

Module

6

Actuators

Lesson

25

Control Valves

Instructional Objectives

At the end of this lesson, the student should be able to:

- Explain the basic principle of operation of a pneumatically actuated control valve
- Distinguish between *air-to-open* and *air-to-close* valves.
- Explain the constructions and relative advantages and disadvantages of single- seated and double-seated valves.
- Name three types of control valves and sketch their ideal flow characteristics.
- Sketch the shapes of the plugs for three different types of control valves.
- Define the term rangeability.
- Explain the different between ideal and effective characteristics.
- Explain the advantage of using equal percentage valve over using linear control valve.

Introduction

The control action in any control loop system, is executed by the final control element. The most common type of final control element used in chemical and other process control is the control valve. A control valve is normally driven by a diaphragm type pneumatic actuator that throttles the flow of the manipulating variable for obtaining the desired control action. A control valve essentially consists of a plug and a stem. The stem can be raised or lowered by air pressure and the plug changes the effective area of an orifice in the flow path. A typical control valve action can be explained using Fig. 1. When the air pressure increases, the downward force of the diaphragm moves the stem downward against the spring.

Classifications

Control valves are available in different types and shapes. They can be classified in different ways; based on: (a) action, (b) number of plugs, and (c) flow characteristics.

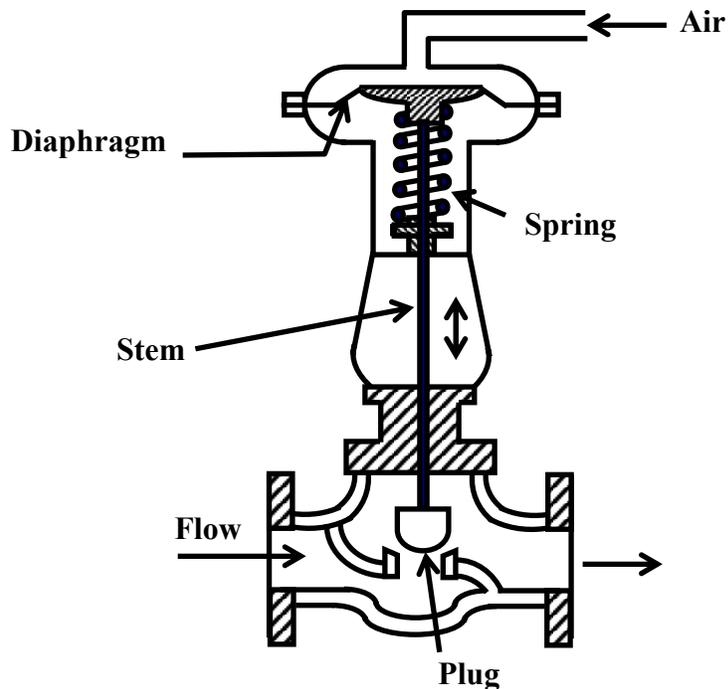
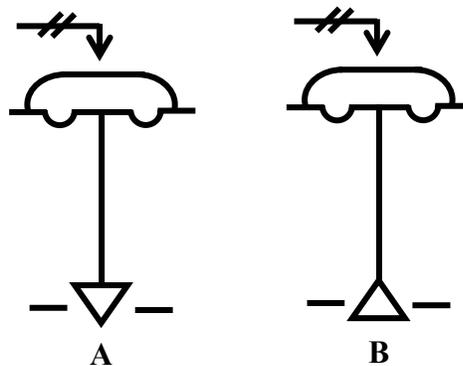


Fig. 1 Control valve

(a) Action: Control valves operated through pneumatic actuators can be either (i) air to open, or (ii) air to close. They are designed such that if the air supply fails, the control valve will be either fully open, or fully closed, depending upon the safety requirement of the process. For example, if the valve is used to control steam or fuel flow, the valve should be shut off completely in case of air failure. On the other hand, if the valve is handling cooling water to a reactor, the flow should be maximum in case of emergency. The schematic arrangements of these two actions are shown in Fig. 2. Valve A are air to close type, indicating, if the air fails, the valve will be fully open. Opposite is the case for valve B.



- Fail open or Air to close : A
- Fail closed or Air to open : B

Fig. 2 Air to open and Air to close valves

(b) Number of plugs: Control valves can also be characterized in terms of the number of plugs present, as *single-seated valve* and *double-seated valve*. The difference in construction between a single seated and double-seated valve are illustrated in Fig. 3.

Referring Fig.1 (and also Fig. 3(a)), only one plug is present in the control valve, so it is single seated valve. The advantage of this type of valve is that, it can be fully closed and flow variation from 0 to 100% can be achieved. But looking at its construction, due to the pressure drop across the orifice a large upward force is present in the orifice area, and as a result, the force required to move the valve against this upward thrust is also large. Thus this type of valves is more suitable for small flow rates. On the other hand, there are two plugs in a double-seated valve; flow moves upward in one orifice area, and downward in the other orifice. The resultant upward or downward thrust is almost zero. As a result, the force required to move a double-seated valve is comparatively much less.

But the double-seated valve suffers from one disadvantage. The flow cannot be shut off completely, because of the differential temperature expansion of the stem and the valve seat. If one plug is tightly closed, there is usually a small gap between the other plug and its seat. Thus, single-seated valves are recommended for when the valves are required to be shut off completely. But there are many processes, where the valve used is not expected to operate near shut off position. For this condition, double-seated valves are recommended.

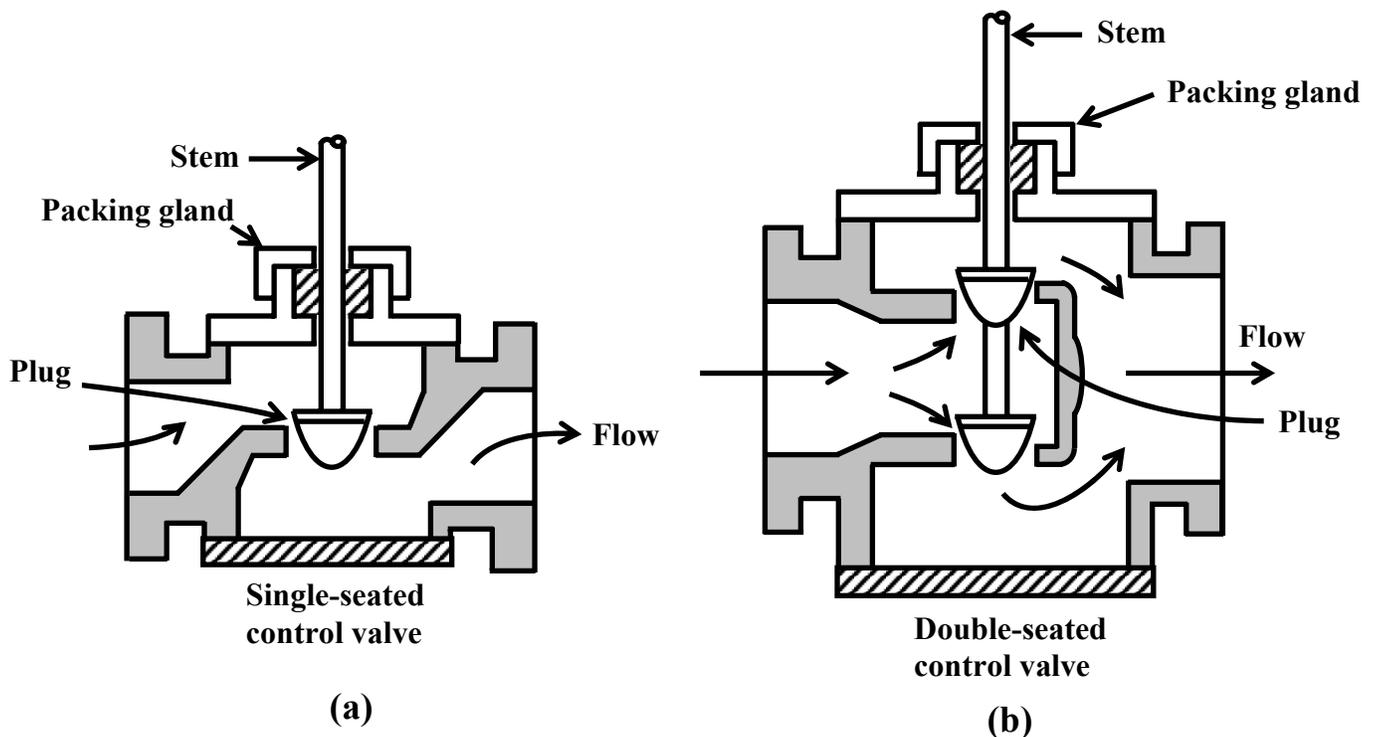


Fig. 3 Single-seated and double-seated valves

(c) **Flow Characteristics:** It describes how the flow rate changes with the movement or lift of the stem. The shape of the plug primarily decides the flow characteristics. However, the design of the shape of a control valve and its shape requires further discussions. The flow characteristic of a valve is normally defined in terms of (a) inherent characteristics and (b) effective characteristics. An inherent characteristic is the ideal flow characteristics of a control valve and is decided by the shape and size of the plug. On the other hand, when the valve is connected to a pipeline, its overall performance is decided by its effective characteristic.

Ideal Characteristics

The control valve acts like an orifice and the position of the plug decides the area of opening of the orifice. Recall that the flow rate through an orifice can be expressed in terms of the upstream and downstream static pressure heads as:

$$q = K_1 a \sqrt{2g(h_1 - h_2)} \quad (1)$$

where q = flow rate in m^3/sec .

K_1 = flow coefficient

a = area of the control valve opening in m^2

h_1 = upstream static head of the fluid in m

h_2 = downstream static head of the fluid in m

g = acceleration due to gravity in m/sec^2 .

Now the area of the control valve opening (a) is again dependent on the stem position, or the lift. So if the upstream and downstream static pressure heads are somehow maintained constant, then the flow rate is a function of the lift (z), i.e.

$$q = f(z) \quad (2)$$

The shape of the plug decides, how the flow rate changes with the stem movement, or lift; and the characteristics of q vs. z is known as the inherent characteristics of the valve.

Let us define

$$m = \frac{q}{q_{\max}} \quad \text{and} \quad x = \frac{z}{z_{\max}}$$

where, q_{\max} is the maximum flow rate, when the valve is fully open and z_{\max} is the corresponding maximum lift. So eqn. (2) can be rewritten in terms of m and x as:

$$m = f(x) \quad (3)$$

and the valve sensitivity is defined as dm/dx , or the slope of the curve m vs. x . In this way, the control valves can be classified in terms of their m vs. x characteristics, and three types of control valves are normally in use. They are:

- (a) Quick opening
- (b) Linear
- (c) Equal Percentage.

The characteristics of these control valves are shown in Fig. 4. It has to be kept in mind that all the characteristics are to be determined after maintaining constant pressure difference across the valve as shown in Fig.4.

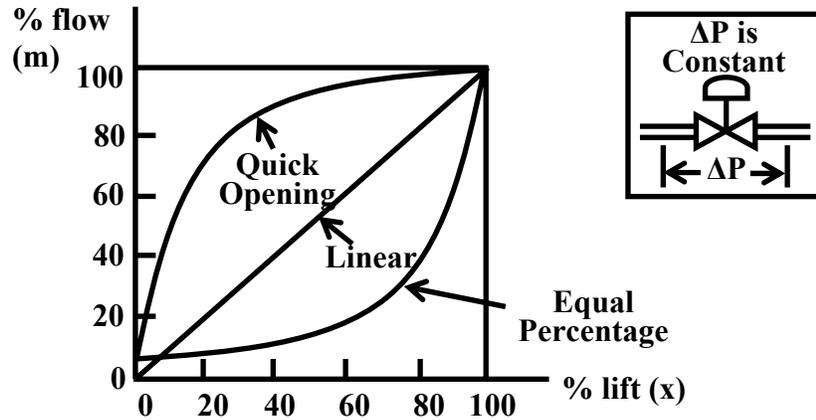


Fig. 4 Flow characteristics of control valves

Different flow characteristics can be obtained by properly shaping the plugs. Typical shapes of the three types of valves are shown in Fig. 5

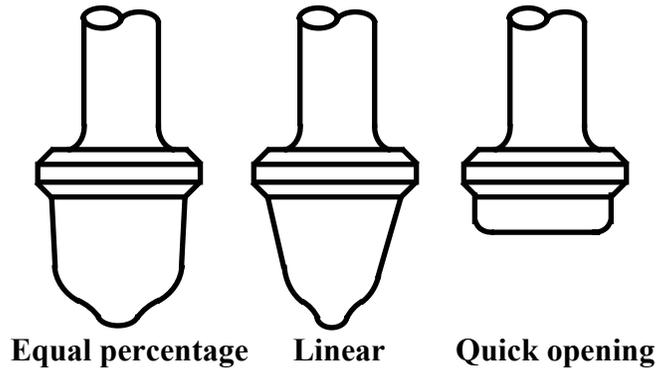


Fig. 5 Valve plug shapes for the three common flow characteristics.

For a linear valve, $dm/dx=1$, as evident from Fig.5 and the flow characteristics is linear throughout the operating range. On the other hand, for an equal percentage valve, the flow characteristics is mathematically expressed as:

$$\frac{dm}{dx} = \beta m \tag{4}$$

where β is a constant.

The above expression indicates, that the slope of the flow characteristics is proportional to the present flow rate, justifying the term equal percentage. This flow characteristics is linear on a semilog graph paper. The minimum flow rate m_0 (flow rate at $x=0$) is never zero for an equal percentage valve and m can be expressed as:

$$m = m_0 e^{\beta x} \tag{5}$$

Rangeability of a control valve is defined as the ratio of the maximum controllable flow and the minimum controllable flow. Thus:

$$\text{Rangeability} = \frac{\text{maximum controllable flow}}{\text{minimum controllable flow}}$$

Rangeability of a control valve is normally in between 20 and 70.

Effective Characteristics

So far we have discussed about the ideal characteristics of a control valve. It is decided by the shape of the plug, and the pressure drop across the valve is assumed to be held constant. But in practice, the control valve is installed in conjunction with other equipment, such as heat exchanger, pipeline, orifice, pump etc. The elements will have their own flow vs. pressure characteristics and cause additional frictional loss in the system and the effective characteristics of the valve will be different from the ideal characteristics. In order to explain the deviation, let us consider a control valve connected with a pipeline of length L in between two tanks, as shown in Fig. 6. We consider the tanks are large enough so that the heads of the two tanks H_0 and H_2 can be assumed to be constant. We also assume that the ideal characteristic of the control valve is linear. From eqn. (1), we can write for a linear valve:

$$K_1 a = Kz$$

where K is a constant and z is the stem position or lift.

Now the pipeline will experience some head loss that is again dependent on the velocity of the fluid.

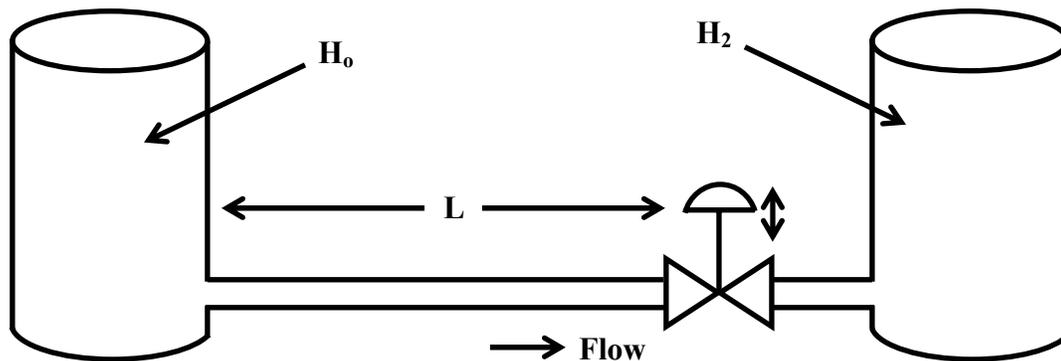


Fig. 6 Effect of friction loss in pipeline for a control valve

The head loss Δh_L will affect the overall flow rate q and eqn.(1) can be rewritten as:

$$q = \left[K \sqrt{2g(H_0 - H_2 - \Delta h_L)} \right] z \quad (6)$$

The head loss (in m) can be calculated from the relationship:

$$\Delta h_L = F \frac{L}{D} \frac{v^2}{2g} \quad (7)$$

where F = Friction coefficient

L = Length of the pipeline in m

D = inside diameter of the pipeline in m

v = velocity of the flow in m.

Further, the velocity of the fluid can be related to the fluid flow q (in m^3/sec) as:

$$v = \frac{q}{\frac{\pi}{4} D^2} \quad (8)$$

Combining (7) and (8), we can write:

$$\Delta h_L = \frac{8}{\pi^2} \frac{FL}{gD^5} q^2 \quad (9)$$

Substituting (9) in (6) and further simplifying, one can obtain:

$$q = \left[K \sqrt{\frac{2g(H_0 - H_2)}{1 + \alpha z^2}} \right] z \quad (10)$$

where $\alpha = \frac{16FLK^2}{\pi^2 D^5}$

From (10), it can be concluded that q is no longer linearly proportional to stem lift z , though the ideal characteristics of the valve is linear. This nonlinearity of the characteristics is dependent on the diameter of the pipeline D ; i.e. smaller the pipe diameter, larger is the value of α and more is the nonlinearity. The nonlinearity of the effective valve characteristics can be plotted as shown in Fig. 7.

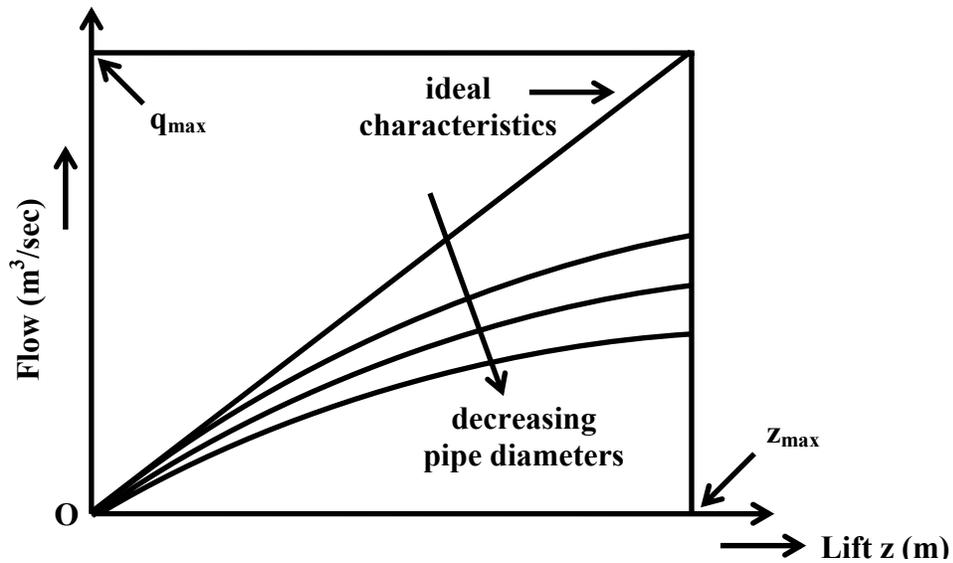


Fig. 7 Effect of pipeline diameter on the effective flow characteristics of the control valve

The nonlinearity introduced in the effective characteristics can be reduced by mainly (i) increasing the line diameter, thus reducing the head loss, (ii) increasing the pressure of the source H_0 , (iii) decreasing the pressure at the termination H_2 .

The effective characteristics of the control valve shown in Fig.7 are in terms of absolute flow rate. If we want to express the effective characteristics in terms of $m (= \frac{q}{q_{\max}})$ in eqn. (3)

deviation from the ideal characteristics will also be observed. Linear valve characteristics will deviate upwards, as shown in Fig. 8. An equal percentage valve characteristic will also shift upward from its ideal characteristic; thus giving a better linear response in the actual case.

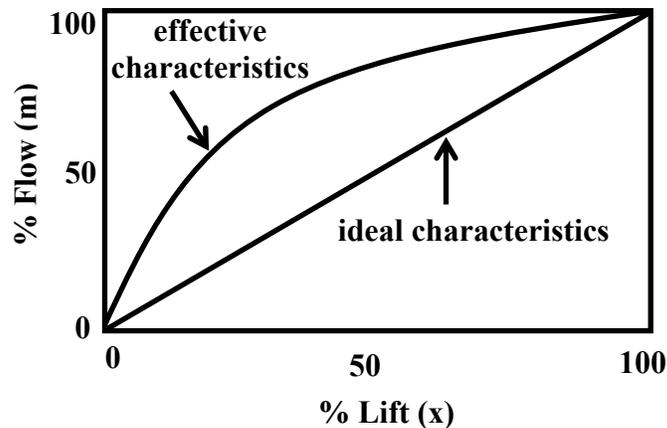


Fig. 8 Comparison of ideal and effective characteristics for a linear valve

Thus linear valves are recommended when pressure drop across the control valve is expected to be fairly constant. On the other hand, equal percentage valves are recommended when the pressure drop across the control valve would not be constant due to the presence of series resistance in the line. As the line loss increases, the effective characteristics of the equal percentage valve will move closer to the linear relationship in m vs. x characteristics.

Conclusion

A control valve is the final control element in a process control. Thus the effectiveness of any control scheme depends heavily on the performance of the control valve. The proper design and fabrication of the valve is very important in order to achieve the desired performance level. Moreover control valves are of different size and shapes. Only few types of control valves have been discussed here, leaving a large varieties of valves, those are in use, to name a few, globe valves, butterfly valves, V-port valves etc. We have discussed here the pneumatically actuated control valves, though electrically and hydraulically actuated valves are also not uncommon.

The shape of a valve plug is not the only deciding factor for determining its effective flow characteristics, but other equipment connected in the line along with the control valve, also affect its flow characteristics. Thus the effective flow characteristics of a linear valve may become nonlinear, as has been shown in this lesson. For this reason, equal percentage valves are preferred in many cases, since their effective characteristics tend to be linear, in presence of head loss in the pipeline. There are distinct guidelines for selecting the valve size and shape depending on load change, pipeline diameter etc. Bypass lines are sometimes used with a control valve in order to change the flow characteristics of the valve.

References

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Review Questions

1. Sketch the construction of a pneumatically actuated diaphragm type single-seated control valve.
2. Discuss the construction, advantages and disadvantages of a double-seated control valve.
3. When would you recommend to use an air-to-close control valve? Give an example.
4. Sketch and discuss the plug shapes and ideal flow characteristics of three different types of control valves.
5. Discuss the ideal flow characteristics of an equal percentage valve.
6. Define the term rangeability of a control valve. Why is the property important?
7. How does the friction loss of a pipeline connecting the control valve affect the flow characteristics of the valve? Explain clearly.
8. Distinguish between the terms- ideal characteristics and effective characteristics.
9. What is the advantage of using a equal percentage valve over a linear valve?

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