Directional control valves

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OBJECTIVES:

The following report aims at discussing and elaborating on the subject of hydraulic control valves, particularly directional control valves. It introduces the following topics:

- Principle of working of hydraulic valves
- Naming and ANSI convention of directional control valves
- Ability to make a hydraulic circuit from the system description
- Judge the specifications of valve needed based on the application and the circuit

Contents:

1 Introduction:

As the name suggests, these are used to control the direction of flow of a fluid in a pneumatic or hydraulic system. These valves cannot regulate the flow to a certain pressure and are simply on/off valves. These are vital components and are extensively used in a variety of systems ranging in precision from robotic hands to assembly line architecture.

The report introduces the topic and the basic understanding of the principles involved are explained. This is followed by the state-of-the-art systems and instances where these valves play a central role in the control and regulation part.

2 Principle of operation:

The objective of the valve is directing or allowing the flow according to the state it is set in at that time. Valves with more than 4 states are available now <cite>. The specifications and the limitations on the system vary one manufacturer to other. Some examples are given here.

- Flow rates: 0 – 100 l/min
- System pressure: up to 240 bar

The selection of the valve has to be done keeping in mind the above limitations which depend on the application where it is to be used.

The main part of any directional control valve is a spool whose movement selectively closes and opens specific channels owing to its geometry. The valves can be classified based on the type of spool. The spool is essentially consists of lands and grooves, which restrict and allow fluid flow respectively. The holes through which the system and the supply pressure lines are connected are called ports. Based on the number of lands and grooves on the spool and the number of ports in the casing, the number of states of the valve changes. This number of unique states the valve can achieve is called the number of positions of the directional control valve.

3 Classifications based on functional features:

Based on the previous description of the working principle of the valve, there are some basic features that dictate a valve and these features can be used to classify the valves.

3.1 Number of ports

The most basic property of the valve is the number of the ports. This limits the total number of input and output lines the valve can control. It has to be noted that this number is going to be less than the number of ports since the supply pressure and the tank or exhaust line will together take up two of the ports in all systems. The tank line cannot be circumvented since in a hydraulic system since the amount of fluid available is limited and has to be recycled unlike pneumatic systems which can forgo the use of a tank.

3.2 Number of flow paths

The number of different possible flows in a valve is usually referred as the 'ways'. Valves are referred as 4-way, 3-way, etc. This is inherently related to the number of ports in the system but may not always be equal to it. If all the different possible flows between the ports are enumerated and counted, that would tell us the number of ways of flow possible in the valve. This will be further explained after the representation of the valves are covered.

3.3 Actuation mechanism

The positions or states possible in the valve are switched by external actuation. This again depends on the application and the actuation can be mechanical, electrical or fluid pressure signals [1]. Irrespective of the principle, a number of actuation mechanisms are possible as shown in Figure 1.

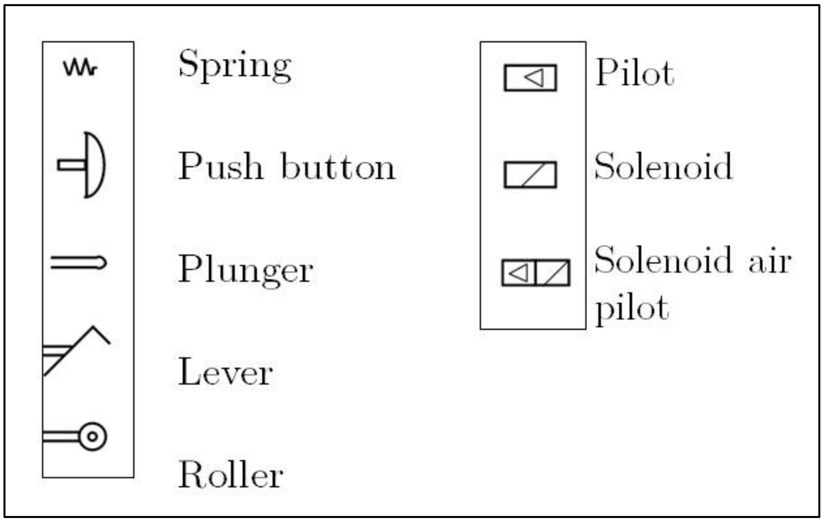


Figure 1 Actuation mechanisms possible

3.4 Spool type

Apart from the above functional variations in the valve, there is another classification based on the type of spool used in the valve. There can be rotary and linear spool valves. An example of a rotary spool valve is shown in Figure 2. The alignment of the ports with the internal groove in the rotor allows flow of the fluid.

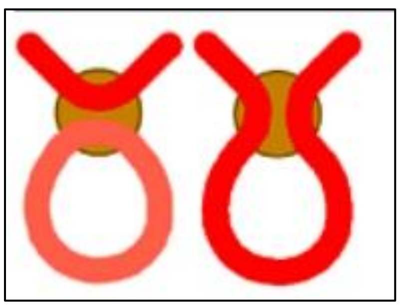


Figure 2 Directional valve with a rotating spool

4 ANSI/ISO representation:

The convention of representation of these valves is vital to the understanding of the above given classifications. This section introduces the conventions and the various symbols associated with the representation of a complete pneumatic circuit and the components involved [2].

In the ANSI system, the valve is represented by a square. The various functional specifications are built upon the square to convey the complete information in one picture. The valve in Figure 3 is used to illustrate this concept.

4.1 Steps to draw the symbol of a valve:

The valve has three ports where P represents the pressure supply or the inlet port. A, B are for the connections of the application.

4.1.1 Representing number of positions -

Step 1: Find the number of positions of the valve. In this example, it is assumed that the actuation is done by solenoid and this gives two possible positions. Activating one solenoid shifts the spool towards it allowing the port closer to the activated solenoid to be open while the one farthest is closed. P is open in both positions.

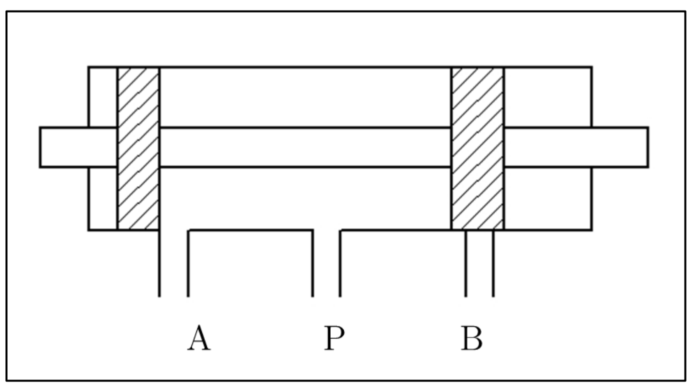
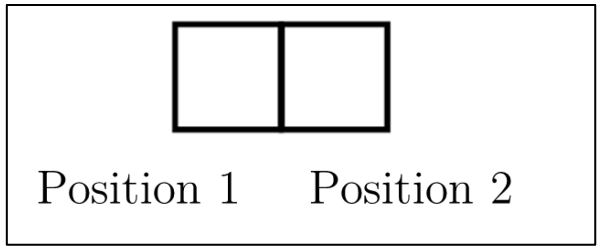


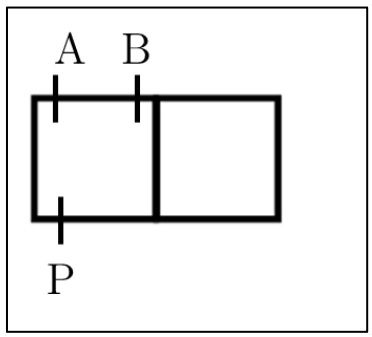
Figure 3 Example system to illustrate ANSI representation

Step 2: Draw a number of squares equal to n_s = number of switching positions as found from above step.



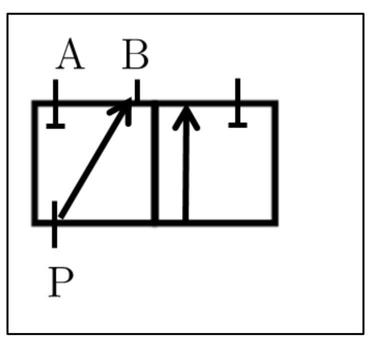
4.1.2 Representing ports -

Step 3: The ports are represented as lines on the boundary of the square. Number of ports (n_p) in above example is three.



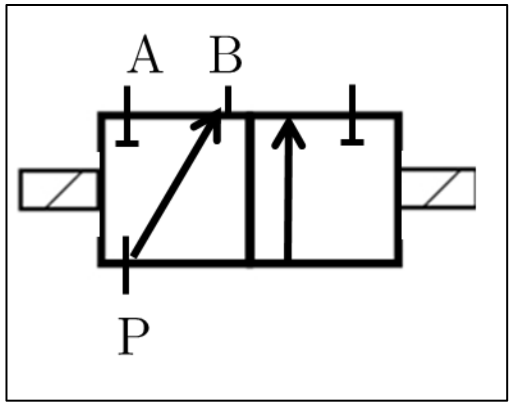
4.1.3 Representing the flow directions –

Step 4: The flow direction for each state is represented inside the box by using an arrow following the fluid flow from source port to destination port. In the example, the flow is from P to A in the first state and from P to B in the second state.



4.1.4 Representation of actuation of mechanism –

Step 5: In the example, both the states are toggled by two solenoids respectively.



A few examples of different types of control valves and their representations are given in the following Table 1.

4.2 Spool center conditions

Based on the middle position of the spool in three-position linear valves, there are a variety of designs. They differ only in the middle position and have identical flow pattern in any of the shifted positions. The open center spool interconnects the ports and the inlet goes to the tank directly at low pressure. The closed center spool has all the spools closed in the middle position. Figure 4 shows some of the configurations of the center position apart from the closed and open center spools [3].

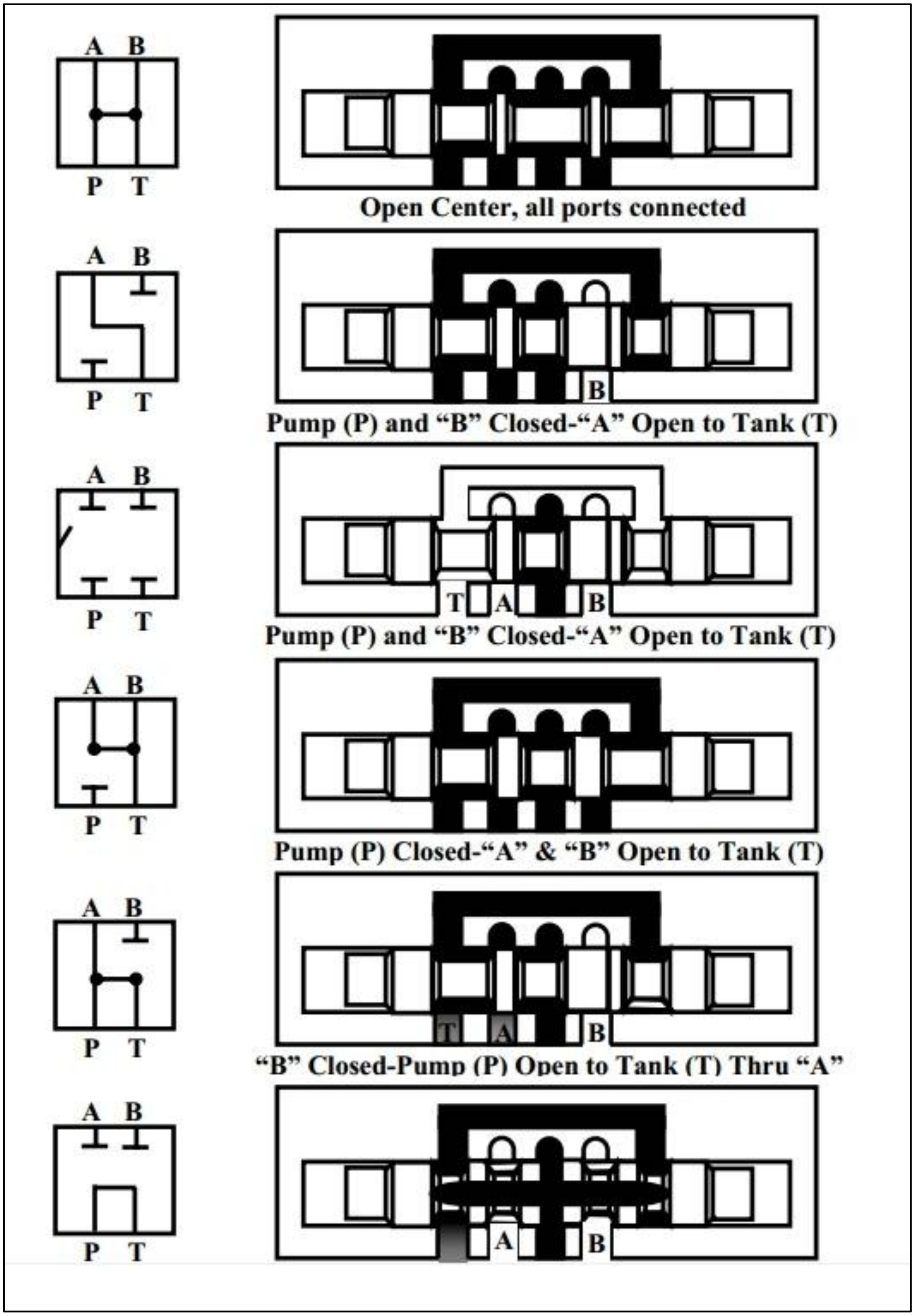
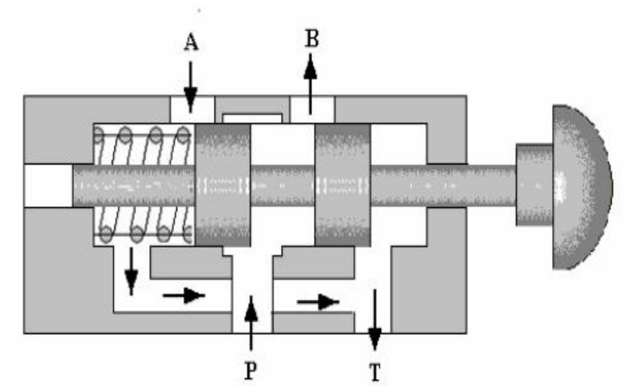
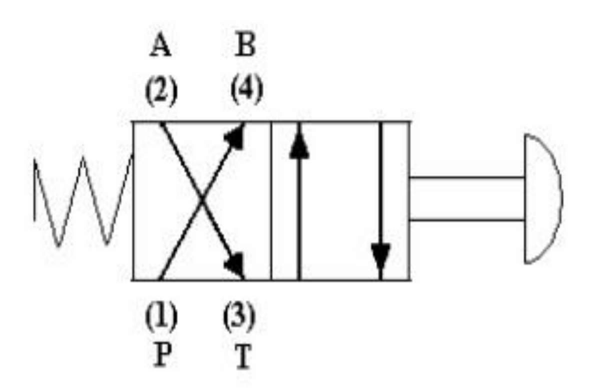
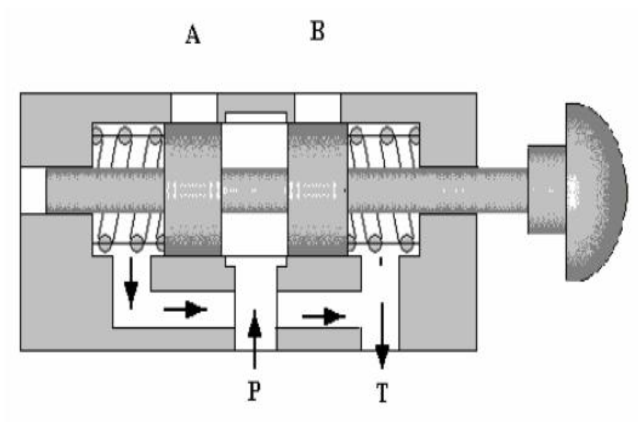
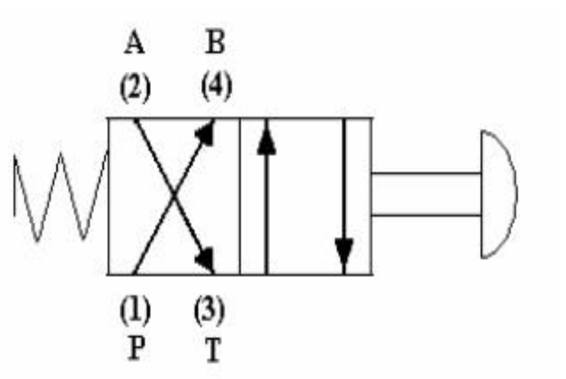
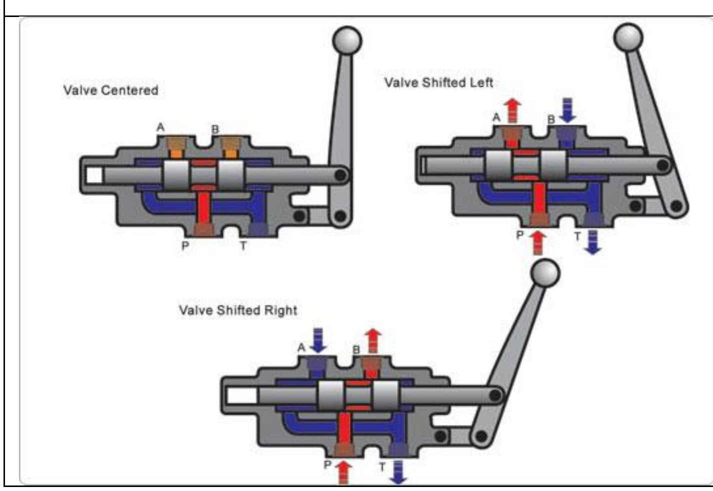
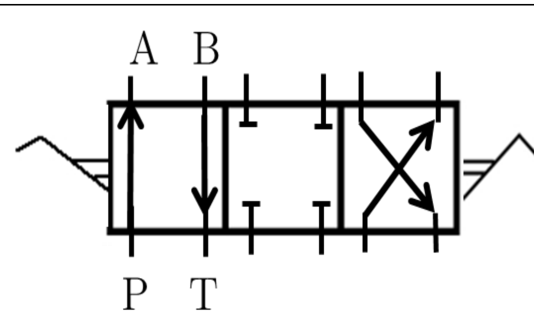


Figure 4 Center configurations of a linear spool

Table 1 ANSI representations of some example systems [4]

System	ANSI representation
	
	
	

4.3 Stability of valves

Stability is a term used to describe the preferred positions in the valve [5]. In Figure 5, the valve has a plunger actuation on one side and a spring on the other. Which means, without external actuation, the preferred position for this valve will be position 2. Hence, this valve with one stable position, is called mono-stable.

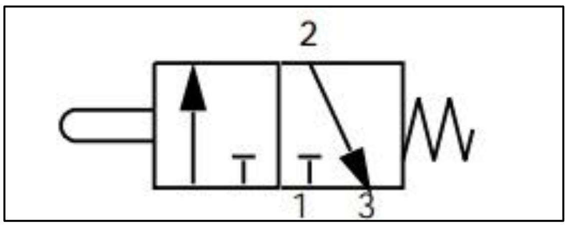


Figure 5 Monostable valve

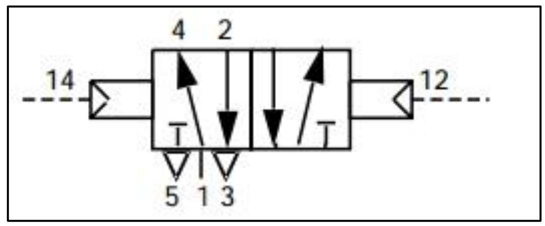


Figure 6 Bistable valve

In Figure 6, we have pilot operation on both the sides. It can be seen that there are multiple stable positions for this valve. An impulse on 14 activates position-1 and it stays that way after the impulse has been taken off. This proves that position 1 is a stable position. This argument can be extended for position-2 also. Hence, this valve with two stable positions is called a bi-stable valve. This is again a way of classifying and it also gives some information about the valves' positions.

5 Specific commercially used valves

5.1 Poppet valve

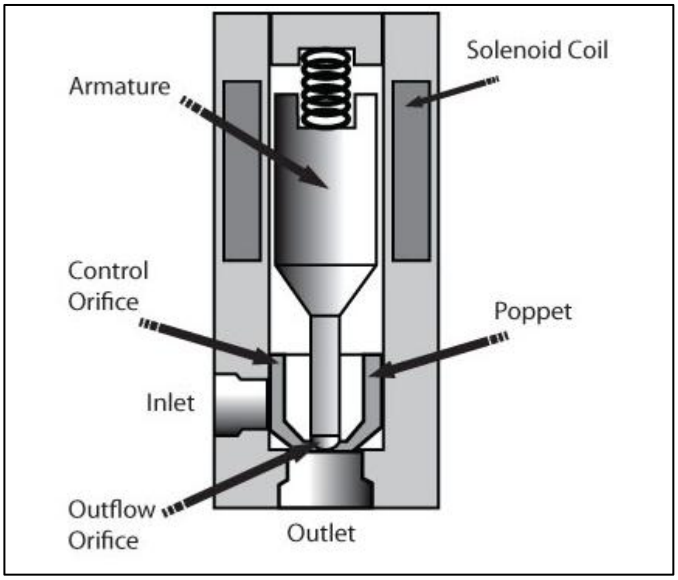


Figure 7 Poppet valve [6]

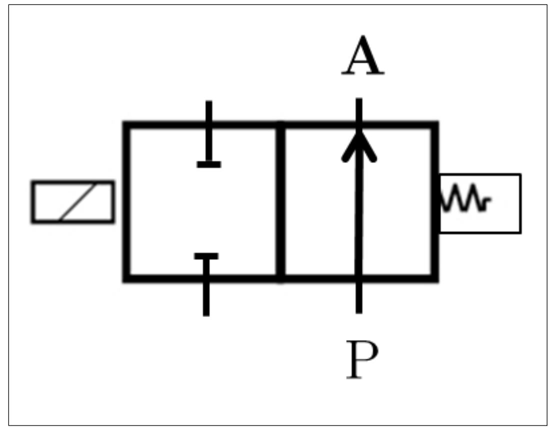


Figure 8 ANSI symbol for the poppet valve

As Figure 7 shows, the poppet valve is a two way, spring activated valve. During solenoid on, the valve is closed and the spring pulls back when the solenoid deactivates allowing fluid flow from P to A.

The poppet valve is one of the important parts of the IC engine. They are located at the cylinder head and it allows the fuel in for combustion and exhausts the remains at end of stroke. It is also used in the steam engine to control the flow of steam into the cylinders.

Poppet valves have the advantage of not needing lubrication since they lift off from the port obviating any sliding motion.

5.2 Pilot operated valves

Sometimes the force needed for the actuation of a valve, i.e. the switching of the spool is huge. Manual switching becomes impractical. Then fluid pressure itself is used for the switching by way of another valve. This is called a pilot valve where one valve's state controls another. The Figure 9 shows an example of one pilot operated valve.

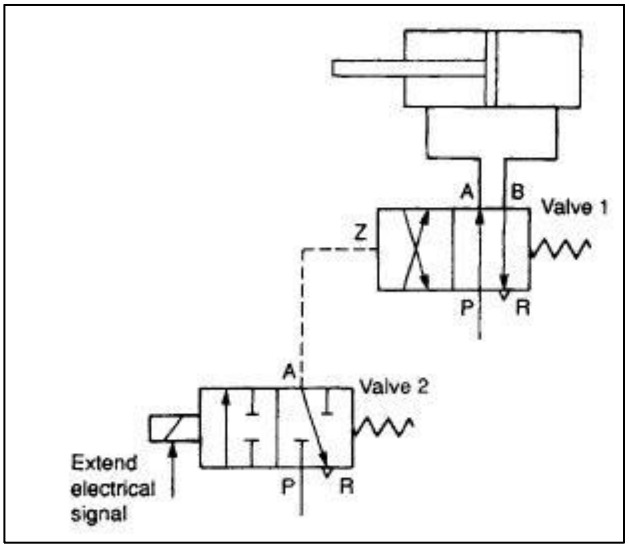


Figure 9 Pilot-operated valve

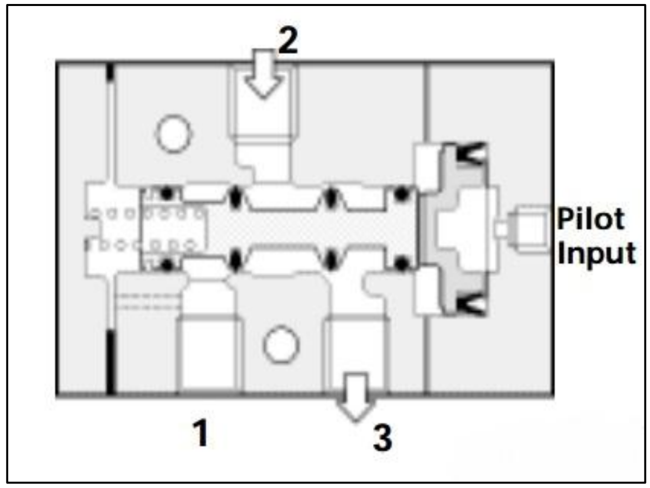


Figure 10 Working principle of an air pilot valve

The pilot valve, valve-2 is of small capacity and can be easily operated by a solenoid or even manually. When activated, flow occurs from P to A in valve-2 leading to a switching to position-1 in valve-1, flow occurring from P to B and A to R. Subsequently, the valve-1 can be used for the actuation of a large capacity application like a hydraulic cylinder.

5.3 Check valves

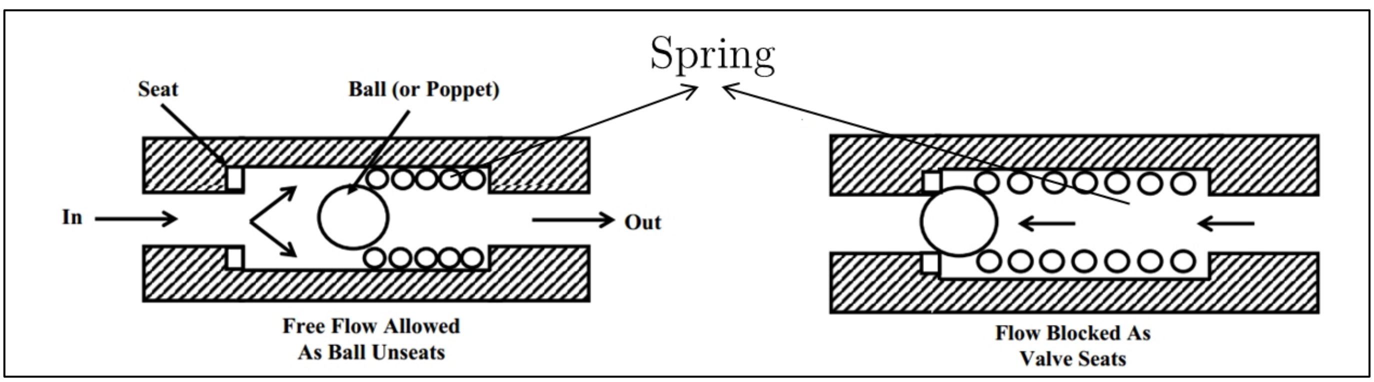


Figure 11 Ball-and-seat check valve

These are uni-directional valves and free flow occurs only in one direction. In Figure 11 it can be seen that the flow can only occur when the ball is pressed by the fluid and the port opened as a result of that. Any flow from the other direction causes the ball to close the port, resulting in no flow passage. When flow stops in the permitted direction, the valve resets by the help of spring. Their represented by the ISO symbol in

Figure 13.

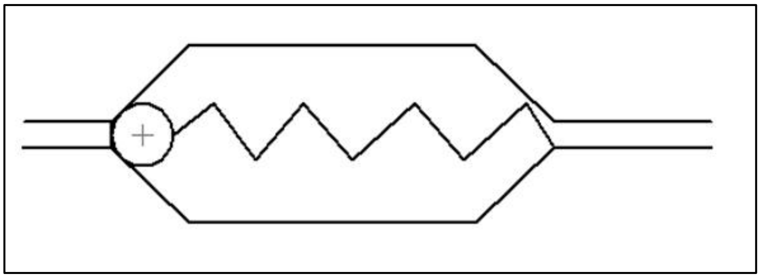


Figure 12 Concept representation of check valves

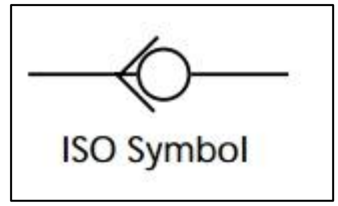


Figure 13 Uni-directional valve representation

5.4 Pilot-operated check valves

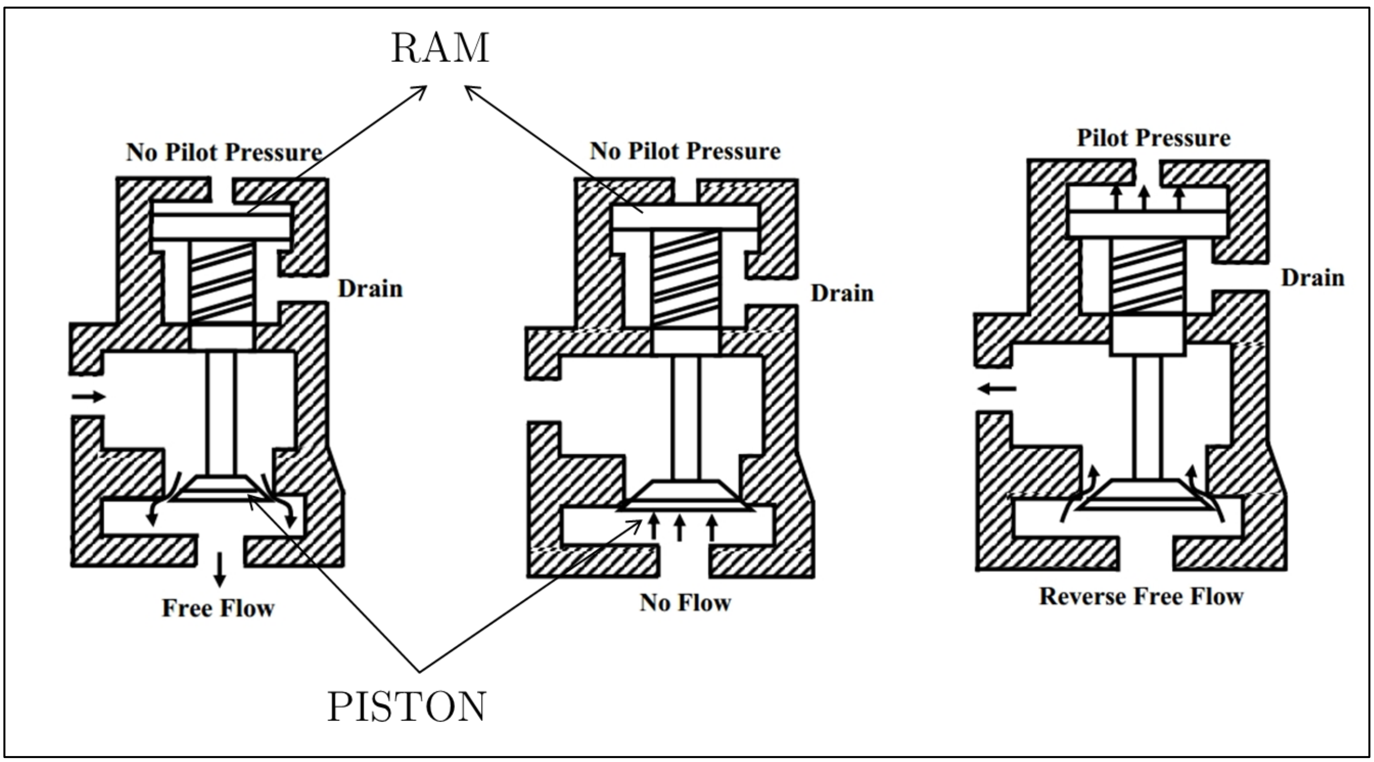


Figure 14 Pilot operated check valves

Pilot check valves are more versatile and have multiple modes of operation, unlike the simple ball-and-seat arrangement. In Figure 14, it can be seen that there is an inlet for allowing hydraulic fluid to exert pilot pressure on the ram. Depending on presence or absence of pilot pressure, there are two modes of operation for this valve.

The pilot operated check valve has a piston that, owing to its geometry allows flow in only one direction. Flow trying to pass through the other direction will lead the piston to close the opening.

5.4.1 Pilot pressure off:

When there is no pressure on the ram, the spring pulls back on the piston forcing it closed. For any fluid flow to occur, the piston has to be moved downwards by the fluid. Opposite flow is not possible since the opening will be closed by the fluid pressure itself.

5.4.2 Pilot pressure on:

When pilot fluid is allowed, the pressure on the ram pushes the piston down, making it open regardless of fluid flow direction. This valve now acts as a both-ways valve.

The application of this valve is in systems where one flow direction has to be quickly stopped in minimum delay time. In such systems, the normal mode of operation is kept with the pilot pressure on. When the reverse flow has to be stopped, the removal of pilot pressure elicits a quick response from the piston and the reverse flow is blocked.

6 References

[1] W. Bolton, *Mechatronics - Electronic Control Systems in Mechanical and Electrical Engineering.* 2009.

[2] “Understanding ANSI / ISO Schematic symbols for fluid power components.” [Online]. Available: http://www.clippard.com/downloads/PDF_Documents/Application_and_Training/Clippard Schematic symbols.pdf.

[3] “Industrial Automation and Control - NPTEL IIT KGP.”

[4] “Spool-type hydraulic directional valves.” [Online]. Available: http://www.hydraulicfacts.com/Hydraulic-Systems/Taking-The-Mystery-Out.html.

[5] “British Pneumatic Handbook,” pp. 59–69.

[6] “Taking the mystery out of hydraulic valves.” [Online]. Available: http://www.hydraulicfacts.com/Hydraulic-Systems/Taking-The-Mystery-Out-2.html.