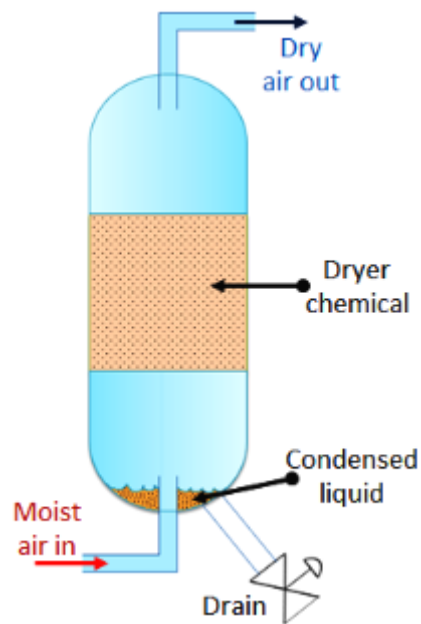


Fig. 6.3.5 Absorption dryer

3. Lubricators

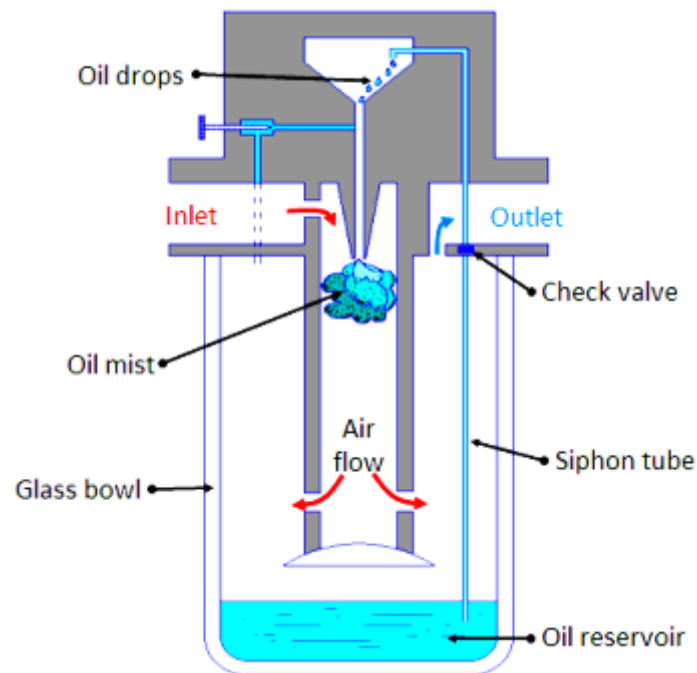


Fig. 6.3.6 Air lubricator

The compressed air is first filtered and then passed through a lubricator in order to form a mist of oil and air to provide lubrication to the mating components. Figure 6.3.6 shows the schematic of a typical lubricator. The principle of working of venturimeter is followed in the operation of lubricator. The compressed air from the dryer enters in the lubricator. Its velocity increases due to a pressure differential between the upper and lower chamber (oil reservoir). Due to the low pressure in the upper chamber the oil is pushed into the upper chamber from the oil reservoir through a siphon tube with check valve. The main function of the valve is to control the amount of oil passing through it. The oil drops inside the throttled zone where the velocity of air is much higher and this high velocity air breaks the oil drops into tiny particles. Thus a mist of air and oil is generated. The pressure differential across chambers is adjusted by a needle valve. It is difficult to hold an oil mixed air in the air receiver as oil may settle down. Thus air is lubricated during secondary air treatment process. Low viscosity oil forms better mist than high viscosity oil and hence ensures that oil is always present in the air.

4. Pressure regulation

In pneumatic systems, during high velocity compressed air flow, there is flow-dependent pressure drop between the receiver and load (application). Therefore the pressure in the receiver is always kept higher than the system pressure. At the application site, the pressure is regulated to keep it constant. There are three ways to control the local pressure, these are shown in Figure 6.3.7.

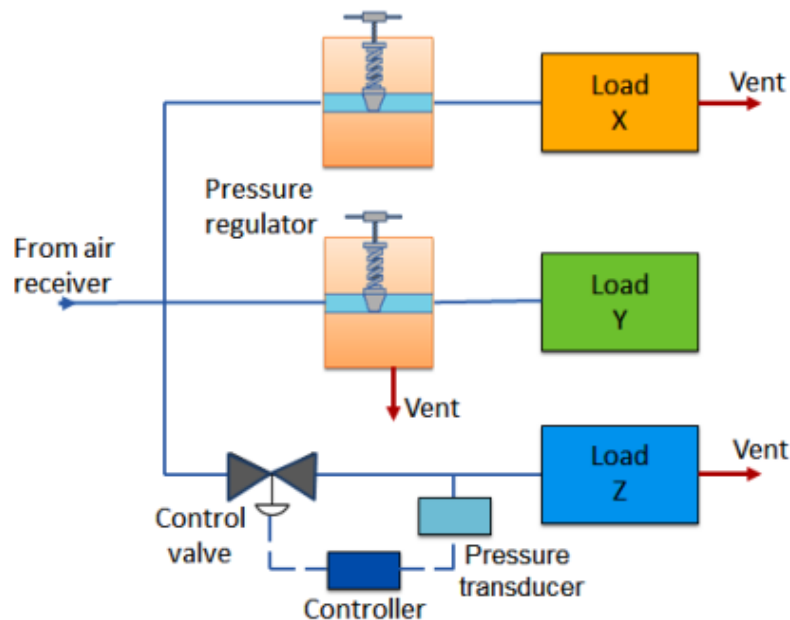


Fig. 6.3.7 Types of pressure regulation

- In the first method, load X vents the air into atmosphere continuously. The pressure regulator restricts the air flow to the load, thus controlling the air pressure. In this type of pressure regulation, some minimum flow is required to operate the regulator. If the load is a dead end type which draws no air, the pressure in the receiver will rise to the manifold pressure. These type of regulators are called as ‘non-relieving regulators’, since the air must pass through the load.
- In the second type, load Y is a dead end load. However the regulator vents the air into atmosphere to reduce the pressure. This type of regulator is called as ‘relieving regulator’.
- The third type of regulator has a very large load Z. Therefore its requirement of air volume is very high and can’t be fulfilled by using a simple regulator. In such cases, a control loop comprising of pressure transducer, controller and vent valve is used. Due to large load the system pressure may rise above its critical value. It is detected by a transducer. Then the signal will be processed by the controller which will direct the valve to be opened to vent out the air. This technique can be also be used when it is difficult to mount the pressure regulating valve close to the point where pressure regulation is needed.

5. Relief valve

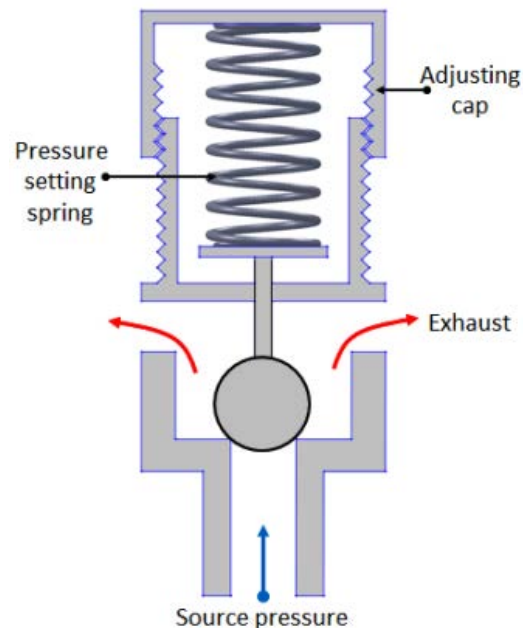


Fig. 6.3.8 Relief valve

Relief valve is the simplest type of pressure regulating device. The schematic of its construction and working is shown in the Figure 6.3.8. It is used as a backup device if the main pressure control fails. It consists of ball type valve held on to the valve seat by a spring in tension. The spring tension can be adjusted by using the adjusting cap. When the air pressure exceeds the spring tension pressure the ball is displaced from its seat, thus releasing the air and reducing the pressure. A relief is specified by its span of pressure between the cracking and full flow, pressure range and flow rate. Once the valve opens (cracking pressure), flow rate depends on the excess pressure. Once the pressure falls below the cracking pressure, the valve seals itself.

6. *Non-relieving pressure regulator*

In a non-relieving pressure regulator (Fig. 6.3.9) the outlet pressure is sensed by a diaphragm which is preloaded by a pressure setting spring. If outlet pressure is too low, the spring forces the diaphragm and poppet to move down thus opening the valve to admit more air and raise outlet pressure. If the outlet pressure is too high the air pressure forces the diaphragm up hence reduces the air flow and causing a reduction in air pressure. The air vents away through the load. At steady state condition the valve will balance the force on the diaphragm from the outlet pressure with the preset force on the spring.

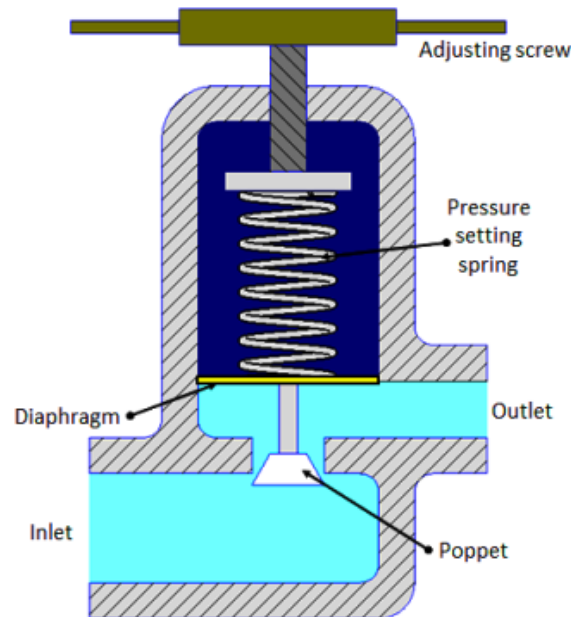


Fig. 6.3.9 Non-relieving type pressure regulator

7. Service units

During the preparation of compressed air, various processes such as filtration, regulation and lubrication are carried out by individual components. The individual components are: separator/filter, pressure regulator and lubricator.

Preparatory functions can be combined into one unit which is called as ‘service unit’. Figure 6.3.10 shows symbolic representation of various processes involved in air preparation and the service unit.

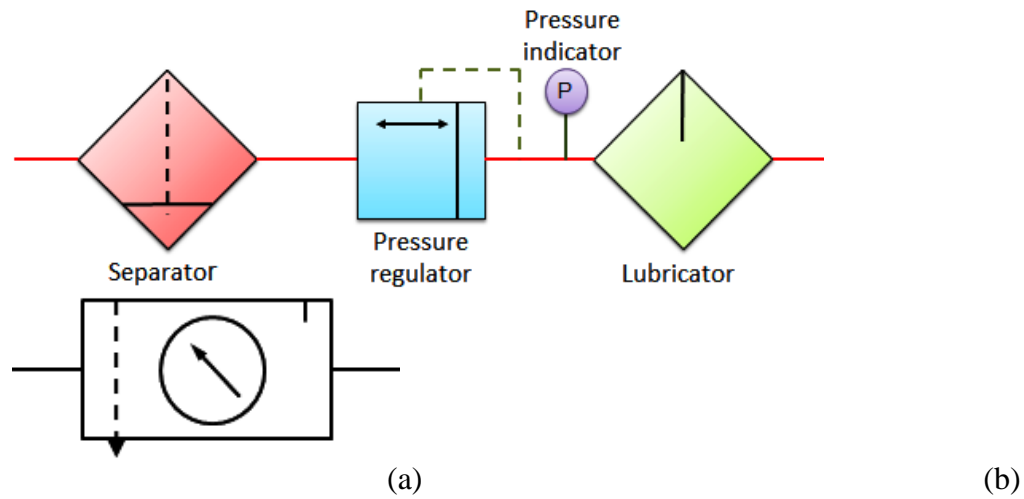


Fig. 6.3.10 (a) Service unit components (b) Service unit symbol

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Lecture 4 Actuators

Actuators are output devices which convert energy from pressurized hydraulic oil or compressed air into the required type of action or motion. In general, hydraulic or pneumatic systems are used for gripping and/or moving operations in industry. These operations are carried out by using actuators.

Actuators can be classified into three types.

1. Linear actuators: These devices convert hydraulic/pneumatic energy into linear motion.
2. Rotary actuators: These devices convert hydraulic/pneumatic energy into rotary motion.
3. Actuators to operate flow control valves: these are used to control the flow and pressure of fluids such as gases, steam or liquid.

The construction of hydraulic and pneumatic linear actuators is similar. However they differ at their operating pressure ranges. Typical pressure of hydraulic cylinders is about 100 bar and of pneumatic system is around 10 bar.

1. Single acting cylinder

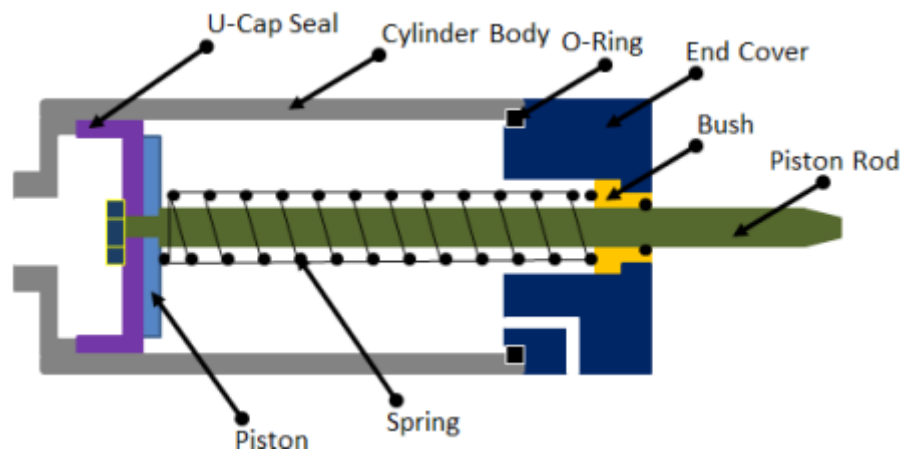


Fig. 6.4.1 Single acting cylinder

These cylinders produce work in one direction of motion hence they are named as single acting cylinders. Figure 6.4.1 shows the construction of a single acting cylinder. The compressed air pushes the piston located in the cylindrical barrel causing the desired motion. The return stroke takes place by the action of a spring. Generally the spring is provided on the rod side of the cylinder.

2. Double acting cylinder

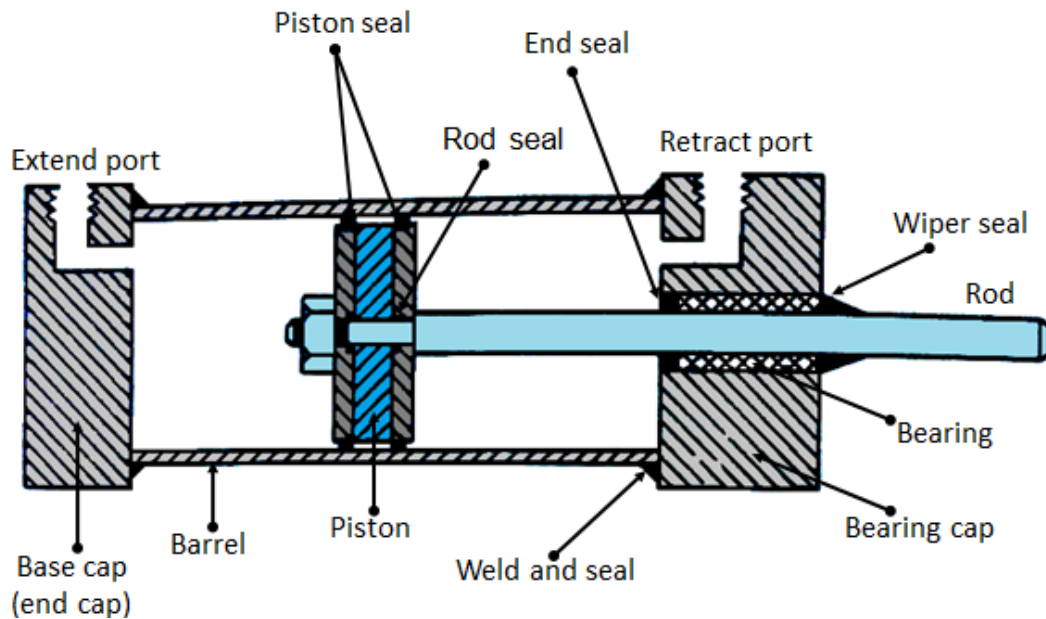


Fig. 6.4.2 Double acting cylinder

The main parts of a hydraulic double acting cylinder are: piston, piston rod, cylinder tube, and end caps. These are shown in Figure 6.4.2. The piston rod is connected to piston head and the other end extends out of the cylinder. The piston divides the cylinder into two chambers namely the rod end side and piston end side. The seals prevent the leakage of oil between these two chambers. The cylindrical tube is fitted with end caps. The pressurized oil, air enters the cylinder chamber through the ports provided. In the rod end cover plate, a wiper seal is provided to prevent the leakage of oil and entry of the contaminants into the cylinder. The combination of wiper seal, bearing and sealing ring is called as cartridge assembly. The end caps may be attached to the tube by threaded connection, welded connection or tie rod connection. The piston seal prevents metal to metal contact and wear of piston head and the tube. These seals are replaceable. End cushioning is also provided to prevent the impact with end caps.

3. Cylinder end cushions

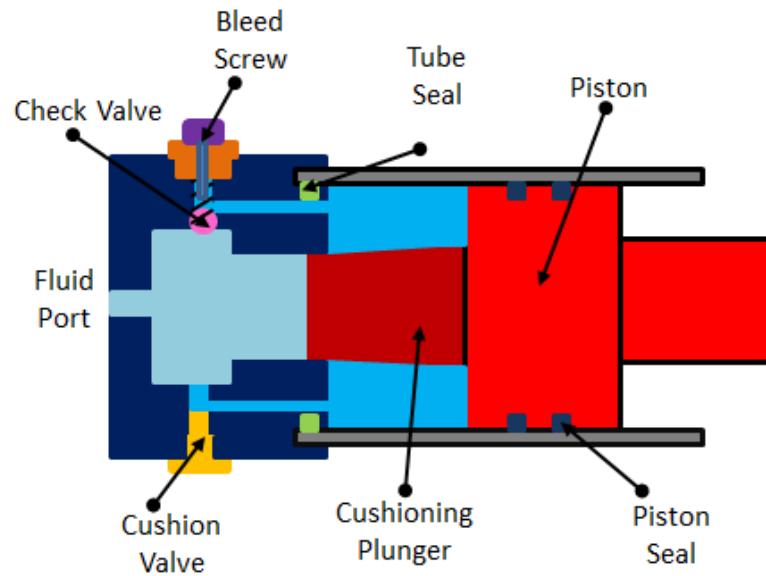


Fig. 6.4.3 Cylinder end cushioning

Double acting cylinders generally contain cylinder cushions at the end of the cylinder to slow down the movement of the piston near the end of the stroke. Figure 6.4.3 shows the construction of actuating cylinder with end cushions. Cushioning arrangement avoids the damage due to the impact occurred when a fast moving piston is stopped by the end caps. Deceleration of the piston starts when the tapered plunger enters the opening in the cap and closes the main fluid exit. This restricts the exhaust flow from the barrel to the port. This throttling causes the initial speed reduction. During the last portion of the stroke the oil has to exhaust through an adjustable opening since main fluid exit closes. Thus the remaining fluid exits through the cushioning valve. Amount of cushioning can be adjusted by means of cushion screw. A check valve is provided to achieve fast break away from the end position during retraction motion. A bleed screw is built into the check valve to remove the air bubbles present in a hydraulic type system.

4. Gear motor: a rotary actuator

Rotary actuators convert energy of pressurized fluid into rotary motion. Rotary actuators are similar to electric motors but are run on hydraulic or pneumatic power.

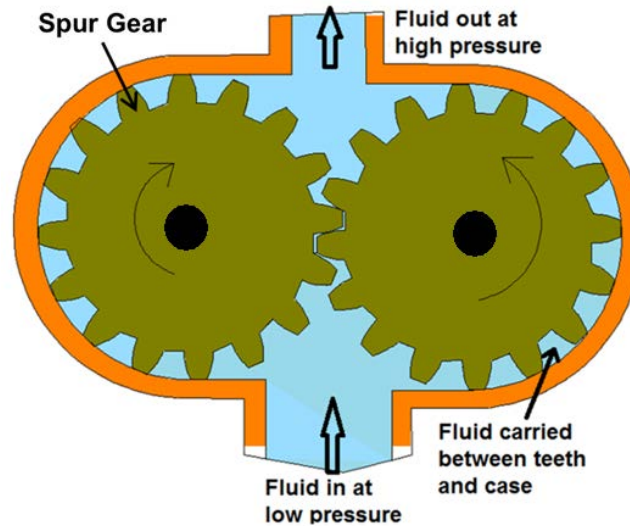


Fig. 6.4.4 Gear motor

It consists of two inter meshing gears inside a housing with one gear attached to the drive shaft. Figure 6.4.4 shows a schematic diagram of Gear motor. The air enters from the inlet, causes the rotation of the meshing gear due to difference in the pressure and produces the torque. The air exits from the exhaust port. Gear motors tend to leak at low speed, hence are generally used for medium speed applications.

5. Vane motor: a rotary actuator

A rotary vane motor consists of a rotor with sliding vanes in the slots provided on the rotor (Fig. 6.4.5). The rotor is placed eccentrically with the housing. Air enters from the inlet port, rotates the rotor and thus torque is produced. Air is then released from the exhaust port (outlet).

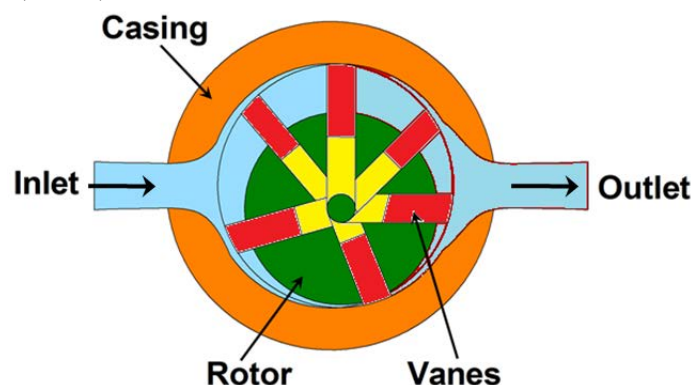


Fig. 6.4.5 Vane motor

6. *Limited rotation actuators*

It consists of a single rotating vane connected to output shaft as shown in Figure 6.4.6. It is used for double acting operation and has a maximum angle of rotation of about 270° . These are generally used to actuate dampers in robotics and material handling applications. Other type of limited rotation actuator is a rack and pinion type actuator.

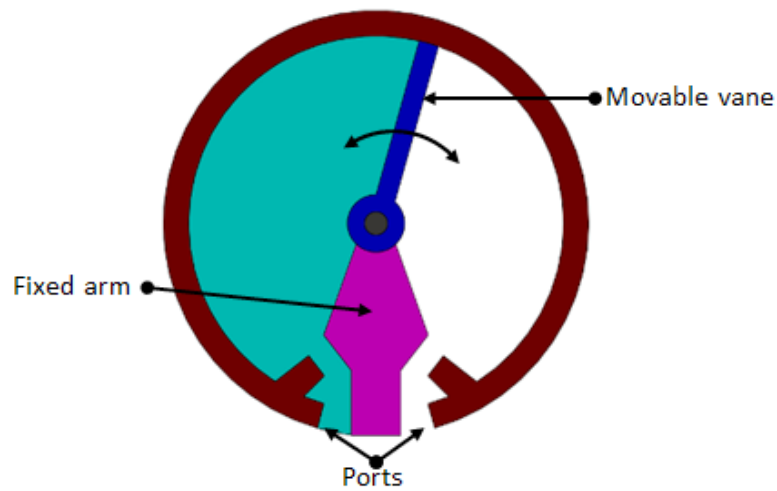


Fig. 6.4.6 Semi rotary vane type actuator

7. Speed control

For an actuator, the operational speed is determined by the fluid flow rate and the cylinder actuator area or the motor displacement. The speed can only be controlled by adjusting the fluid flow to the actuator, because the physical dimension of the actuator is fixed. Since the air is compressible, flow control is difficult as compared to the hydraulic system. There are various ways of controlling the fluid flow. One of the methods is discussed as below-

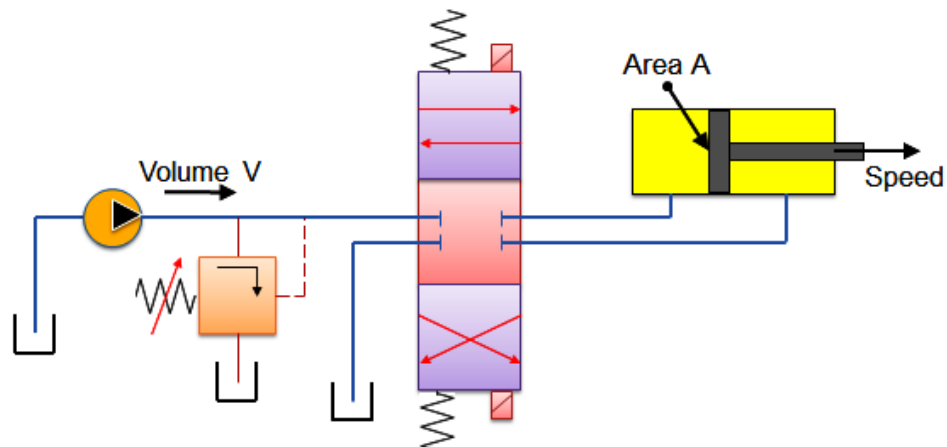


Fig. 6.4.7 Speed control by pump volume

Figure 6.4.7 shows the circuit diagram of hydraulic system developed to control the speed of motion of a piston. Consider a pump which delivers a fluid volume of ‘V’ per minute. The pump has a fixed displacement. The volume of fluid goes either to the pump or to the actuator. When the direction control valve moves from its center position the actuator of area ‘A’, the piston moves with a velocity,

$$v = \frac{V}{A} \quad (6.4.1)$$

If the pump delivery volume ‘V’ can be adjusted by altering swash plate angle of a piston pump or by using a variable displacement vane pump, no further speed control will be needed.

Module 6: Pneumatic Systems

Lecture 5

Pneumatic controllers

In automated industrial processes, it is always essential to keep the process variables such as temperature, flow rate, system pressure, fluid level, etc. at the desired value for safety and economical operation. Consider an example where the flow of water through a pipe has to be kept constant at some predetermined value (Fig. 6.5.1). Let the value of flow to be measured is 'V' (process variable PV). This flow rate is compared with the required flow value say 'V₁' (set point SP). The difference between these two values is the error which is sent to the controller. If any error exists, the controller adjusts the drive signal to the actuator, informing it to move the valve to give the required flow (zero error). This type of control system is called closed loop control system. It mainly includes a controller, actuator and a measuring device.

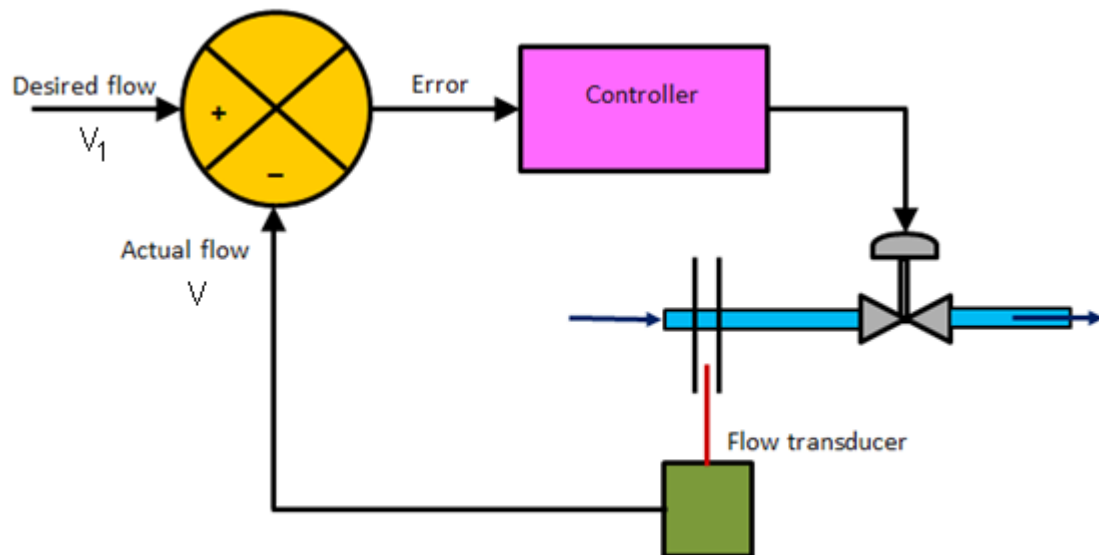


Fig. 6.5.1 Closed loop control system

The control can be achieved by using control electronics or by pneumatic process control. The pneumatic systems are quite popular because they are safe. In the process industries like refinery and chemical plants, the atmosphere is explosive. Application of electronics based systems may be dangerous in such cases. Since the pneumatic systems use air, there are very scant chances of any fire hazards. Even though electrical actuators are available, but most of the valves employed are driven by pneumatic signals.

1. Components of a pneumatic controller

- Flapper nozzle amplifier
- Air relay
- Bellows
- Springs
- Feedback arrangements

1.1 Flapper nozzle amplifier

A pneumatic control system operates with air. The signal is transmitted in the form of variable air pressure (often in the range of 0.2 to 1.0 bar (3-15 psi)) that initiates the control action. One of the basic building blocks of a pneumatic control system is the flapper nozzle amplifier. It converts very small displacement signal (in order of microns) to variation of air pressure. The basic construction of a flapper nozzle amplifier is shown in Figure 6.5.2

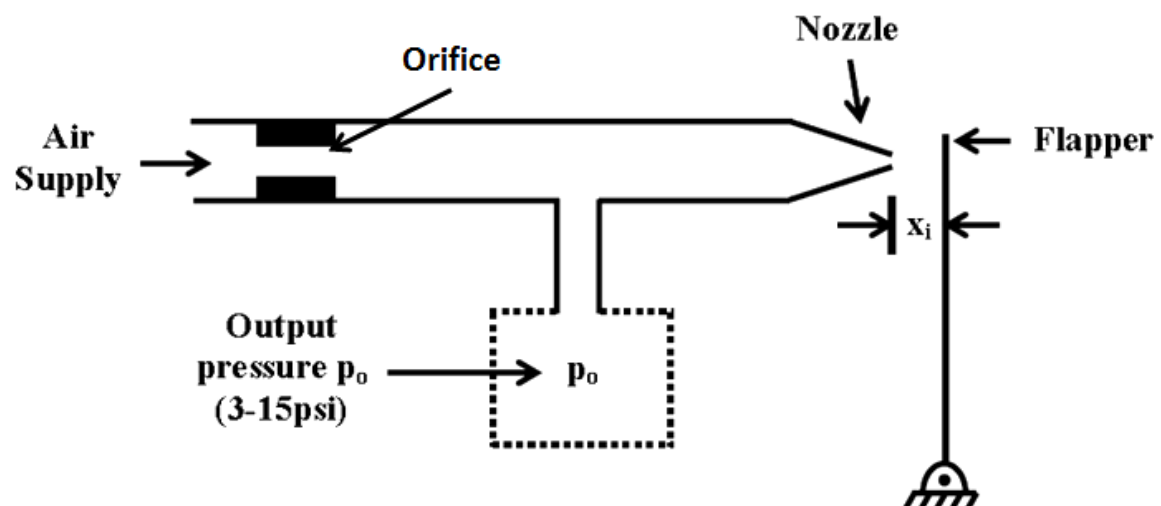


Fig 6.5.2 Nozzle flapper amplifier

Constant air pressure is supplied to one end of the pipeline. There is an orifice at this end. At the other end of the pipe, there is a nozzle and a flapper. The gap between the nozzle and the flapper is set by the input signal. As the flapper moves closer to the nozzle, there will be less airflow through the nozzle and the air pressure inside the pipe will increase. On the other hand, if the flapper moves further away from the nozzle, the air pressure decreases. At the extreme, if the nozzle is open (flapper is far off), the output pressure will be equal to the atmospheric pressure. If the nozzle is blocked, the output pressure will be equal to the supply pressure.

1.2 Air Relay

The major limitation of a flapper nozzle amplifier is its limited air handling capacity. The variation of air pressure obtained cannot be used for any useful application, unless the air handling capacity is increased. It is used after the flapper nozzle amplifier to enhance the volume of air to be handled. The principle of operation of an air relay can be explained using the schematic diagram shown in Figure 6.5.3. It can be seen that the air relay is directly connected to the supply line (no orifice in between). The output pressure of the flapper nozzle amplifier (p_2) is connected to the lower chamber of the air relay with a diaphragm on its top. The variation of the pressure p_2 causes the movement (y) of the diaphragm. There is a double-seated valve fixed on the top of the diaphragm. When the nozzle pressure p_2 increases due to decrease in x_1 , the diaphragm moves up, blocking the air vent line and forming a nozzle between the output pressure line and the supply air pressure line. More air goes to the output line and the air pressure increases. When p_2 decreases, the diaphragm moves downwards, thus blocking the air supply line and connecting the output port to the vent. The air pressure will decrease.

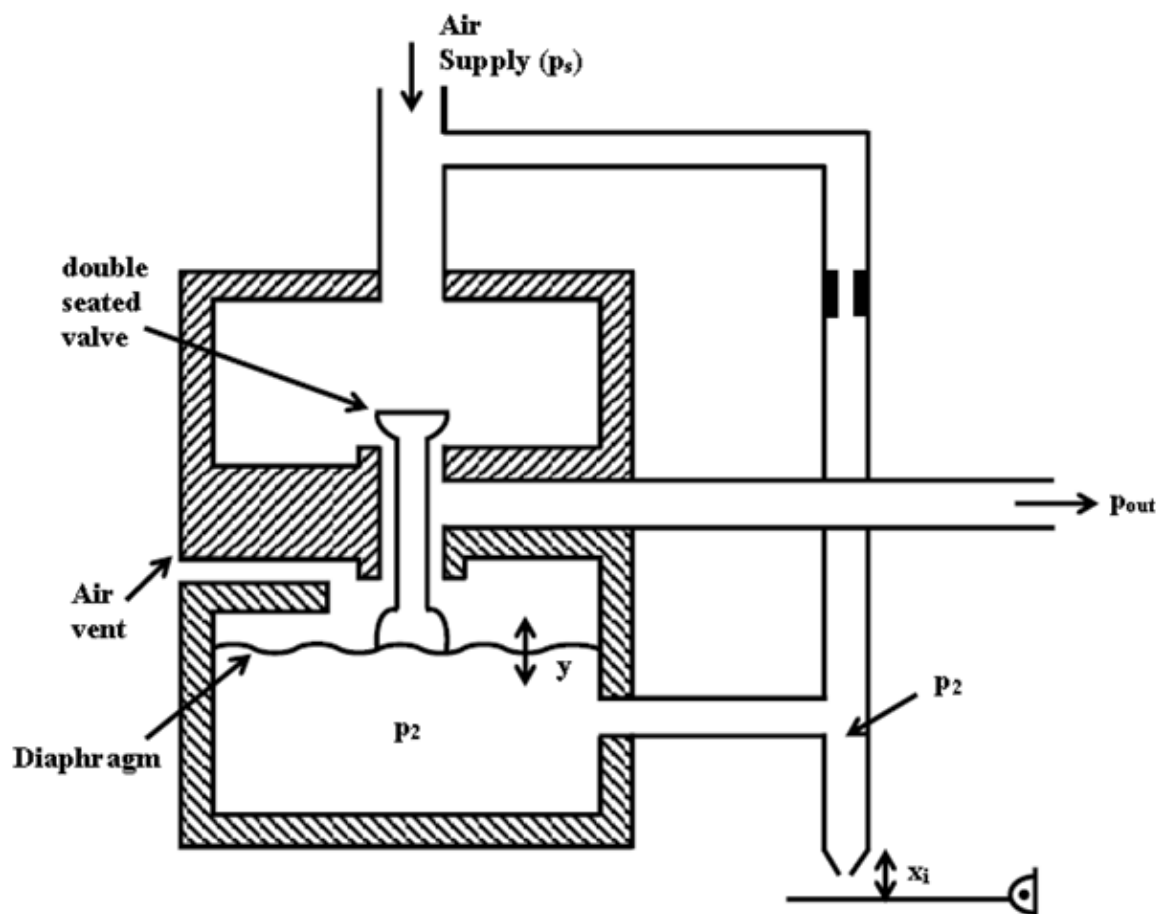


Fig 6.5.3 Air relay

2. Types of pneumatic controllers

Following is the list of variants of pneumatic controllers.

- Proportional only (P) controller
- Proportional-Derivative (PD) controller
- Proportional-Integral (PI) controller
- Proportional-Integral-Derivative (PID) controller

2.1 Proportional only (P) controller

The simplest form of pneumatic controller is proportional only controller. Figure 6.5.4 shows the pneumatic circuit of 'proportional only' controller. The output signal is the product of error signal multiplied by a gain (K).

$$\text{Output} = (\text{Error} * \text{gain}) \quad (6.5.1)$$

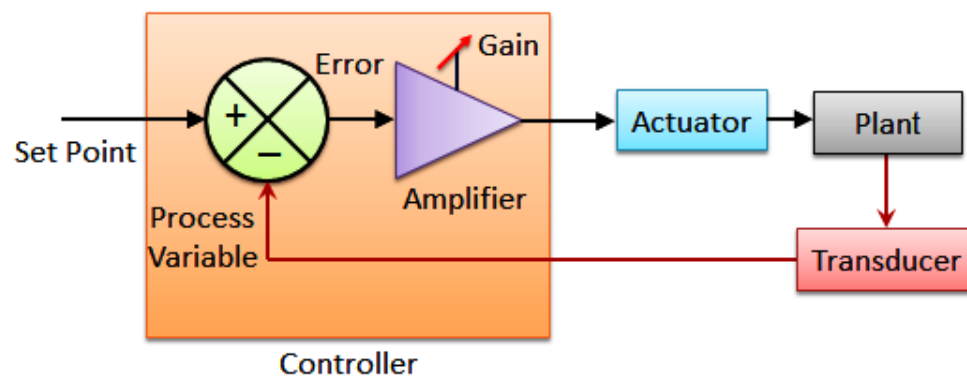


Fig. 6.5.4 Proportional only controller

Consider the pneumatic system consisting of several pneumatic components, viz. flapper nozzle amplifier, air relay, bellows and springs, feedback arrangement. The overall arrangement is known as a pneumatic proportional controller as shown in Figure 6.5.5.

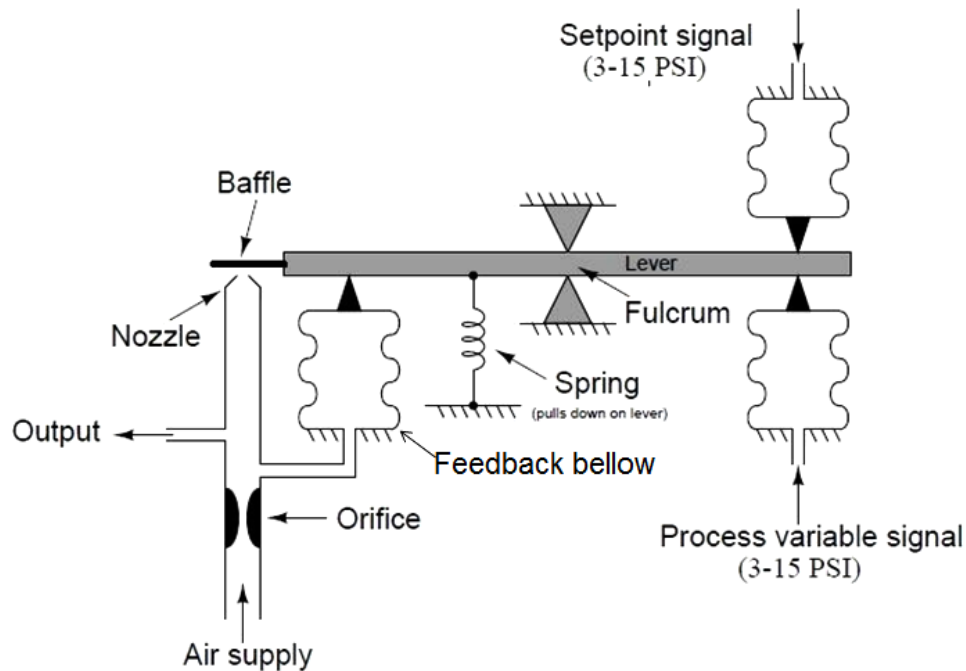


Fig 6.5.5 Proportional only (P) controller elements

It acts as a controller in a pneumatic system generating output pressure proportional to the displacement at one end of the beam. The action of this particular controller is direct, since an increase in process variable signal (pressure) results in an increase in output signal (pressure). Increasing process variable (PV) pressure attempts to push the right-hand end of the beam up, causing the baffle to approach the nozzle. This blockage of the nozzle causes the nozzle's pneumatic backpressure to increase, thus increasing the amount of force applied by the output feedback bellows on the left-hand end of the beam and returning the flapper (very nearly) to its original position. If we wish to reverse the controller's action, we need to swap the pneumatic signal connections between the input bellows, so that the PV pressure will be applied to the upper bellows and the SP pressure to the lower bellows. The ratio of input pressure(s) to output pressure is termed as a gain (proportional band) adjustment in this mechanism. Changing bellows area (either both the PV and SP bellows equally, and the output bellows by itself) influences this ratio. Gain also affects by the change in output bellows position. Moving the fulcrum left or right can be used to control the gain, and in fact is usually the most convenient to engineer.

2.2 Proportional-Derivative (PD) controller

A proportional-derivative (PD) controller is shown in Figure 6.5.6. To add derivative control action to a P-only controller, all we need to place a restrictor valve between the nozzle tube and the output feedback bellows, causing the bellows to delay filling or emptying its air pressure over time.

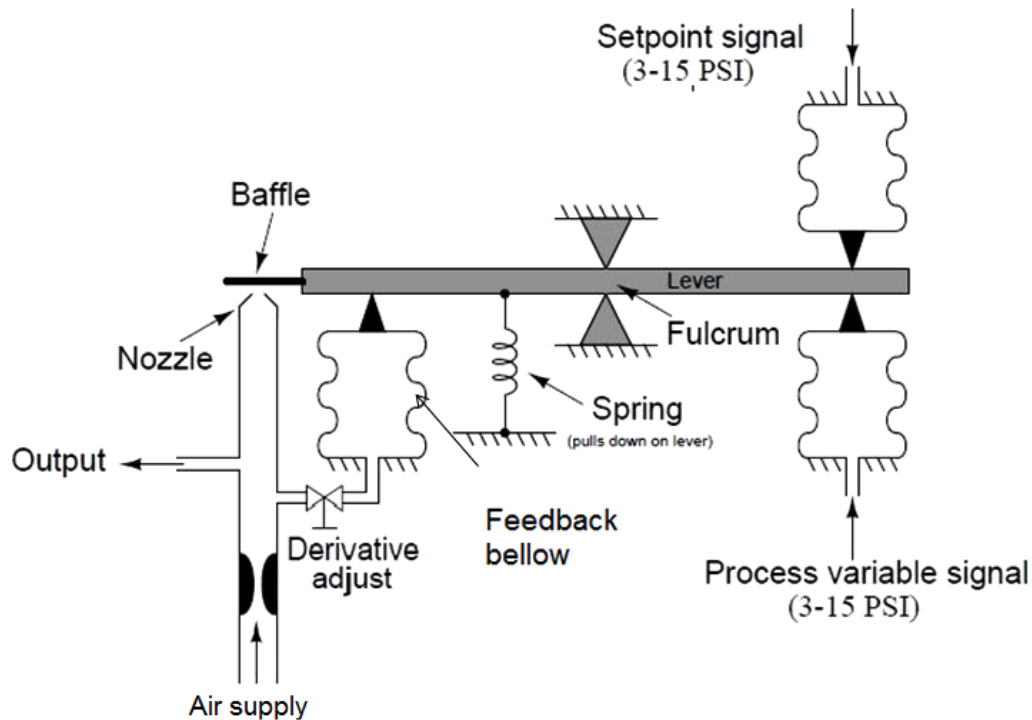


Fig 6.5.6 Proportional-Derivative (PD) controller

If any sudden change occurs in PV or SP, the output pressure will saturate before the output bellows has the opportunity to equalize in pressure with the output signal tube. Thus, the output pressure “spikes” with any sudden “step change” in input: exactly what we would expect with derivative control action. If either the PV or the SP ramps over time, the output signal will ramp in direct proportion (proportional action). But there will be an added offset of pressure at the output signal in order to keep air flowing either in or out of the output bellows at a constant rate to generate the necessary force to balance the changing input signal. Thus, derivative action causes the output pressure to shift either up or down (depending on the direction of input change) more than it would with just proportional action alone in response to a ramping input.

2.3 Proportional-Integral (PI) controller

In some systems, if the gain is too large the system may become unstable. In these circumstances the basic controller can be modified by adding the time integral of the error to control the operation (Fig 6.5.7). Thus the output can be given by an equation,

$$OP = K \left(\text{error} + \frac{1}{T_i} \int \text{error} dt \right) \quad (6.5.2)$$

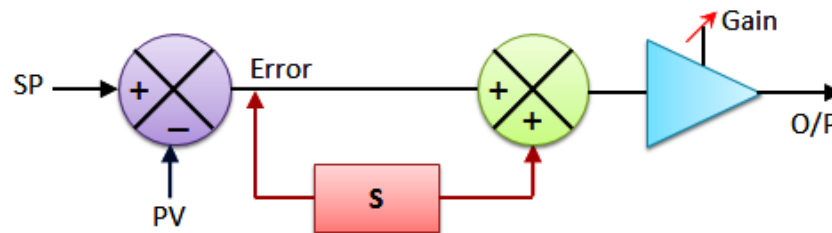


Fig. 6.5.7 Block diagram of P-I controller

The T_i is a constant called integral time. As long as there is an error the output of the controller steps up or down as per the rate determined by T_i . If there is no error then the output of the controller remains constant. The integral term in the above equation removes any offset error.

Figure 6.5.8 shows the configuration of pneumatic proportional plus integral controller. Integral action requires the addition of a second bellows (a “reset” bellows, positioned opposite the output feedback bellows) and another restrictor valve to the mechanism.

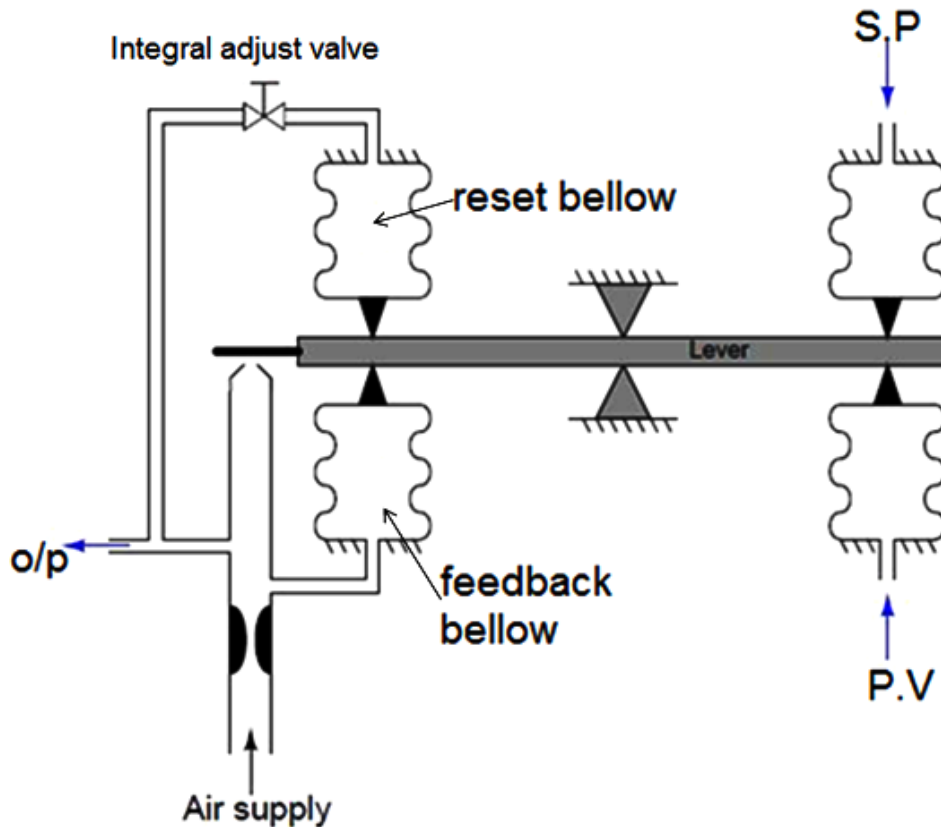


Fig. 6.5.8 Proportional-Integral (P-I) controller

As the reset bellows fills with pressurized air, it begins to push down the left-hand end of the force beam. This forces the baffle closer to the nozzle, causing the output pressure to rise. The regular output bellows has no restrictor valve to impede its filling, and so it immediately applies more upward force on the beam with the rising output pressure. With this greater output pressure, the reset bellows has an even greater “final” pressure to achieve, and so its rate of filling continues.

2.4 Proportional-Integral-Derivative (PID) controller

Three term pneumatic control can be achieved using a P-I-D controller. Here the action of the feedback bellows is delayed. The output is given by,

$$OP = K \left(\text{error} + \frac{1}{T_i} \int \text{error} dt + T_d \frac{d \text{error}}{dt} \right) \quad (6.5.3)$$

The terms gain K , derivative time T_d , integral time T_i which can be set by beam pivot point and two bleed valves (Fig. 6.5.9). This is a combination of all the three controllers described above. Hence it combines the advantages of all three. A derivative control valve is added to delay the response at feedback bellow. Addition of derivative term makes the control system to change the control output quickly when SP and PV are changing quickly. This makes the system more stable.

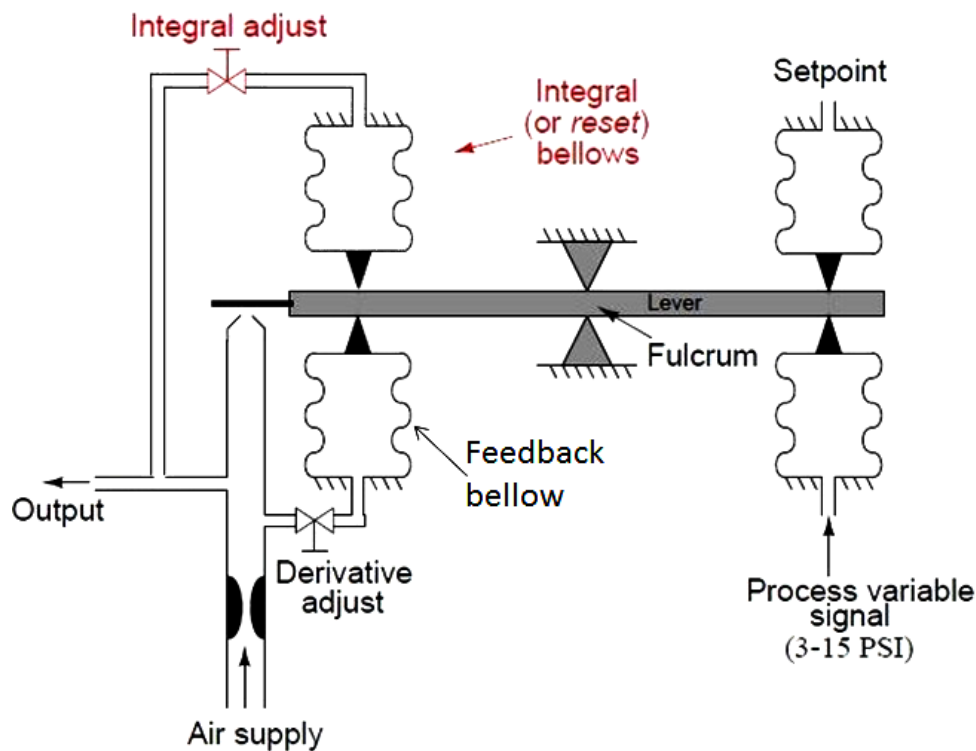


Fig. 6.5.9 Proportional-Integral-Derivative (P-I-D) controller

Advantages of pneumatic controllers

- Simplicity of the components and no complex structure
- Easy maintainability
- Safe and can be used in hazardous atmospheres
- Low cost of installation
- Good reliability and reproducibility
- Speed of response is relatively slow but steady
- Limited power capacity for large mass transfer

Limitations of pneumatic controllers

- Slow response
- Difficult to operate in sub-normal temperatures
- Pipe-couplings can give rise to leaks in certain ambient conditions
- Moving parts - more maintenance

Module 6: Pneumatic Systems

Lecture 6

Applications of pneumatic systems

In this section we will study the application of various pneumatic components in designing a pneumatic circuit. The graphical symbols of pneumatic components and equipments have already been discussed in lecture 7 of module 5.

1. Case study A

Consider a simple operation where a double-acting cylinder is used to transfer parts from a magazine. The cylinder is to be advanced either by operating a push button or by a foot pedal. Once the cylinder is fully advanced, it is to be retracted to its initial position. A 3/2-way roller lever valve is to be used to detect the full extension of the cylinder. Design a pneumatic circuit for the above-mentioned application.

1.1 Components used

The pneumatic components which can be used to implement the mentioned task are as follows:

- double acting cylinder
- 3/2 push button valve
- 3/2 roller valve
- shuttle valve
- 3/2 foot pedal actuated valve
- 5/3 pneumatic actuated direction control valve
- compressed air source and connecting piping

1.2 Working

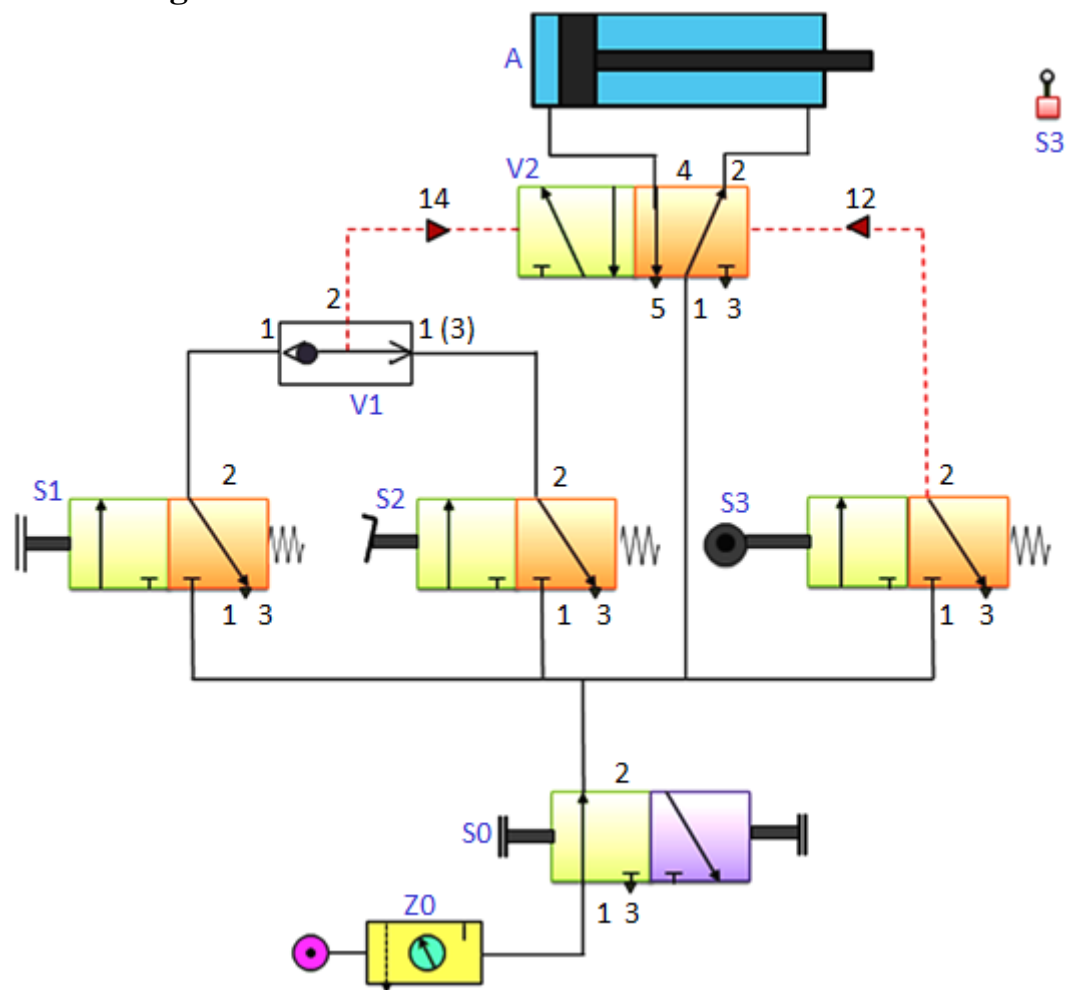


Fig. 6.6.1 Pneumatic circuit for shuttle valve operation

Figure 6.6.1 shows the proposed circuit diagram. As the problem stated, upon actuation of either the push button of valve (S1) or the foot pedal valve (S2), a signal is generated at 1 or 1(3) side of the shuttle valve. The OR condition is met and the signal is passed to the control port 14 of the direction control valve (V2). Due to this signal, the left position of V2 is actuated and the flow of air starts. Pressure is applied on the piston side of the cylinder (A) and the cylinder extends. If the push button or pedal valve is released, the signal at the direction control valve (V2) port is reset. Since DCV (V2) is a double pilot valve, it has a memory function which doesn't allow switching of positions. As the piston reaches the rod end position, the roller valve (S3) is actuated and a signal is applied to port 12 of the DCV (V2). This causes actuation of right side of DCV (V2). Due to this actuation, the flow enters at the rod-end side of the cylinder, which pushes the piston towards left and thus the cylinder retracts.

2. Case study B

A plastic component is to be embossed by using a die which is powered by a double acting cylinder. The return of the die is to be effected when the cylinder rod has fully extended to the embossing position and the preset pressure is reached. A roller lever valve is to be used to confirm full extension. The signal for retracting must only be generated when the piston rod has reached the embossing position. The pressure in the piston chamber is indicated by a pressure gauge.

2.1 Components used

The pneumatic components to be used to implement this task are:

- double acting cylinder
- 3/2 push button valve
- 3/2 roller valve
- shuttle valve
- 5/3 pneumatic actuated direction control valve
- pressure sequence valve
- compressed air source
- pressure gauge and connecting piping

2.2 Working

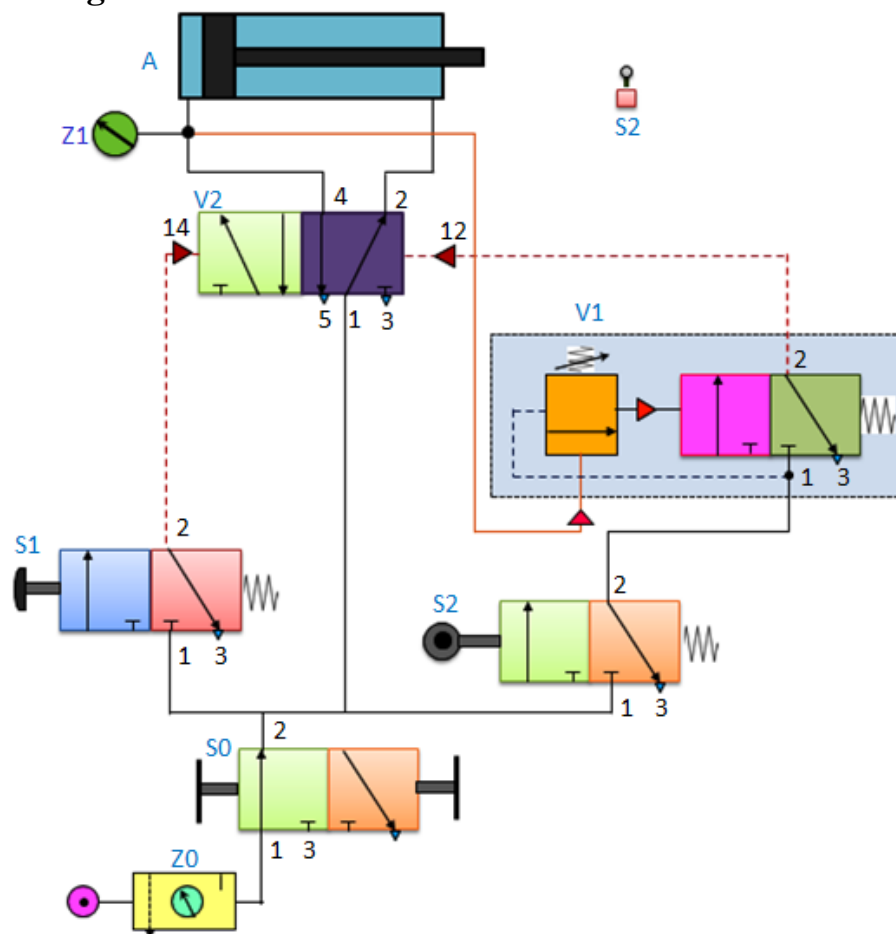


Fig. 6.6.2 Pneumatic circuit for embossing application

The proposed pneumatic circuit diagram for embossing application is shown in fig. 6.6.2. When the push button valve (S1) is pressed, the flow takes place through the valve and a signal is sent to the control port 14 of the direction control valve (V2). The left position of the direction control valve (V2) is switched-on and the flow enters at the piston-end of the cylinder (A). It causes the extension of the cylinder. Even if the push button is released the position of the DCV (V2) will not change due to its memory function. As the piston nears the end position, the roller valve (S2) is actuated and pressure line is connected to the pressure sequence valve (V1). During the embossing process the pressure at the piston-side of the cylinder (A) increases. This increase in pressure is indicated by the pressure regulator (Z1). When the pressure reaches to its pre-set value in the pressure sequence valve (V1), the 3/2 valve of pressure sequence valve switches and the signal is applied to port 12 of the DCV (V2). The right position of the DCV is actuated and the piston retracts. During the retracting movement, the roller valve (S2) is released and the signal at the control port 12 of the DCV (V2) is reset and the pressure sequence valve is also reset.

3. Case study C

Sequencing application

In process control applications such as sequencing, the Pneumatics systems are generally employed. Electrical components such as relays, programmable logic controllers are used to control the operations of Pneumatic systems. A simple example of a pneumatic sequencing is shown in Figure 6.6.3.

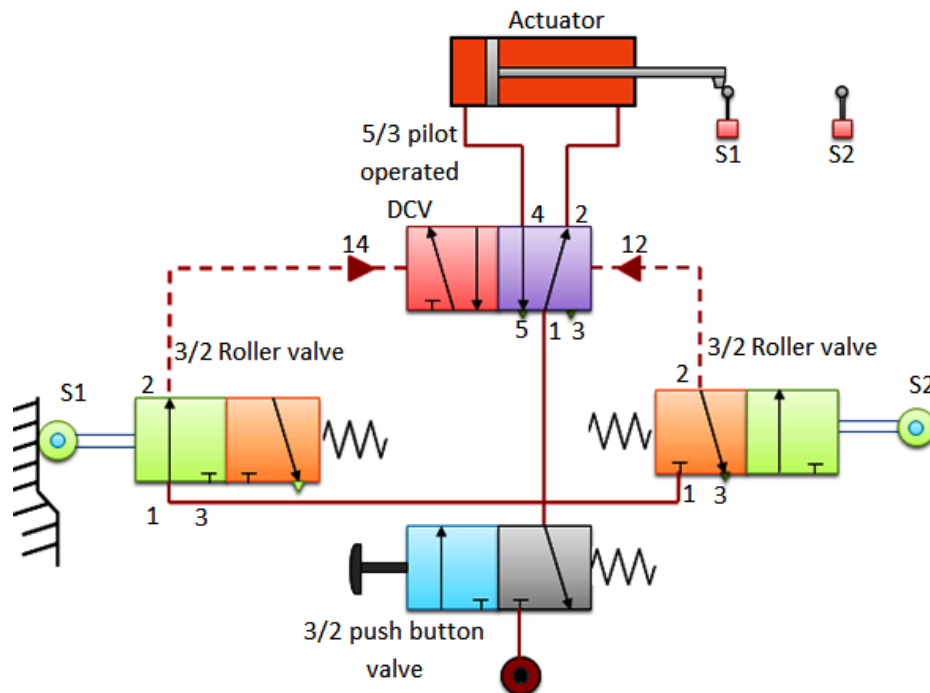


Fig. 6.6.3 Cylinder sequencing- Oscillating cylinder

3.1 Components used

The components used in the circuit are: double acting cylinder, 3/2 roller lever valve, 5/3 pilot operated direction control valve and a 3/2 push button valve. By using this circuit, a continuous to and fro motion of the actuator is obtained.

3.2 Working

When the 3/2 push button is actuated, the air flows from the source through the push button valve to the 3/2 roller valve (S1). The roller valve is already actuated by the cylinder when the piston rod hits the lever of S1. Therefore, there is continuous flow to the 5/3 pilot operated direction control valve (DCV). The flow given to the pilot line 14 actuates the first position of DCV. The air flows from port 1-4 pushes the piston head which causes the extension of the cylinder. As the cylinder fully extends it actuates the 3/2 roller lever valve (S2). The roller valve is actuated and air flows through the valve to the 5/3 DCV. The air enters the DCV through pilot port 12 actuating the second position. Hence the air flows from port 1-2 to the actuator rod end, causing its retraction. The cylinder reciprocates till the supply is stopped. In this way, we can achieve the sequencing operation by controlled actuation of various valves in a pneumatic system.