Chapter 4 Pneumatic and Hydraulic Actuators

4.1	**Basic principles of pneumatic and hydraulic circuitry, Comparison of pneumatic and hydraulic circuitry and their applications.**
4.2	**Pneumatic actuators:** • **Single acting and double acting cylinder, Directional control valve** • **Principles of pneumatic control, Pneumatic circuit diagram** • **Basic Pneumatic circuits (flow amplification, signal inversion, memory, delay, single acting cylinder control, double acting cylinder control)**
4.3	**Hydraulic actuators: Linear -Single acting, double acting, Double Rod Cylinder**
4.4	**Selection of actuators based on principle of operation, performance characteristics, maximum loading condition, safety**

1. Basic principles of pneumatic and hydraulic circuitry

- A pneumatic system is a system that uses compressed air to transmit and control energy. In a pneumatic system, information is carried by the pressure of gas in a pipe. Pneumatic systems are used in controlling train doors, automatic production lines, and mechanical clamps etc.

- A hydraulic system is a system that uses pressurized fluid to transmit and control energy. In a hydraulic system, information is carried by the pressure of fluid in a pipe. The power of liquid fuel in hydraulics is very high; so, hydraulic are commonly used in heavy equipment.

2. Comparisons of electrical, hydraulic and pneumatic actuator/circuitry

	Electrical	Hydraulic	Pneumatic
Energy source	Electrical	Fluid pressure	Air pressure
Distribution	Excellent	Limited	Good
Output force	low actuating forces	High actuating forces	medium actuating forces
Energy cost	Lowest	Medium	Highest
Energy storage	Limited (batteries)	Limited (accumulator)	Good (reservoir)
Disadvantages	Danger from electric shock	Leakage and Fire Hazard	Noise

3. Actuators:

- In a process system, the actuator is a device that translates small energy signal of the controller into a large energy action or force or torque as required to manipulate a control element in the process. It is known as actuator because it uses the controller signal to actuate (operate) the final control element.
- Thus, the actuator does a translation of the converted control signal into action on the control element. Example: if a valve is to be operated, the actuator is a device that converts the control signal into the physical action of opening or closing the valve.

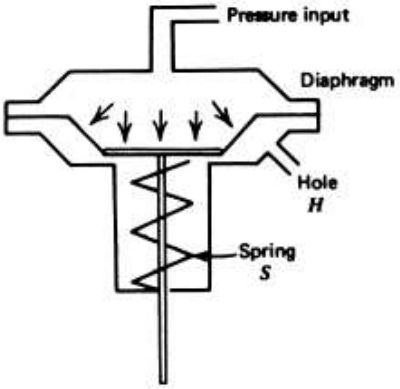
- Types of actuators are pneumatic, hydraulic and electrical actuators. DC motor**,** AC motor and stepper motor are the commonly used electical actuators.

4. Pneumatic actuator:

- It converts pressure signals into mechanical shaft motion. The principle is based on the concept of pressure as force per unit area.
- For a pressure difference $(\boldsymbol{P_1 - P_2})$applied across a diaphragm of surface area $\boldsymbol{A}$, force acting on the diaphragm is given by:

$$\boldsymbol{F = A(P_1 - P_2)}$$

- By increasing the diaphragm area, the force can be increased. Very large forces can be developed by standard signal-pressure ranges of 3 to 15 psi (20 to 100 kPa).

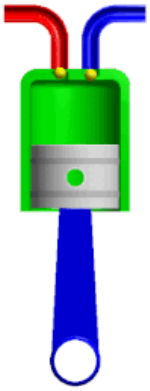


5. Types of pneumatic actuators:

- The types of pneumatic actuators are Single acting cylinder, double acting cylinder and Directional control valve.

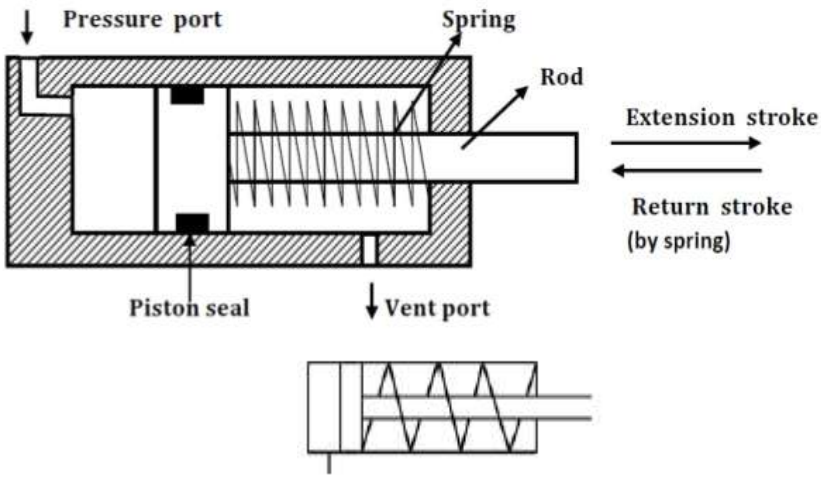
6. Pneumatic cylinders

- Pneumatic cylinders, also called air cylinders are the mechanical devices that use the force or energy of compressed air and turn it into linear motion to move the load.
- It consists of a cylinder or tube that is sealed on both ends, with a cap at one end and head at the other end. The cylinder contains a piston, which is attached to a rod. The rodwith piston moves in and out of one end of the tube, actuated by compressed air.
- Two types of pneumatic cylinders are single-acting and double-acting.
- The main design difference between both cylinders is the number of ports. Port means number of holes in the device for air input/output (combined). Single acting cylinders have one port where pressurized air enters and double acting cylinders have two ports.
- Pneumatic cylinders are lightweight, have low maintenance, operate at lower speeds and less force than hydraulic or electric actuators.
- Animation of a piston system:



7. Single acting cylinder

- In single acting cylinder, the fluid pressure is applied to just one side of the piston. The piston can move in only one direction for a task such as lifting an object
- So it has only one port for connection where pressurized air enters and only push or pull can be done with it.
- The other side vents air to the environment.
- Movement of the piston rod in the opposite direction takes place by means of a mechanical spring, which returns the piston rod to its original or base position.



Pneumatic symbol of a single acting cylinder

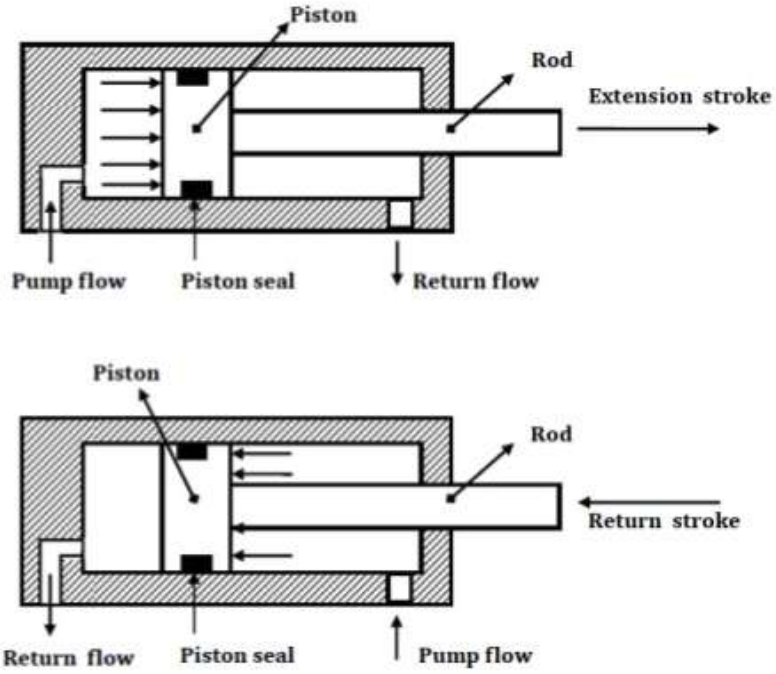
- Single acting cylinders are used in stamping, printing, moving materials, etc. A car jack is an example of a simple single-acting cylinder

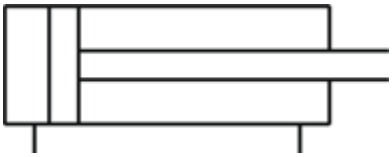
- https://www.youtube.com/watch?v=ClOXkkVDIiY
- https://www.youtube.com/watch?v=O_2BZs3WiQY
- https://www.youtube.com/watch?v=R-OBtVCPjMc
- https://www.youtube.com/watch?v=mYMgmnN9Hmw

8. Double acting cylinder

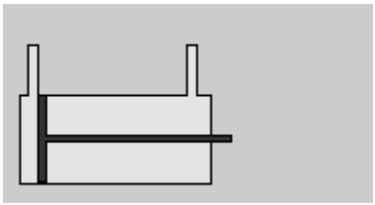
- In double acting cylinder, the fluid pressure is applied on both sides of the piston. Therefore, it works in both directions or it can move load in both directions.
- So it has two ports for connection where air pressure is applied alternately to the relative surface of the piston. It makes both chambers pressurized.

- Any difference in pressure between the two sides of the piston moves the piston to one side or the other.
- Thus movement of the piston in both direction (the retraction and extension of the piston) takes place with pressure (without the need of a spring unlike single acting air cylinders).
- A double-acting cylinder is used where an external force is not available to retract the piston or it can be used where high force is required in both directions of piston travel or machine requires more than one movement.





Pneumatic symbol of a double acting cylinder



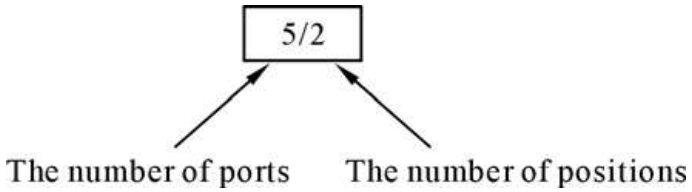
Double-acting cylinder

9. Directional control valve –DCV

https://www.youtube.com/watch?v=9k8_uQJhBMM
https://www.youtube.com/watch?v=bXXL-0sf8gs
https://www.youtube.com/watch?v=9n4IMSLkFF4

- Directional control valves are the valves which control the direction of fluid flow in pneumatic and hydraulic systems.
- They allow fluid flow (hydraulic oil, water or air) into different paths from one or more sources.
- They are used to direct the inlet flow to a specific outlet port.

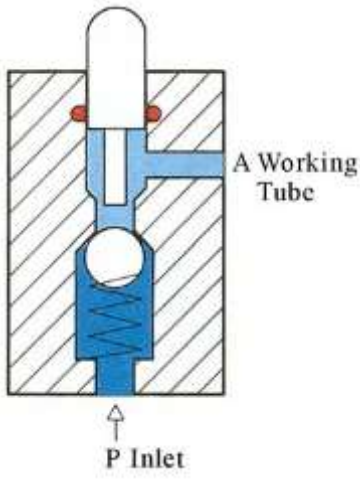
- Thus, they perform 3 functions: stop fluid flow, allow fluid flow and change the direction of fluid flow.
- DCVs ensure the flow of air between air ports by opening, closing and switching their internal connections in pneumatic systems. It is done by a spool inside a cylinder which is mechanically or electrically actuated. The position of the spool controls the fluid flow.
- DCVs are described by the numbers of ports in the main valve where pressurized air enters (excluding pilot ports) and the number of positions the valve can take.
- The ports of a directional control valve are the places on the valve body where the fluid flow lines can be attached.
- Position means different states of valve. i.e. 2 position valve has two different switching positions; one for ON condition and one for OFF condition.
- There are two fundamental positions of directional control valve which are normal position and working / actuated position. Normal position is the position where valve returns on removal of actuating force (not energized) and working position is the position of a valve when actuating force is applied (energized).
- The normal position can be Normally Open (NO) or Normally Closed (NC).
- A NO contact is one that is open (means valve is open and flow passes through the valve) when the DCV is not energized and becomes closed when it is energized.
- The NC contact is one that is closed (means valve is closed; no flow through the valve) when DCV is not energized and opens when it is energized.
- Common types of directional control valves are 2/2, 3/2, 5/2, etc.
- The first number represents the number of ports; the second number represents the number of positions. **[number of ports] / [number of positions]**
- A 5/2 directional control valve that has five ports and two positions is shown below:



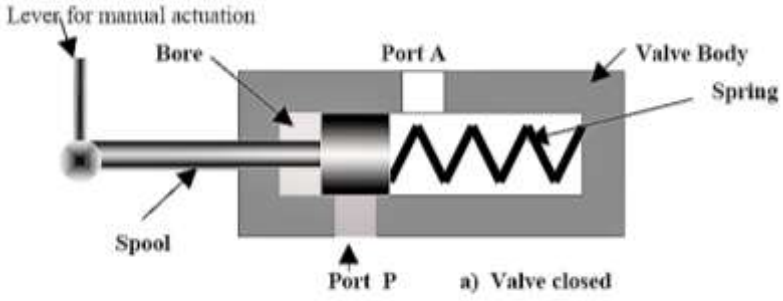
10. 2/2 Directional control valve

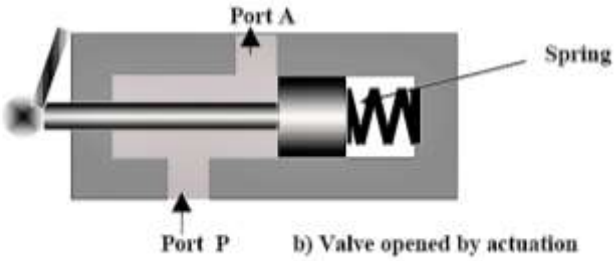
- The 2/2 directional control valve has 2 ports and 2 positions.
- Ports are
    1. Pressure port or Air inlet port (P in the diagram)
    2. Working port (A in the diagram) that connect to the device to be controlled
- It uses the thrust from the spring to open and close the valve.
- When a force is applied to the control axis (valve is energized), the valve will be pushed open, and thus connecting 'P' with 'A' and fluid flows through the valve. When valve is de-energized, flow through the valve stops. This is Normally Closed (NC) condition.
- The direction of the airflow is represented by an arrow.
- The control valve can be driven manually or mechanically, and restored to its original position by the spring.

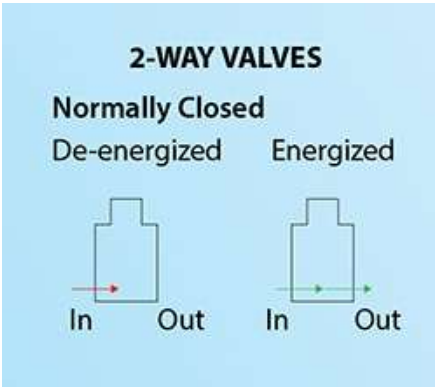
(a) 2/2 directional control valve



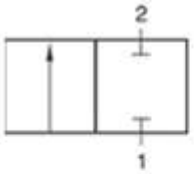
(b) Cross section



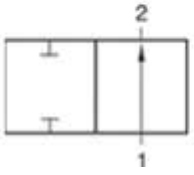




Pneumatic symbol:



Normally closed



Normally open

- The number 1 &2 represents ports.

11. 3/2 Directional control valve

- The 3/2 directional control valve has 3 ports and 2 positions.
- Ports are
    1. Pressure port or Air inlet port (P or 1in the diagram),

2. Working port (A or 2 in the diagram) that connect to the device to be controlled
3. Exhaust port (R or T or 3 in the diagram).

- The valves can be driven manually, mechanically, electrically or pneumatically.
- 3/2 directional control valve is used to control a single acting cylinder.

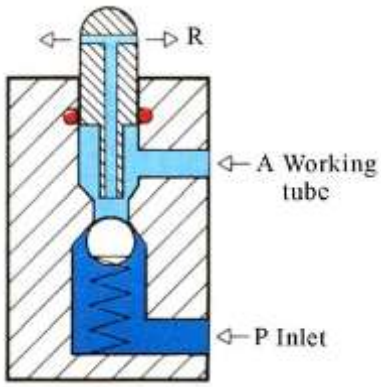
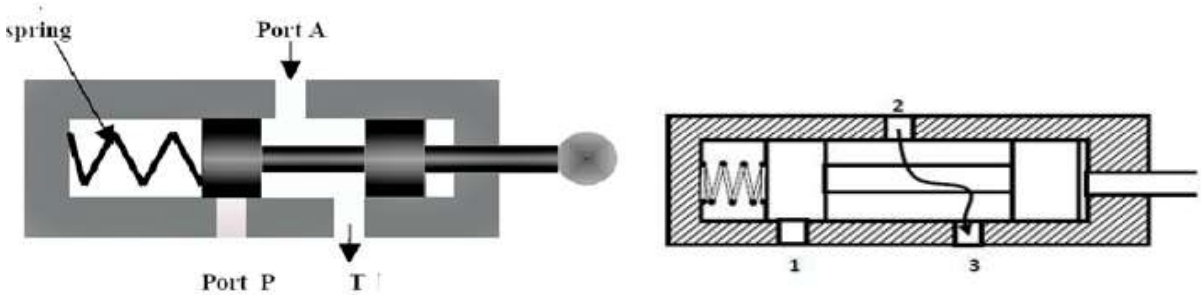
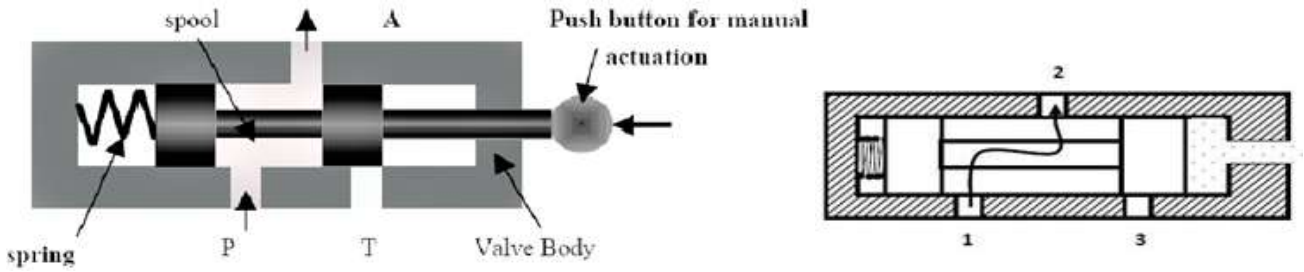


Fig. 3/2 directional control valve Cross section



When de-energized, valve is closed; port P to port A is closed.

- In normal position (when the valve is not actuated), pressure port (port 1 or P) is blocked, the working port (port 2 or A) is closed to the pressure port and open to the exhaust port (port 3 or T). The pressure port is not connected to the working port since there is no air flow. (Normally closed).
- In the actuated position, when the compressed air is applied, the spool is moved against the spring. The working port is open to the pressure port and closed to the exhaust port. Thus, the application of the compressed air causes the pressure port to be connected to the working port.

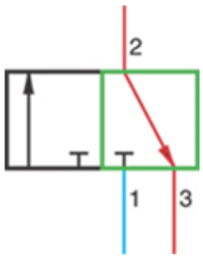


When energized, valve is open; port P to port A is open.

- Explanation of the pneumatic symbol for Normally Closed (NC) 3/2 DCV:

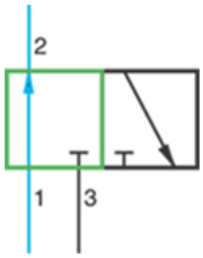
On the right hand side you can see the basic position of a normally closed 3/2-way valve.

- Port 1 = pressure supply is closed (blue).
- Port 2 = working, in basic position connected to port 3 = exhaust (red).
- Basic position or normal position drawn in green.

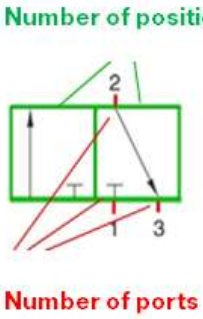


The second square displays the actuated position of the valve.

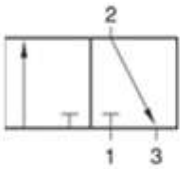
- Valve has been actuated (actuation elements not shown here).
- Port 1 is connected to working port 2 (blue).
- Exhaust port 3 is closed (black).
- Actuated positon drawn in green.



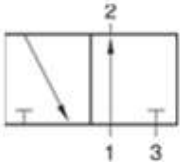
- Ports are shown in red color and positions are shown as squares in green color



- Pneumatic symbol for NC and NO 3/2 DCV



Normally closed



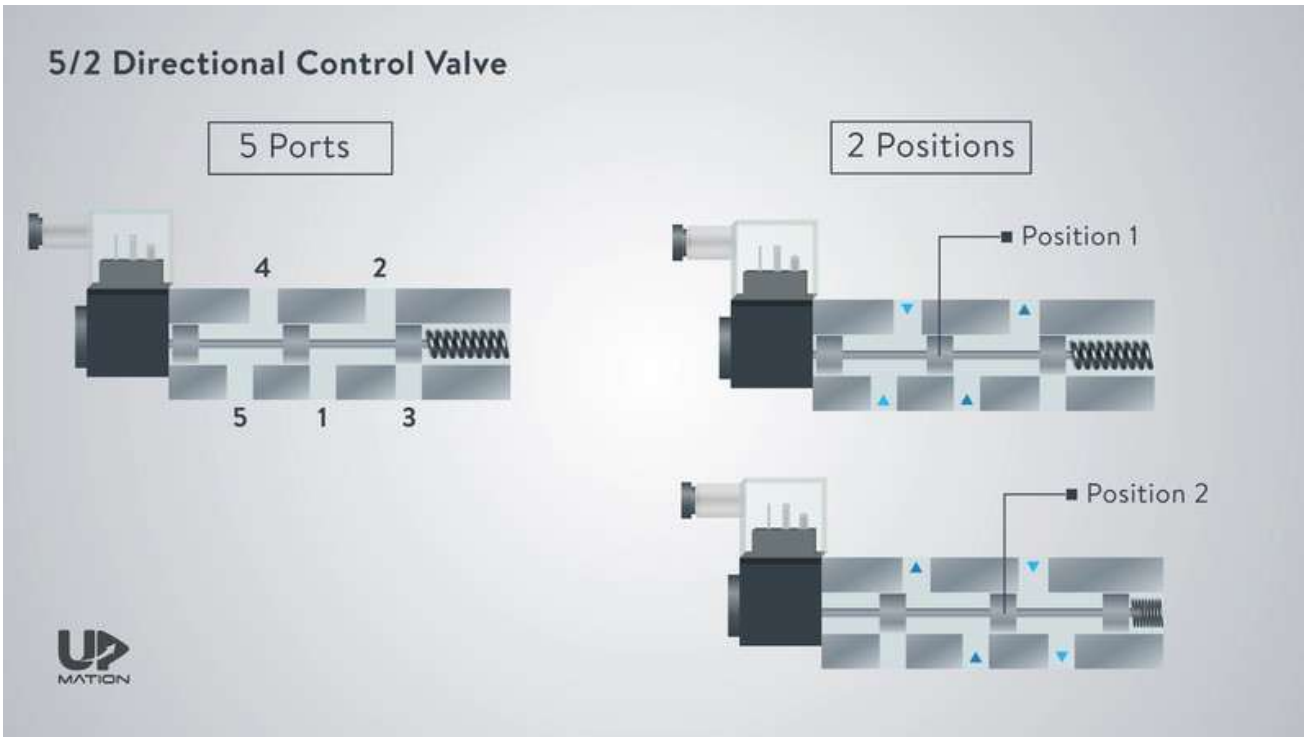
Normally open

12. 5/2 Directional control valve

- The 5/2 directional control valve has 5 connection ports and 2 positions.
- The ports are
    1. Pressure port or air inlet port (P or 1)

2. Two working ports (A or 4) and (B or 2) that connect to the device to be controlled
3. Two exhaust ports (R1 or 3) and (R2 or 5).

- The two states of the valve are:
  1. Pressure port (P or 1) connects to port (B or 2), while port (A or 4) vents through exhaust port (R2 or 5)
  2. Pressure port (P or 1) connects to port (A or 4), while port (B or 2) vents through port (R1 or 3).



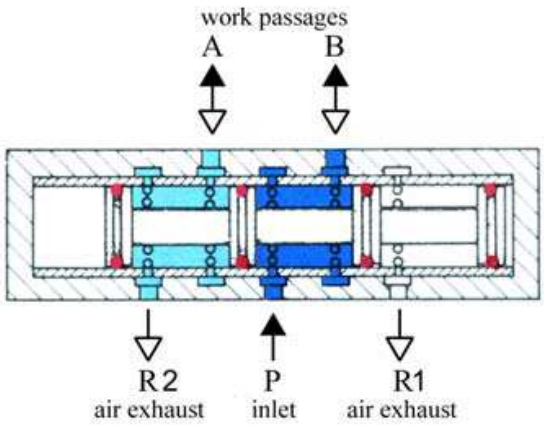


Fig. 5/2 directional control valve Cross section

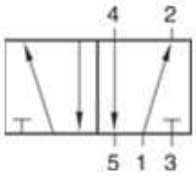
Working:

- When air pressure input is given to the pressure control port ‘P’, the spool will move to the left, connecting inlet ‘P’ and work passage ‘B’. Work passage ‘A’ will then make a release of air through ‘R2’.

- The directional valves will remain in this operational position until signals of the contrary are received. Therefore, this type of directional control valves is said to have the function of 'memory'.

- 5/2 directional control valve Pneumatic symbol:

Or



13. Principles of pneumatic control, Pneumatic circuit diagram

- Pneumatic control systems can be designed in the form of pneumatic circuits. A pneumatic circuit is formed by various pneumatic components, such as cylinders, directional control valves, flow control valves, etc.

- Pneumatic circuits have the following functions:
  1. To control the injection and release of compressed air in the cylinders.
  2. To use one valve to control another valve.

14. Pneumatic circuit diagram

- A pneumatic circuit diagram uses pneumatic symbols to describe its design. Some basic rules must be followed when drawing pneumatic diagrams.

(i) Basic rules: Explanation of valve symbols:

1. A pneumatic circuit diagram represents the circuit in de-energized form and assumes there is no supply of pressure. The placement of the pneumatic components on the circuit also follows this assumption.
2. The pneumatic symbol of a directional control valve is formed by one or more squares. Each function of the valve (the position of the valve) is represented by a square. The number of squares is the number of positions or function of the valve. If there are two or more functions, the squares should be arranged horizontally. The right-side square shows the normal position and left one shows working/actuated position. The arrangement of symbols and arrows inside each square indicates how the ports are interconnected when the valve is in that position.
3. The inlet and exhaust are drawn underneath the square, while the outlet is drawn on the top. The symbol "⊙" underneath the square represents the air inlet and the symbol "▽" represents the exhaust.
4. The air pathways are represented by lines. The direction of the airflow is represented by arrows "↓↖". Double arrow indicates that air flow in both directions. An arrow that is not in-line with the inlet and outlet ports indicates that the valve is normally closed. An arrow that is in-line with the inlet and outlet ports indicates that the valve is normally open.

5. If the external port is not connected to the internal parts (ie. closed ports), the symbol "┬" is used.
6. The ports carry numbers. The numbers are only shown in the square with the basic position of the valve. The type of actuation is also symbolized.

Fig. 3/2 directional control valve (normally closed type)

7. The pneumatic symbols of operational components should be drawn on the outside of the squares. They can be divided into two classes: mechanical and manual

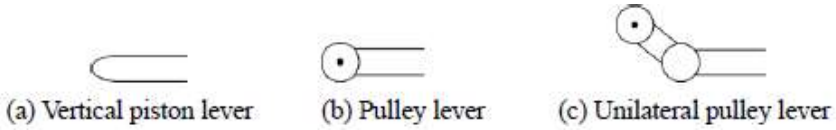
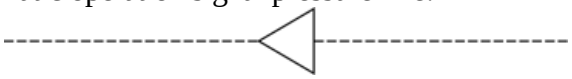


Fig. Mechanically operated pneumatic components

Fig. Manually operated pneumatic components

8. Pneumatic operation signal pressure lines should be drawn on one side of the squares, while triangles are used to represent the direction of air flow.
   Fig. Pneumatic operation signal pressure line:



(ii) Basic principles:

- Fig. below is the example of some of the basic principles of drawing pneumatic circuit diagrams.

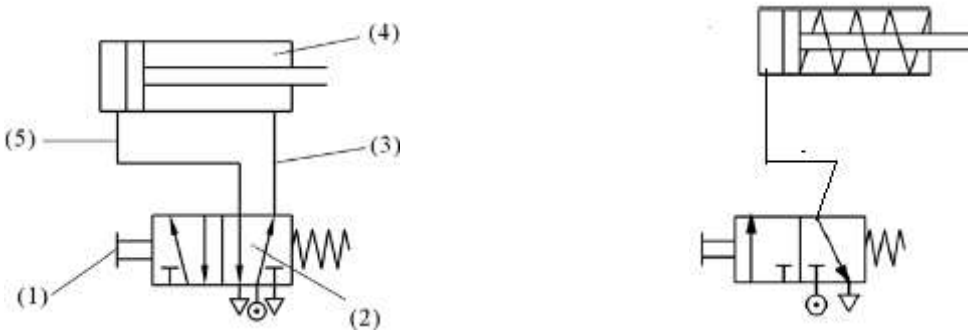


Fig. Basic principles of drawing pneumatic circuit diagrams

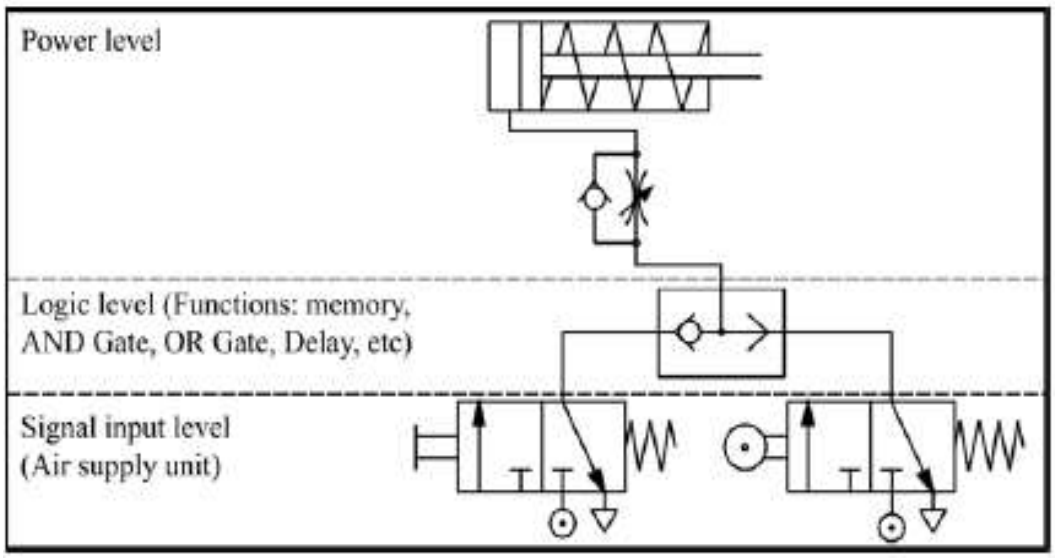
- The numbers in the diagram correspond to the following points:

1. When the manual switch is not operated, the spring will restore the valve to its original position.
2. The position of the spring shows that the block is operating. The other block will not operate until the switch is pushed.
3. Air pressure exists along this line because it is connected to the source of compressed air.
4. As this cylinder cavity and piston rod are connected to inlet pressure, the piston rod is in its restored position.
5. The rear cylinder cavity and this line are connected to the exhaust, where air is released.

(iii) The setting of pneumatic circuit diagrams

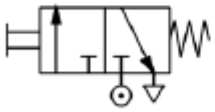
- When drawing a complete pneumatic circuit diagram, the pneumatic components should be placed on different levels and positions; thus, the relations between the components can be expressed clearly. This is called the setting of circuit diagrams.

- A circuit diagram is divided into three levels: power level, logic level and signal input level



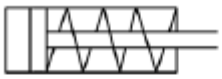
The basic rules of circuit diagram setting are as follows:

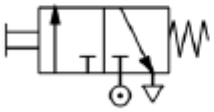
1.



In a pneumatic circuit, the flow of energy is from the bottom to the top. Therefore, the air supply unit should be put at the bottom left corner.

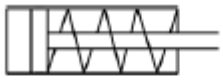
2.

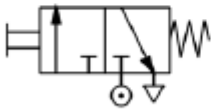




The work cycle should be drawn from left to right. The first operating cylinder should be placed at the upper left corner.

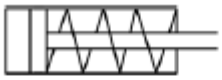
3.

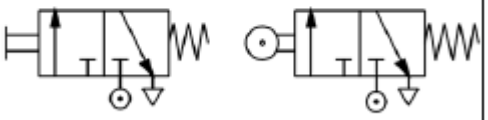




Power control valves should be drawn directly under the cylinder controlled by them, forming a power unit.

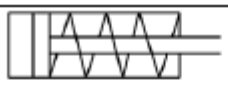
4.

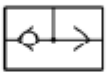


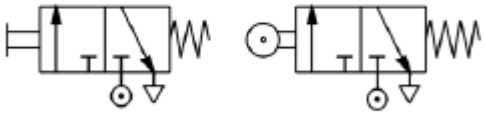


Control cylinders and operational valves (signal components) driven by power control valves should be placed at the lower levels of the diagram.

5.

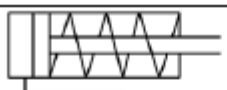


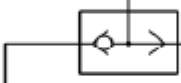


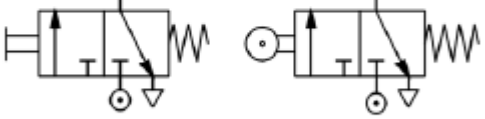


Assistance valves, such as those with logic functions (for example, memory, 'AND', 'OR', 'NOT', delay, etc), can be put between the pneumatic components and the power control valves.

6.







Use the line which represents the connecting pipe to connect all the air supply unit and the pneumatic components to complete the pneumatic circuit. Check carefully the circuit and the logic of the operation before use to avoid any accident.

15. Basic Pneumatic circuits: (Flow amplification, signal inversion, memory, delay, single acting cylinder control, double acting cylinder control)

- A basic pneumatic circuit performs basic tasks, such as flow amplification, signal inversion, memory, delay, single acting cylinder control and double acting cylinder control.

16. Flow amplification

- Cylinders with a large capacity require larger flow of air from pneumatic directional control valves with large flow capacity.
- It is unsafe to manually operate pneumatic directional control valves with large flow capacity.
- Therefore, a small control valve is first operated manually; it is used to operate the pneumatic control system with large flow capacity. It ensures the safety of the operators.
- This is called flow amplification.
- During operation, valves with large flow capacity should be placed near the cylinder, while valves with smaller flow capacity should be placed on control boards some distances away.
- Fig. below shows a basic flow amplification circuit.

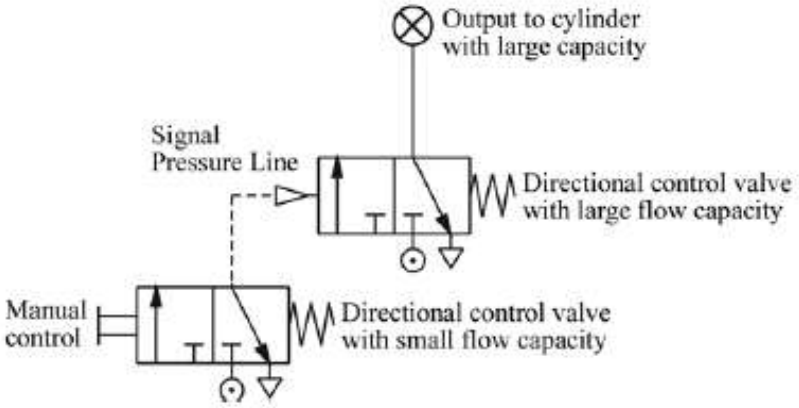
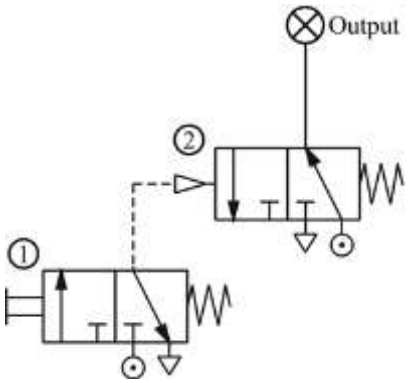


Fig. Flow amplification system

17. Signal inversion

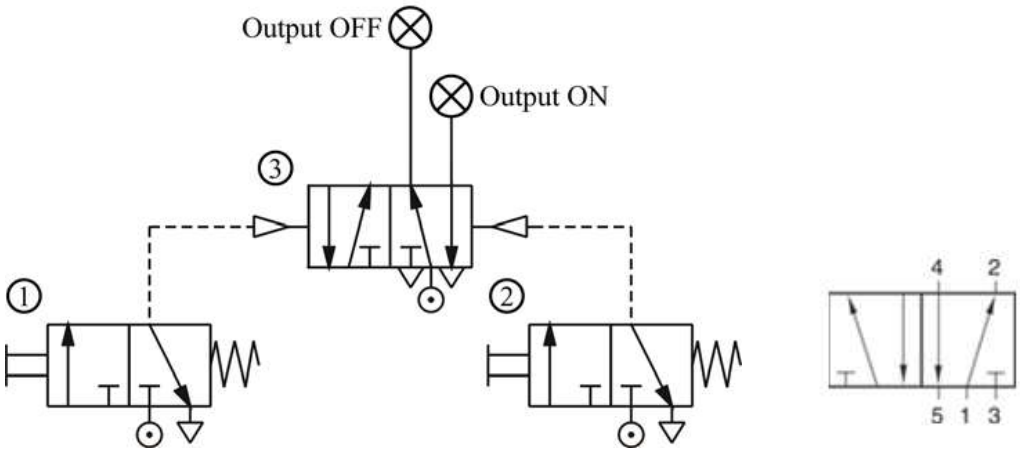
- When the pressure output of control valve 1 is the exact opposite of that of control valve 2, it is called signal inversion.
- Here, the working port of control valve 1 is connected to the pneumatic signal pressure line of the control valve 2 for controlling the operation of valve 2.
- When control valve 1 is operated, control valve 2 will stop producing pressure output.
- When control valve 1 stops operation and is restored to its original position, control valve 2 will resume its output.
- Therefore, at any given time, the pressure output of control valve 1 is the exact opposite of that of control valve 2. This is signal inversion.
- The diagram below shows how directional control valves can be switched. Control valve 1 is 3/2 DCV in NC mode. Control valve 2 is 3/2 DCV in NO mode.

Signal inversion:



18. Memory

- Memory function can keep a component at a certain state permanently until there is a change of signals.
- Fig. below shows a pneumatic memory function circuit. Control valve 1&2 are 3/2 DCV in NC mode. Control valve 3 is 5/2 DCV.
- Here, the working port of control valve 1 and 2 are connected to the pneumatic signal pressure line of valve 3 for controlling the operation of valve 3.
- When control valve 1 is operated for a short time, the output signal of the control valve 3 will be ON. It will be ON until control valve 2 is operated for a short time. Now the output of the control valve 3 will be OFF till another signal comes.



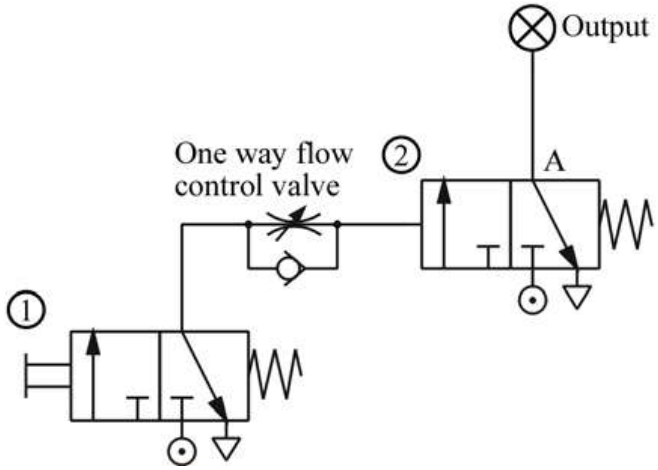
19. Delay

- A pneumatic delay circuit can delay the operating time of the next control valve. It uses one-way flow control valve as a restriction to slow down the flow of air and control the time of pneumatic operation.
- Delay functions are of two types: ON-signal delay and OFF signal delay. In ON delay, after the input is turned ON, there is a delay before the output is turned ON. In OFF delay, after the input is turned OFF, there is a delay before the output is turned OFF.

- ON-signal delay:

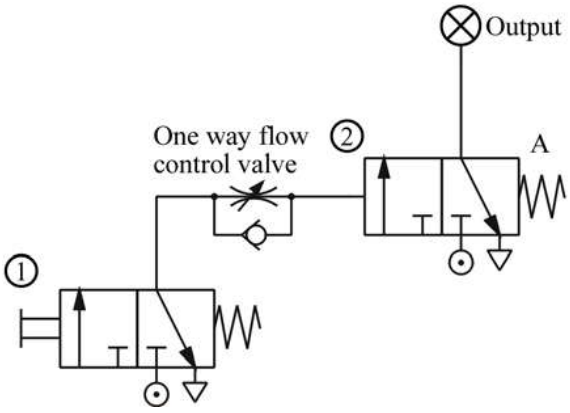
- ON-signal delay function delays the output of the control valve 2 by connecting a one-way flow control valve in the forward direction to its pneumatic signal pressure line for controlling its operation.
- When control valve 1 is operated, the one-way flow control valve will slow down the flow of air to the valve 2.
- Thus, it delays the signal output of the control valve 2 (A). There is a delay before the output is turned ON after the input is turned ON.
- This results in ON-signal delay.

    - Fig. below shows the circuit diagram of an ON-signal delay circuit



- OFF-signal Delay:

    - OFF-signal delay function delays the output of the second control valve by connecting a one-way flow control valve in the opposite direction to its pneumatic signal pressure line for controlling its operation.
    - Therefore, when control valve 1 is operated, the outlet of control valve 2 (A) will continue to output signals.
    - However, when control valve 2 is restored to its original position, the release of air is slowed down by the one-way flow control valve, resulting in a persistent OFF-signal.



20. Single acting cylinder control

- Single acting cylinders use 3/2 directional control valve. When they are controlled by two or more valves, it is called logic control. Examples of logic control include 'OR' function, 'AND' function, 'NOT' function, etc.

NOT

x	x'
0	1
1	0

AND

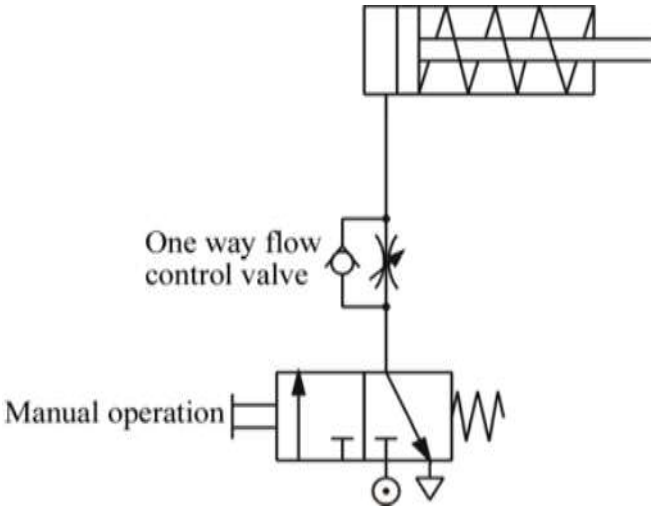
x	y	xy
0	0	0
0	1	0
1	0	0
1	1	1

OR

x	y	x+y
0	0	0
0	1	1
1	0	1
1	1	1

21. Direct control and speed control of Single acting cylinder:

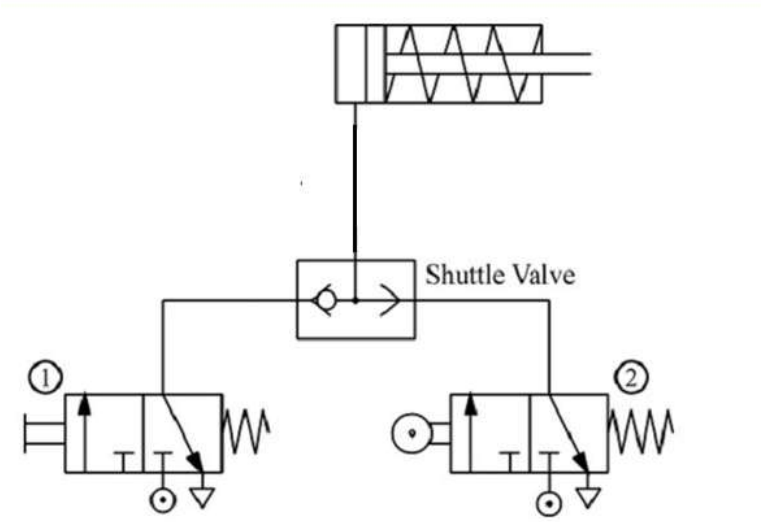
- Here, a single acting cylinder is connected to a manual 3/2 (NC) directional control valve.
- When the control valve is operated manually, it will cause the cylinder to work. Therefore, the circuit allows the cylinder to be controlled manually.



- By restricting the flow of air at the inlet and using the spring to determine the speed of retraction, the extension speed of the piston of a single acting cylinder can be changed.
- Therefore, a one-way flow control valve is placed in the circuit to control the speed of piston.

22. OR Function of Single acting cylinder

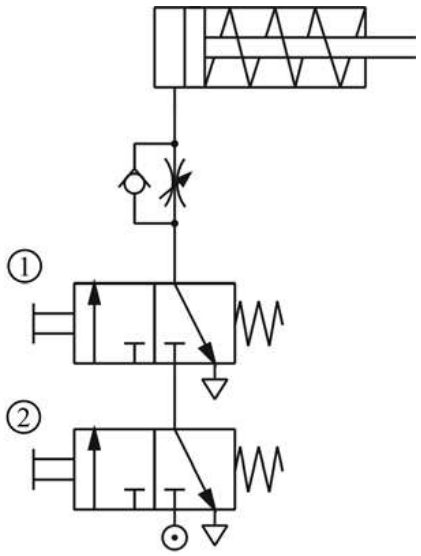
- In OR function, control is possible when any one of the two conditions or both are satisfied.
- In pneumatic OR function system, the flow passage will open when any one or both control valves are operated.
- The single acting cylinder here is controlled by two control valves. When either control valve 1 or control valve 2 is operated, the cylinder will work. Therefore, the circuit has OR function. The output of two 3/2 directional control valves (1 &2) are connected through the shuttle valve to the cylinder.
- The circuit consists of two 3/2 directional control valves (in NC mode), shuttle valve and cylinder.



23. AND Function of Single acting cylinder

- In AND function, control is possible only when two conditions are satisfied.
- In pneumatic AND function system, the flow passage will open only when both control valves are operated.
- Another name for an AND function is interlock control.
- Fig. below shows the circuit diagram of an AND function circuit. The cylinder will work only when both valve 1 and 2 are operated.

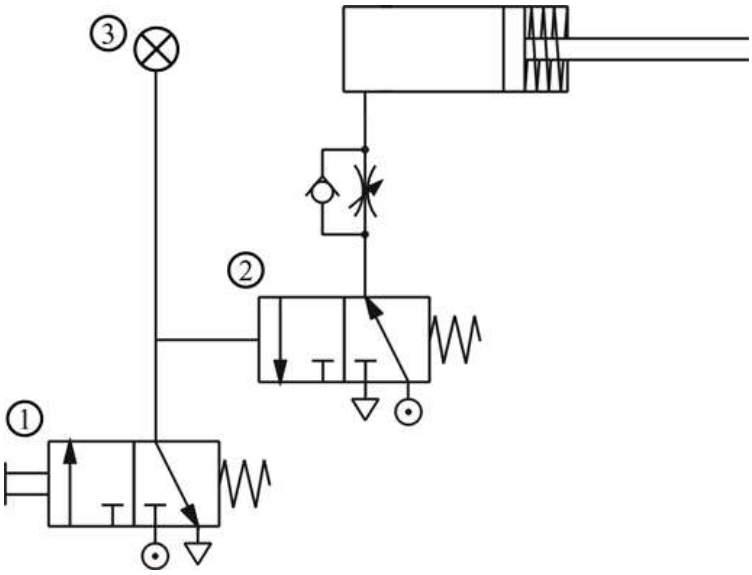
AND function:



24. NOT Function of Single acting cylinder

- Another name for a NOT function is inverse control.
- Here, the normally closed type control valve 1 is used to cut off the normally open type control valve 2 and thus it changes the output signal.
- In order to hold or lock an operating conveyor or a similar machine, the cylinder must be locked until a signal for cancelling the lock is received. Therefore, the signal for cancelling the lock should be operated by a normally open type control valve.
- But to cancel the lock, the same signal must also cancel the locks on other devices, like the indication signal 3 in Fig. below.

NOT Function:



25. Double acting cylinder control

(i) Direct control

- The double acting cylinder uses a 5/2 directional control valve.
- Usually, when a double acting cylinder is not operated, outlet 'B' and inlet 'P' will be connected. In this circuit, whenever the operation button is pushed manually, the double acting cylinder will move back and forth once.

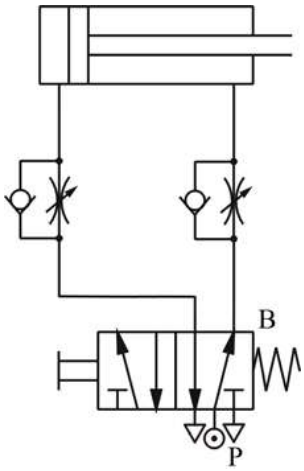


Fig. Circuit diagram of a double acting cylinder direct control circuit

- In order to control the speed in both directions, flow control valves are connected to the inlets on both sides of the cylinder. Connecting the circuit in this way allows the input of sufficient air pressure and energy to drive the piston.

(ii) Single control:

- A cylinder always has to maintain its position in a lot of situations, even after the operational signal has disappeared. This can be achieved by the use of a circuit that possesses the memory functions.
- As shown in Fig. below, the extension path of a double acting cylinder is activated by control valve 1, while retraction is controlled by control valve 2. Control valve 3, is for

maintaining the position of the cylinder by maintaining its own position. Control valve 3 will be changed only when one of the manual control valves is pushed.

- If both control valves 1 and 2 are operated at the same time, control valve 3 will be subject to the same pressure and will remain in its original position.

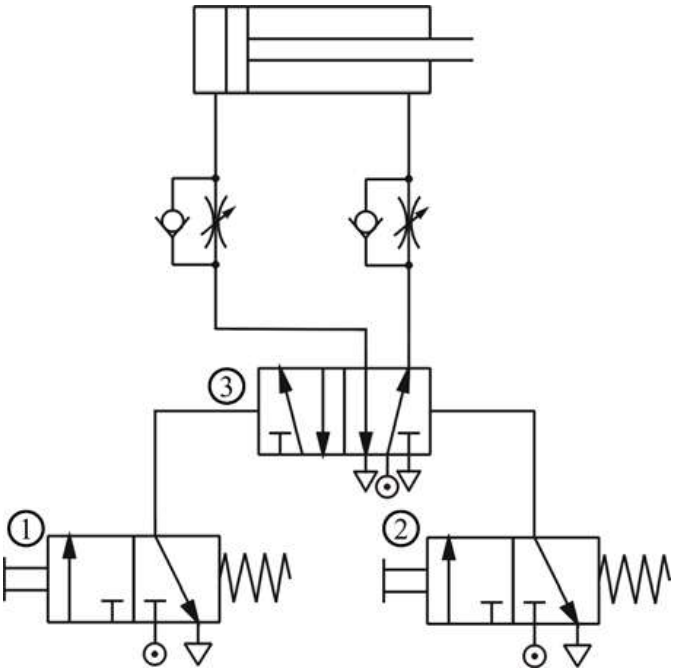
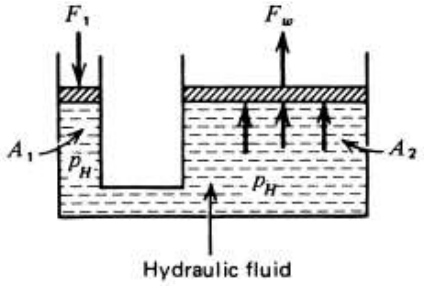


Fig. Circuit that maintains the position of a double acting cylinder

26. Hydraulic actuators: Linear -Single acting, double acting, Double Rod Cylinder

Hydraulic Actuators:

- In pneumatic systems, there is an upper limit to the forces that can be applied using gas as the working fluid. So, when large forces are required, a hydraulic actuator is used. A hydraulic actuator converts a small force into an amplified force.
- An incompressible fluid is used to provide the pressure, which can be made very large by adjusting the area of the forcing piston, A_1. The hydraulic pressure is given by $P_{H.}$ It is transferred equally throughout the liquid, so the resulting force on the working piston is $F_W=P_H*A_2$



- A single-acting hydraulic cylinder has only one port. This is where the hydraulic fluid enters and forces the plunger out in one direction.

- A double-acting cylinder has two ports: one for the hydraulic fluid to enter and extend the plunger, and the other for retracting the cylinder.