

4

Control Valves

4.1 Introduction to Control Valves

4.1.1 Definition of Control Valves

Over the years, some confusion has existed between the definitions of a throttling valve and a control valve. Some use the words interchangeably because they both have a similar purpose: to regulate the flow anywhere from full-open to full-closed. For the most part, a *throttling valve* is any valve whose closure element has a dual purpose of not only opening or blocking the flow but also moving to any position along the stroke of the valve, thus regulating the process flow, temperature, or pressure. Using the term *closure element* is not adequate in describing this portion of the throttling valve; thus, for purposes of differentiation, the term *regulating element* is used to describe any portion of the valve that allows for throttling control. A throttling valve is designed to take a pressure drop in order to reduce line pressure, flow, or temperature. The interior passageways of a throttling valve are designed to handle pressure differential, while on-off valves are designed to allow straight-through flow without allowing a significant pressure drop. Because the purpose of the throttling valve is to provide reduced flow to the process, rangeability is a critical issue. The valve's trim size is almost always smaller than the size of the pipeline or flow passages of the valve. Using a full-size valve in a similarly sized pipe will provide poor controllability by not utilizing the entire stroke of the valve. Throttling valves must have some type of mechanical device that uses power supplied by a human being, spring, air pressure, or hydraulic fluid to assist with this positioning. Some manually operated on-off valves can be used or adapted for throttling service. Pressure regulators are also considered throttling valves, since

they vary in the position of the regulating element to maintain a constant pressure downstream.

By definition, a *control valve* (also known as an *automatic control valve*) is a throttling valve, but is almost always equipped with some sort of actuator or actuation system that is designed to work within a control loop. As discussed in Sec. 1.2.5, the control valve is the final control element of a process loop (consisting of a sensing device, controller, and final control element). This involvement with the control loop is what distinguishes control valves from other throttling valves. Manually operated valves and pressure regulators can stand alone in a throttling application, while a control valve cannot, hence the difference: a control valve is a throttling valve, but not all throttling valves are control valves. In some cases, a manually operated valve can be converted to a control valve with the addition of an actuation system and can be installed in a control loop—thus in the pure sense of the definition it becomes a control valve.

Control valves are seen as two main subassemblies: the body subassembly and the actuator (or actuation system). This chapter will concentrate on the operation, design, installation, and maintenance of body subassemblies, while Chap. 5 will detail actuators and actuation systems.

Generally, control valves are divided into four types: globe, butterfly, ball, and eccentric plug valves. Variations of these four types have resulted in dozens of different available designs, the most common of which will be covered in this chapter. Each design has specific applications, features, advantages, and disadvantages. Although some control valves have a wider application than others, no control valve is perfect for all services, and each design should be examined to find the best solution at minimal cost.

4.2 Globe Control Valves

4.2.1 Introduction to Globe Control Valves

Of all control valves, the linear-motion (also called rising-stem) globe valve is the most common, due in part to its design simplicity, versatility of application, ease of maintenance, and ability to handle a wide range of pressures and temperatures. The globe valve is the most commonly found control valve in the process industry, although demand is not as great with the advent of high-performance rotary valves, which offer lower cost and smaller packages, size for size. Sizes range

from 0.5 to 42 in (DN 12 through DN 1000) in lower-pressure classes (up through ANSI Class 600 or PN 100); from 1 to 24 in in ANSI Classes 900 to 2500 (PN 160 through PN 400); and from 1 to 12 in in ANSI Class 4500 (PN 700).

By definition, a *globe valve* is a linear-motion valve characterized by a globe-style body with a long face-to-face dimension that accommodates smooth, rounded flow passages. The most common regulating element is the *single-seat design*, which operates in linear fashion and is found in the middle of the body. The single-seat design uses the plug-seat arrangement, where a plug moves into a seat to permit low flows or away from the seat to permit higher flows. The alternative to the single-seat arrangement is the double seat, which will be discussed in detail in Sec. 4.2.4.

The advantages of globe control valves are many—hence their overall popularity. Generally, globe valves are quite versatile and can be used in a wide variety of services. The same valve can be used in dozens of different applications as long as the pressure and temperature limits are not exceeded, and the process does not require special alloys to combat corrosion. This versatility allows for reduction in spare parts inventory and maintenance training. Their simple linear-motion design permits a wider range of modifications than other valve styles. Because of the linear motion, the force generated by the actuator or actuation system is transferred directly to the regulating element; therefore, a minimal amount of the energy to the regulating element is lost. On the other hand, rotary valves lose some transfer energy and accuracy because of the dead band (amount of input change needed to observe shaft movement) associated with linear- to rotary-motion linkage. For this reason, globe valves are capable of high performance and are used in applications where such performance is mandatory.

A major advantage to using globe control valves is their ability to withstand process extremes. They are designed to work in extremely high pressure drops, handling pressure differentials of thousands of pounds of pressure (or hundreds of kilograms per centimeter squared). Globe valves can be designed to handle higher pressure classes by increasing the wall thickness of the body and using heavier-duty flanges, bolting, and internal parts. Severe temperatures can be handled with extension modifications to the bonnet or the body, keeping the top-works (actuator, positioner, supply lines or tubing, and accessories) away from the process temperature.

An important advantage of a globe control valve is that it can have a flow characteristic designed into the trim or the regulating element

itself—unlike butterfly valves whose design only allows for an inherent characteristic.

Most globe control valves with single seats have top-entry to the trim (plug, seat, and cage or retainer). This allows easy entry into the valve to service the trim by removing the bonnet flange and bonnet-flange bolting and removing the top-works, bonnet, and plug as one assembly. Unlike rotary valves, globe valves can remain in the line during internal maintenance. For this reason, globe valves are preferred in the power industry where steam applications require the welding of the valve into the pipeline.

As mentioned earlier, the main disadvantages of globe valves are that, size for size, they are larger, heavier, and more expensive than rotary valves. They present seismic problems because of their greater height—a problem where an earthquake or process vibration could cause the top-works to place stress on the body subassembly or line.

Another disadvantage is that globe valves are restricted by the significant stem forces required by the throttling process. Globe valves with pneumatic actuators are restricted to sizes smaller than 24 in (DN 600), or 36 in (DN 900) with a hydraulic or electrohydraulic actuator. With higher-pressure classes, the bulk of the globe-valve body assembly, as well as the stem forces, decreases the size availability even more. When large flows must be regulated beyond the size capabilities of a globe valve, users sometimes divide the flow between two smaller pipelines, preferring smaller valves. In some cases, butterfly or eccentric disk rotary valves are used instead.

4.2.2 Globe-Control-Valve Design

In describing the design elements of a globe valve, the *globe body* is the main pressure-retaining portion of the globe valve, which has matching end connections to the piping and also encloses the trim (Fig. 4.1). The flow passages in a globe valve are designed with smooth, rounded walls without any sharp corners or edges, thus providing a smooth process flow without creating unusual turbulence or noise. The flow passages themselves must be of constant area to avoid creating any additional pressure losses and higher velocities. Globe-valve bodies are adaptable to nearly every type of end connection, except the flangeless design. Obviously with a long face-to-face dimension, the long bolting required between two pipe flanges would be susceptible to thermal expansion during temperature cycles.

The *single-seated trim* is more than just a closure element, because a throttling valve does more than just open or close; rather, it is a regulat-

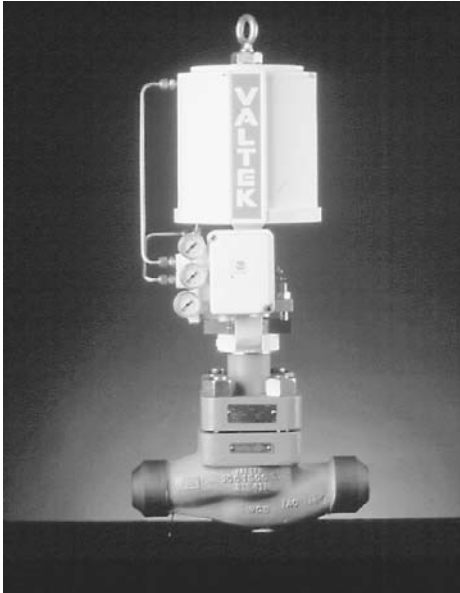


Figure 4.1 Globe-style control valve. (Courtesy of Valtek International)

ing element that allows the valve to vary the flow rate with respect to the position of the valve according to the flow characteristic, which may be equal percentage, linear, or quick open (Sec. 2.2). Typically, the trim consists of three parts: the *plug*, which is the dynamic portion of the regulating element; the *seat ring*, which is the static portion; and the *seat retainer* or *cage*. The portion of the plug that seats into the seat ring is called the *plug head*, and the portion that extends up through the top of the globe body subassembly is called the *plug stem*. The plug stem is threaded to the *actuator stem*, allowing a solid connection without any play or movement. The actuator stem is assembled to an actuator piston or diaphragm plate, which transfers pneumatic or hydraulic force to the regulating element. The basic advantage of the single-seated trim design is that it allows the tightest shutoff possible, usually better than 0.01 percent of the maximum flow or C_v of the valve. This is because the actuation force can be applied directly to one seating surface. The greater the actuation force, the greater the shutoff of the valve.

Two sizes of trim can be used in globe valves. *Full trim* refers to the area of the seat ring that can pass the maximum amount of flow in that particular size of globe valve. On the other hand, *reduced trim* is used

when the globe valve is expected to throttle a smaller amount of flow than that size is rated for. If full trim is used, the valve would have to throttle close to the seat as well as in small increments—which is difficult for some actuators. The preferred method, then, is to use a seat ring with a smaller seat area—with a matching plug—which is defined as *reduced trim*. Most manufacturers offer four or five sizes of reduced trim for each size of valve.

The *bonnet* is an important pressure-retaining part that has two purposes. First, it provides a static cap or cover for the body, sealed by bonnet or body gaskets. Second, it seals the plug stem with a packing box—a series of packing rings, followers or guides, packing spacers, and antiextrusion rings that prevent or minimize process leakage to atmosphere. Mounted above the packing box is the gland flange, which is bolted to the top of the bonnet. When the gland-flange bolting is tightened, the packing is compressed and seals the stem as well as the bonnet bore.

Guiding the plug head in relation to the seat ring is accomplished by two types of guiding: double-top stem guiding or caged guiding. *Double-top stem guiding* uses two close-fitting guides at both ends of the packing box to keep the plug concentric with the seat ring (see Fig. 4.2). These guides can be made entirely from a compatible, dissimilar

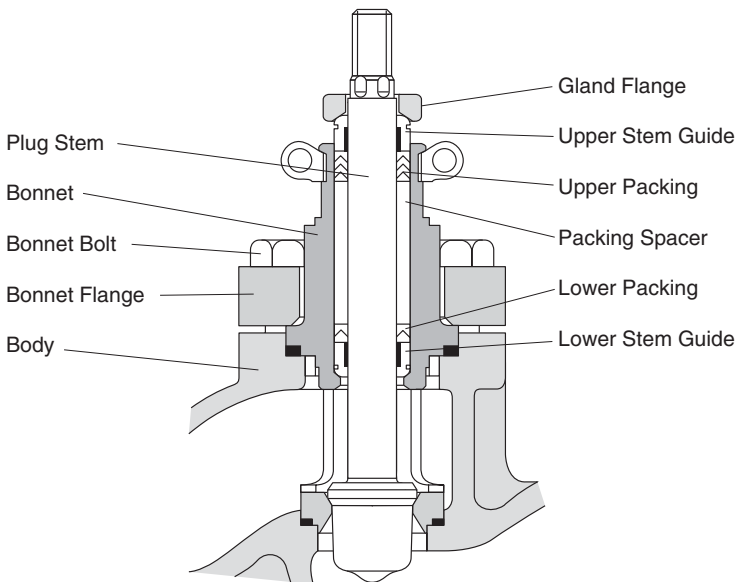


Figure 4.2 Double-top stem guiding in a globe valve. (Courtesy of Valtek International)

metal with the plug to avoid galling or can include a hard elastomer or graphite liner. The key element of double-top stem guiding is that the guides must be widely separated to avoid any lateral movement from the process fluid acting on the plug head, which is exposed to the forces of the process stream. The guides—as well as the bonnet bore and the actuator stem—must be held to close tolerances to maintain a fit that will allow a smooth linear motion without binding or slop. To avoid lateral movement as the process impinges on the plug head, some plugs have large-diameter stems to resist flexing. However, when compared to smaller-diameter stems, larger plug stems do have an increased circumference, which increases the sealing surface and the possibility of seal leakage as well as packing friction. However, the stem-friction problem is easily rectified by using higher thrust actuators, such as piston cylinder actuators, which can easily handle the increased stem friction.

The second type of guiding configuration is *caged guiding*. With the cage-guided design (Fig. 4.3), the upper guide is placed at the top of the packing box and the lower guiding surface is placed inside the flow stream, using the outside diameter of the plug head to guide within the inside diameter of the cage. Because the distance between

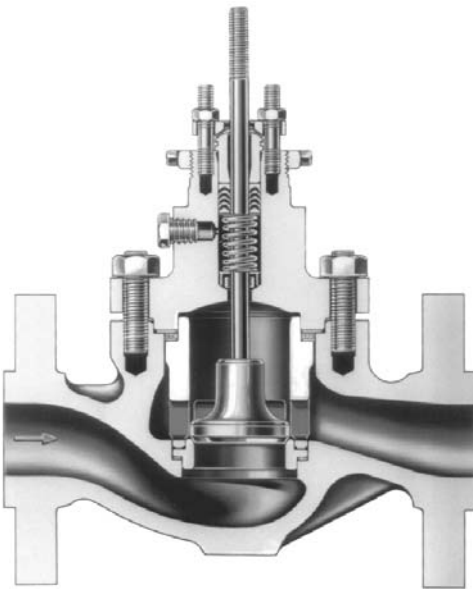


Figure 4.3 Caged-guided trim in a globe valve.
(Courtesy of Fisher Controls International, Inc.)

the upper guide and the lower guide is at a maximum length, lateral plug movement due to process flow is not an issue and the tolerances required for this type of guiding are not required to be as close as double top-stem guiding. This also permits the use of smaller-diameter plug stems, providing a smaller sealing surface and decreased stem friction (which is necessary when lower-thrust diaphragm actuators are used). Caged guiding also minimizes any change of vibration of the plug in service and helps support the weight of the plug head. Because this guiding surface is in the flow stream, the process must be relatively free from particulates, or binding or scoring may occur. In some situations, identical or similar materials between the plug head and the cage may gall during prolonged operation. High temperatures may also lead to thermal expansion and binding. Galling and temperature problems can be remedied using guiding rings made from an elastomer or nongalling metal, which are installed in grooves machined into the plug head.

Cages are designed with large flow holes (anywhere from two to eight) that allow passage of the flow into or from the seat, depending on the flow direction. They can also be modified to allow a staged pressure drop—reducing the pressure drop and velocities inside the valve to avoid cavitation, flashing, erosion, vibration, or high noise levels. To ensure the alignment of the plug seating surface with the seat-ring seating surface, some designs combine the cage and the seat ring into one part. This one-piece design maintains the concentricity between the inside diameter of the cage and the inside diameter of the seat.

The cage is also used to determine the flow characteristic. The flow holes in the cage are sometimes shaped such that the plug lifts from the seat ring. In this way a certain percentage of the flow hole is opened up, allowing only so much flow at that portion of the stroke. By varying the size and shape of the hole, certain flow characteristics can be generated. Figure 2.2 in Chap. 2 shows a variety of shapes available according to the flow characteristic.

In trim designs that do not feature cages (such as those that use a seat-ring retainer or screwed-in seats, which is discussed later), the plug head can be machined to a particular shape that provides an inherent flow characteristic. Figure 2.3 in Chap. 2 shows how the contour of a plug head can be turned to provide the flow characteristic. In contrast, Fig. 4.4 shows a V-port plug head, which is cylinder shaped with V-shaped grooves machined into the cylinder for a linear characteristic.

With globe valves, the seating surface of the plug is designed to make full contact with the seating surface of the seat ring at the point

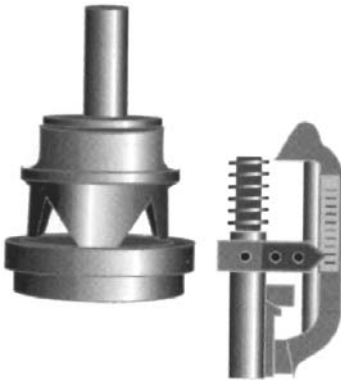


Figure 4.4 V-ported characterized plug.
(Courtesy of Pacific Valves, a unit of the Crane Valve Group)

of closure. Although some early valve designs used identical angles, current designs use angles that slightly differ, with the plug at a steeper angle than the seat ring. This slight mismatch ensures a narrow point of contact, allowing the full axial force of the plug to be transferred to the seat, ensuring the tightest shutoff possible for metal-to-metal contact (normally ANSI Class II shutoff is standard, although Class IV shutoff can be achieved with high-thrust cylinder actuators). Even with ANSI Class IV shutoff, metal-to-metal seats can never completely shut off the flow, as the classification allows a small amount of process leakage.

The seat ring is fixed in the body, while the gap between the seat ring and the body is sealed by a gasket. The seat ring can be fixed in the body by one of two arrangements. First, a common method of fixing the seat ring is through a retained arrangement. The seat ring is inserted into a slightly larger diameter machined into the body and held in place by a part between the bonnet and the seat ring, called the *seat retainer*. If the retainer is used to guide the plug head, it is called a cage, but it can serve the dual purpose of retaining the seat ring. If the diameter machined into the body is wide enough, the seat ring will have some play, allowing lateral movement, which can lead to a quick, easy method of correct plug and seat-ring alignment. During assembly, and before the bonnet-flange bolting is completely tightened, a signal can be sent to the actuator to seat the plug in the seat, providing the correct alignment between the matching seat surfaces of the two parts. After the plug and seat ring are aligned, the bonnet-flange bolting is tightened and the subsequent force is transferred through the retainer

or cage to secure the location of the seat ring with the plug head. If the seat ring does not have this self-adjustment feature, its seating surface must be lapped with the seating surface of the plug head. *Lapping* is the process in which an abrasive compound is placed on the seat-ring seat surface and the plug is seated and turned until a full contact is achieved. The retained seat ring is also known for easy disassembly, especially in corrosion-prone applications, since it just lifts out of the body once the bonnet and seat retainer or cage are removed. The only disadvantage to retained seat rings is that they work best when a high-thrust actuator is used, since high seating force is needed to ensure a good seat-ring gasket seal.

The second method of securing the seat ring is the threaded arrangement in which the seat ring is threaded into the body. This process normally requires a special tool from the manufacturer to turn the seat ring into the body. The major advantage of this design is that no other part is needed to retain the seat ring, providing a simplified trim arrangement, as well as no cage or seat retainer to restrict the flow. With three-way or double-seated valves, the use of seat retainers or cages is not possible from a design standpoint, and the only alternative is to use threaded seats. Threaded seat rings are widely used with cryogenic applications in which the top of the body must be elongated to provide a fluid barrier between the process and the packing box and top-works.

The disadvantages of threaded seats are threefold. First, and most evident, the threads can become corroded, making disassembly difficult, if not impossible in some long-term situations. Second, alignment between the plug and seat ring will require the extra step of lapping to achieve the required shutoff. And third, in situations in which vibration is present and the seat ring is not held in place by the plug in the closed position, the seat ring may eventually loosen and allow leakage and misalignment. Overall, the disadvantages of the threaded seat ring far outweigh the advantages; therefore many newer single-seat designs use the retained arrangement. When a seat retainer or cage is not possible or preferred and the application is too corrosive to allow a threaded seat ring, a split-body arrangement is a practical substitute.

Some globe-valve applications require bubble-tight shutoff (ANSI Class VI), which cannot be attained with a metal-to-metal seal. To accomplish this, a soft elastomer can be inserted in the seat ring. In most designs, the seat ring is made from two parts with the elastomer sandwiched between the two, as shown in Fig. 4.5. The combination of the metal plug surface pressing against the seat ring's soft seat surface can achieve bubble-tight shutoff if the plug and seat-ring surfaces are



Figure 4.5 Exploded view of soft-seat design.
(Courtesy of Valtek International)

concentric. Some manufacturers also insert the elastomer in the plug, which achieves the same effect (Fig. 3.22, Chap. 3).

4.2.3 Globe-Control-Valve Operation

The most common globe valve uses a T-style body, which allows the valve to be installed in a straight pipe with the top-works or actuator perpendicular to the line and will be used to explain the basic operation of a globe valve. Flow enters through the inlet port to the center of the valve where the trim is located. At this point, the flow must make a 90° turn to flow through the seat, followed by another 90° turn before exiting the valve through the outlet port.

The flow direction of globe valves is defined by the manufacturer and in many applications is critical to the valve's operation. With standard single-seated globe valves using inlet and outlet ports, the two choices are flow-under-the-plug and flow-over-the-plug. With manually operated globe valves, flow is almost always under the plug. The plug closing against the flow provides constant resistance, but not enough to be insurmountable, and is relatively easy to close as long as the fluid pressure and flow rate are low to moderate. Flow-under-the-

plug provides for easy opening, as the fluid pushes against the bottom of the plug. However, flow direction is an important consideration with control valves equipped with diaphragm actuators, which are not capable of high thrusts. If the flow is over the plug and the process involves high pressures, the diaphragm actuator is not usually stiff enough to prevent the plug from slamming into the seat ring when throttling is close to the seat. Also, the actuator must pull the plug out of the seat against the full upstream pressure, which may be difficult in a high-pressure application. Therefore, lower-thrust actuators demand flow-under-the-plug, allowing the full thrust to close against the upward force of the fluid pressure. Another situation in which flow-under-the-plug is an issue is with fail-open applications, where the service requires the valve to remain open during a signal or power failure. Even if an actuator with a fail-safe spring is rendered inoperable during a fire, the flow-under-the-plug design will ensure continued flow as the flow pushes the plug away from the seat.

Inversely, flow-over-the-plug is important in fail-closed situations, where the service requires the valve to shut during a loss of signal or power. If the actuator fails and the fail-safe spring also fails, the flow acts on the top of the plug to push it into the seat. Obviously, with flow-over-the-plug situations, throttling close to the seat presents a problem if the actuator does not have sufficient stiffness (the ability to hold a position despite process forces). The actuator must have enough thrust to pull the plug out of the seat against the fluid's upstream pressure—which increases to its maximum value in a nonflow state. As the issues of stiffness and thrust are considered, in a majority of situations where the flow must be over the plug, piston cylinder actuators are preferred over diaphragm actuators.

As alluded to earlier in Sec. 4.2.2, the globe-valve trim can be modified to allow for equal-percentage, linear, or quick-open flow characteristics. As explained in detail in Sec. 2.2, flow characteristics determine the expected flow rate (expressed in flow coefficient or C_v) at a certain valve position. Therefore, with a particular flow characteristic, the user can determine the flow rate at a given instrument signal. As the flow reaches the trim, and if the trim is in a throttling position, the flow is directed to a restriction. This restriction may be created by the exposed portion of a hole in a cage, which is based upon the linear position of the plug. It may also be created by the portion of the V-shaped slot of a V-port plug that is exposed above the seat ring. Also, the restriction may be created by the amount of the seat that is open to the flow when the area of a contoured plug is filling a portion of the seat area. When a pressure-drop situation occurs (the downstream

pressure is lower than the upstream pressure), the flow moves from the inlet through the seat to the outlet. As the flow moves through the seat, line pressure decreases as velocity increases. After the fluid enters the lower portion of the globe body, the area expands, the pressure recovers to a certain extent, the velocity decreases, and flow continues through the outlet port and downstream from the valve. As the flow enters the trim area of the valve, an important consideration is the gallery area of the body surrounding the trim. In ideal situations the flow should freely circulate around the trim, allowing flow to enter the trim from every possible direction. With cages and retainers, flow should enter equally from every hole to provide equal forces to act on the plug head. If the gallery is narrow in any one area (for example, in the back side of the cage), velocities can increase, causing noise, erosion, or downstream turbulence. In addition, unequal forces acting on the plug head can cause slight flexing of the plug head if it is not supported by a cage.

When the globe control valve closes, the axial force from the actuator is transferred to the plug and its seating surface makes contact against the slightly mismatched angle of the seat ring. As full contact is made, the valve is closed, allowing minimal or no flow to pass through the trim according to the ANSI leakage classification. If the axial force is applied in the opposite direction, the plug lifts and, in the full-open position, the entire seating area is open to the flow as well as the holes of the cage or retainer.

Because the process flow is under pressure and the environment outside the valve is at atmospheric pressure, the flow seeks to escape through the gaps in the valve. This leakage is prevented by the static seal of the gaskets in the end connections (if flanges or RTJ end connections are used) and the bonnet gaskets. Flow seeking to escape through the sliding stem of the plug is prevented by the packing's dynamic seal in the bonnet's packing box. In closed positions, flow may escape through the seat but is prevented by the static seal between the seat ring and the body.

4.2.4 Globe-Control-Valve Trim Variations

With special service requirements, globe control valves can use a number of specialized trims for unique flow requirements. Some applications require extremely low flow coefficients, with C_v s anywhere down to 0.000001. Because of these extremely low flows, these designs are found only in smaller valve sizes (less than 2 in or DN 50). The

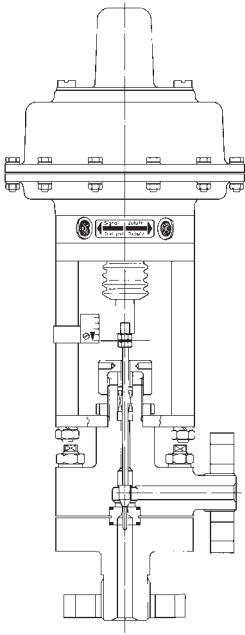


Figure 4.6 Low-flow control valve with needle trim. (Courtesy of Kammer Valves)

plug head is shaped very narrowly, earning the designation *needle-valve trim* because of its needlelike appearance (Fig. 4.6). Because even the smallest variations in diameter can have a wide impact on the overall flow coefficient and flow rate, needle plugs are machined using special micromachining procedures (using technologies developed by the watchmaking industry). These precise trims require the flow characteristic to be machined into the plug head contour. Needle-valve trim requires a very precise method of adjustment of the distance between the seat and plug-seating surfaces. A very fine thread (twice the magnitude of a normal plug thread) is normally required, allowing a very minute amount of linear adjustment per turn.

Pressure-balanced trim is defined as a special trim modification that allows the upstream pressure to act on both sides of the plug head, significantly reducing the off-balance forces and operator thrust needed to close the valve. It is sometimes used to replace normal trim arrangements when the valve must close against a large seat diameter coupled with high-pressure process forces or high-pressure drops. Because the regulating element must overcome these forces, exceptional actuator

force from a high-thrust actuator or a larger lower-thrust actuator must be used to close the valve. In other applications, a standard valve may need a smaller actuator size to fit into a tight space. In this case, pressure-balanced trim reduces the valve's need for a larger standard actuator by reducing the off-balanced area of the trim. Pressure-balanced trim is common with valves in larger sizes [size 12 in (DN 300) and higher] in which a large amount of flow is passing through a large seat and where the cost of a larger actuator would be greater than the cost of the pressure-balanced trim.

Pressure-balanced trim requires a special plug and *sleeve*, which is similar in many respects to a cage. These parts allow the upstream pressure to act on both sides of the plug, as shown in Fig. 4.7. The sleeve's inside diameter is slightly larger than the inside diameter of the seat ring. The plug requires a smaller plug stem to minimize the off-balance area, and is equipped with metal piston rings, O-rings, or polymer rings that, when installed inside the sleeve, create a pressure chamber above the plug. One or two holes are machined through the plug head, allowing the fluid pressure to act on both sides of the plug. In effect, this results in a net force equal to the pressure multiplied by the off-balance area.

With high inlet pressures and a large seat area, a high actuator force is required to close the valve. With standard trim (unbalanced plug),

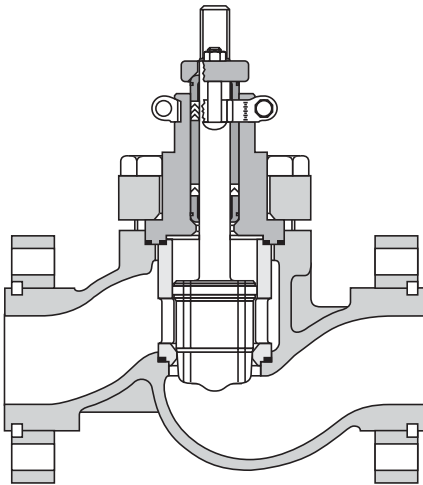


Figure 4.7 Globe-body subassembly with pressure-balanced trim. (Courtesy of Valtek International)

the force necessary to close the valve is the total *off-balance area*, which is written as

$$F_{\text{OBA}} = P_1(A_S - A_{\text{stem}}) - P_2(A_S)$$

where F_{OBA} = actuator force required to overcome the off-balance area
 P_1 = upstream pressure
 P_2 = downstream pressure
 A_S = area of the inside diameter of the seat
 A_{stem} = area of the outside diameter of the plug stem

However, with pressure-balanced trim and its counter-balanced design, the off-balance area is far less, which requires less actuator force, as written in the following equation:

$$F_{\text{OBA}} = P_1(A_{\text{sleeve}} - A_{\text{stem}}) - P_2(A_S)$$

where A_{sleeve} = area of the inside diameter of the sleeve

With pressure-balanced trim, the larger the off-balance area (slight as it may be), the greater the shutoff. For example, in smaller globe-valve sizes (0.5 through 3 in or DM 12 through DN 80), the off-balance area is slight and an ANSI Class II shutoff is usually the standard—ANSI Class II calls for a maximum leakage rate of 0.5 percent of rated valve capacity. On the other hand, for sizes of 4 in (DM 100) and larger, the off-balance area of the trim increases and ANSI Class III shutoff is possible—ANSI Class III calls for a maximum leakage rate of 0.1 percent of rated valve capacity.

With standard unbalanced trim, the direction of the flow assists with the motion of failure (flow-over-the-plug is used for fail-closed and flow-under-the-plug is used for fail-open cases). With pressure-balanced trim, however, the opposite occurs. Flow direction is under the plug for fail-closed situations and over the plug for fail-open situations. The actuator force required to fail-open or fail-closed is related to the off-balance area. Hence, for flow-over-the-plug and fail-closed situations, this off-balance area is equal to the sleeve area minus the seat-ring area. The spring must be able to overcome this off-balance area, which can be written as

$$F_{\text{open}} = P_1(A_{\text{sleeve}} - A_{\text{seat}})$$

where F_{open} = spring force required to fail-open

With flow-over-the-plug and fail-closed applications, the off-balance area is equal to the sleeve area minus the plug stem area, as indicated in the following equation:

$$F_{\text{closed}} = P_1(A_{\text{sleeve}} - A_{\text{stem}} - A_{\text{seat}})$$

where F_{closed} = spring force required to fail-closed

In standard services, the major advantage of using pressure-balanced trim is that smaller or less powerful actuators can be used. Another advantage is that high-pressure drops or higher process pressures can be handled without resorting to expensive, large nonstandard actuators. In some instances, use of pressure-balanced trim is the only method by which some applications can be handled because an actuator with extremely high thrust may not be available for the required valve size or may not fit in the available space.

On the other hand, pressure-balanced trim has four major disadvantages: First, because pressure-balance trim only works with a sliding seal between the plug and the sleeve, the fluid must be relatively clean and free from particulates; otherwise, the seals can be damaged and cause leakage or galling between the plug and sleeve. Second, because of the balanced nature of the plug, coupled with the lower thrust of a smaller actuator, leakage rates through the seat are not as good as with unbalanced trim—ANSI Class II is normal. Third, pressure-balanced trim is more costly initially than standard trim, although the use of a smaller actuator may offset that cost or even make the overall cost more attractive. And fourth, because of the seal within the process flow, the trim may require a shorter servicing cycle, especially if the process has entrained particulates.

Double-ported trim is a special trim design used to fill the same purpose as pressure-balanced trim: to reduce the effect of the process forces on the plug, thereby lowering the thrust requirement and allowing the use of smaller actuators. Flow is directed by the inlet port to the body gallery and the trim, which features two seats and a single plug that features two plug heads, one above the other (Fig. 4.8). In air-to-open (fail-closed) applications, the plug-seat combination at the top of the gallery is a flow-under-the-plug design, while the plug-seat combination at the bottom is a flow-over-the-plug design. In air-to-close (fail-open) applications, the opposite design is used. The plug-seat arrangement at the top is flow over the plug and that at the bottom is flow-under-the-plug.

Upon opening, the net forces working on these two seats nearly cancel each other out. The fluid pressure is pushing the upper plug head out of the seat, while the lower plug head is pulling out against the fluid pressure. Upon closing the opposite occurs. The upper plug head

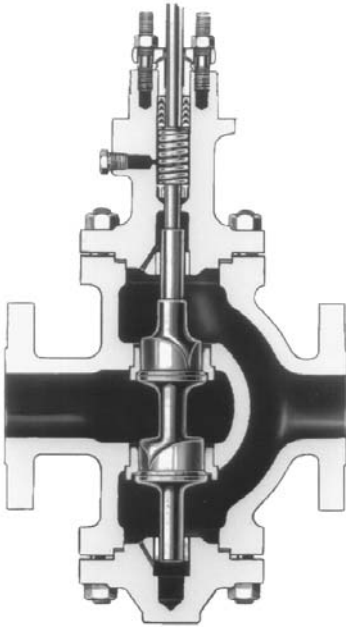


Figure 4.8 Double-seated globe-body assembly.
(Courtesy of Fisher Controls International, Inc.)

pushes against the flow, while the lower plug head is assisted by the flow. Although in principle double-seated valves are close to pressure-balanced valves, in reality they are somewhere between pressure balanced and unbalanced. This is because the fluid is acting against the plug contour with one seat and the top of a plug head (usually a flat surface) with the other seat, creating a dynamic imbalance. With double-seated valves, flow characteristics are nearly always determined by the contour of the plug head. Guiding is accomplished with upper and lower guides. The upper guide is placed above the upper seat, while the lower guide is located in the lower body region with a lower body cap for access and assembly. This arrangement also allows for easy reversal of the stroke direction (air-to-open to air-to-close, or vice versa). The body can be inverted, with the bonnet and the lower body cap retaining their previous positions.

Double-seated trim can also be used with three-way valves for diverting, combining, or dividing flows. In the case of diverting flow, the plugs are offset, meaning that one of the two plug heads is always seated, while the other is in the full-open position. As the valve moves

from one end of the stroke to the other, the opposite occurs: the previously closed plug head moves to the full-open position and the previously open plug head moves to full-closed. To divide flow between the two outlets, this same arrangement can be used, except that the stroke remains in the middle as if throttling, allowing both seats to be open to some extent and flow to move down both outlets. For combining flows, the flow direction of the valve is reversed, allowing for two inlet ports and a single outlet port. Using a double-seated valve for three-way service means that a lower guide surface as part of the body is not possible, since that area is used as a port. In these cases, the plug head is designed to guide in the seats, using notches in the plug head to achieve flow control.

Double-ported trim does have drawbacks: First, the alignment of the plug and the seat is critical in T-line valve styles (one inlet and one outlet), and if one plug head is out of alignment, one may fully seat, while the other will be slightly off the seat, allowing leakage through that seat. Because of the extreme difficulty of aligning the two seats to provide equal shutoff, allowable leakage is 0.5 percent of the rated flow of the valve. Thermal expansions can also cause the distance between the seats to widen, leading to increased leakage. The second drawback is that the design requires screwed-in seat rings, which are prone to corrosion and must be lapped to ensure tight shutoff.

Another trim variation is *sanitary trim*, which is required for those valves used in the food and beverage industry. Such valves require stainless-steel construction of all wetted parts and are specified with angle-style bodies, which allow the downstream port to be 90° from the inlet port. In other words, the flow is directed straight down from the seat ring. With sanitary applications, pockets of fluid cannot be allowed to stand or pool; otherwise contamination or bacterial growth can result. When the system is flushed by water or steam, the self-draining allows for the system to quickly dry and be readied for another type of process fluid or for the system to remain dormant.

Sanitary-trim design (Fig. 4.9) allows the valve to self-drain when the system is depressurized or if the valve is closed, allowing the outlet side to drain. To avoid pockets of trapped fluid, sanitary trim has very few flat areas and no walled pockets. In some designs, the seating surface is machined into the body to avoid a gap between a seat ring and the body. The plug head is tapered on its top side until it reaches the plug stem. Because sanitary services must have tight shutoff, the plug head is fitted with an elastomeric insert to provide bubble-tightness. Because of possible pooling areas, pressure-balanced trim is never an option with sanitary services. Most sanitary valves also

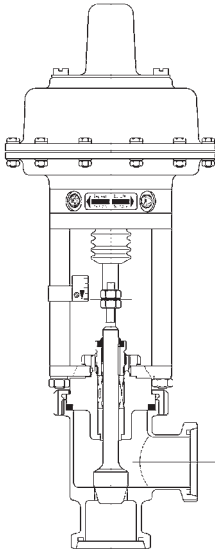


Figure 4.9 Sanitary-trim control valve.
(Courtesy of Kammer Valves)

require stainless-steel actuators to avoid any sort of oxidation in the clean environment.

4.2.5 Globe-Control-Valve Body Variations

Globe valves are considered to be one of the most versatile valve designs because the body can be varied in numerous ways to allow for different piping configurations or functions. The most common single-seated globe body style is the flow-through design (or sometimes called the *T-style body*), which is shown in Fig. 4.10. Basically, this body style allows the valve to be installed in a straight piping configuration, with the rising-stem action perpendicular to the centerline of the piping. Unlike most quarter-turn valves or gate valves where the flow moves straight through the body relatively unimpeded, the flow-through design brings the flow through two right-angle turns, allowing for a significant pressure drop, which is essential for some applications. As the flow moves through the inlet port, the flow passage shifts up (or down, depending on the flow direction) approximately 30° until the flow reaches the gallery of the body, bringing the flow above (or below) the seat, which is usually on the piping centerline. At that

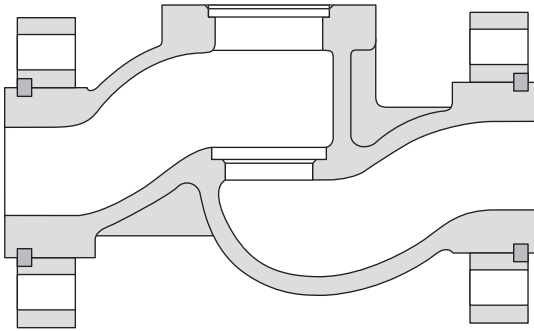


Figure 4.10 Globe body with top-entry to the trim and separable flanges. (Courtesy of Valtek International)

point, in flow-over-the-plug situations, the flow enters the gallery area that surrounds the trim. The flow then turns 120° to flow through the seat. At this point, the flow is perpendicular to the piping centerline. As the flow exits the seat, it turns 120° again by the flow passage, shifting up (or down) until the flow meets the outlet port and moves out into the downstream piping.

Globe flow-through bodies can be modified with an elongated body chamber above the regulating element (Fig. 4.11) for cryogenic applications. The upper chamber of this body style allows for a small amount of liquefied gas to vaporize between the process and the packing, acting as a vapor barrier—the pressure from the vaporization actually prevents any further liquid from entering the chamber.

An alternative single-seated body style, somewhat related to the flow-through style, is the *angle-body* style (Fig. 4.12). Instead of the two ports being in-line with the straight piping configuration, one port is turned 90° from the other port (or at a right angle) to match piping that requires such a turn. The port that is perpendicular to the rising stem is called the *side port*, and the port that is in-line with the rising stem is called the *bottom port*. Valves with an angle-style body are used in a number of applications. First, angle valves are sometimes used in cavitating services where the imploding bubbles are channeled directly into the center of the downstream piping. Depending upon the severity of the cavitation, the bubbles may not directly impact a metal wall (such is the case with the bottom of the globe straight-through body). Rather, they implode harmlessly in the middle of the pipe. If the control valve is part of a piping system that discharges into a tank, an angle valve can be used so that any cavitating liquid can flow into the large vessel, where it

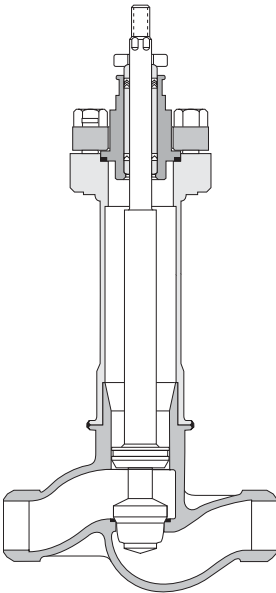


Figure 4.11 Elongated globe body for cryogenic service. (Courtesy of Valtek International)

will not affect any nearby metal surfaces. An angle valve also allows the use of a *Venturi seat ring* (Fig. 4.13), which is an extended seat ring that can protect the sides of the bottom port and downstream piping from adverse process effects, such as abrasion or erosion. Also, because of the right-angle turn in the body design, angle valves can be installed in services that have a natural upward flow, such as in crude oil or natural gas applications or boiler services. A special kind of

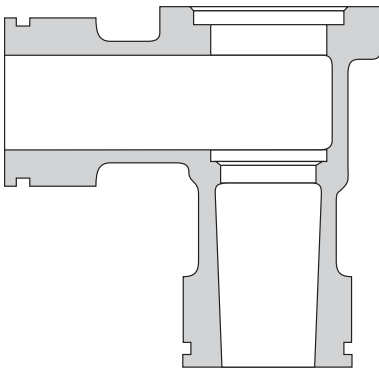


Figure 4.12 Angle body with top-entry to the trim and separable flange hubs. (Courtesy of Valtek International)

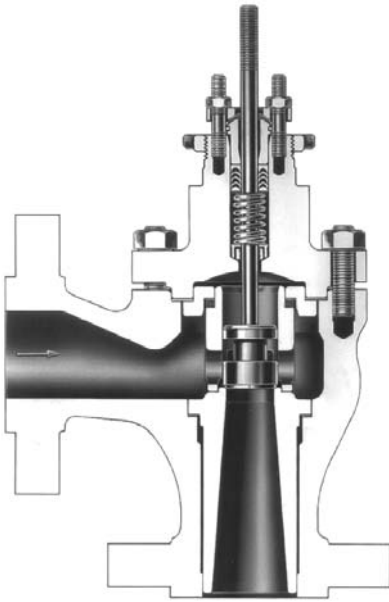


Figure 4.13 Venturi seat ring design. (Courtesy of Fisher Controls International, Inc.)

angle valve, called a *choke valve*, is used for most wellhead applications. Many mining applications involve gas services that have particulate matter such as sand or dirt, which have a tendency to erode—a process similar to sandblasting. Modified-sweep-style angle valves (Fig. 4.14), with trim made from ceramic for durability, allow the particulates to be channeled down a pipe without directly impinging on any body walls. Also, angle valves allow for easy draining, since no pockets exist that allow the fluid to pool.

One disadvantage of using an angle valve is that turbulent flow created by the regulating element can channel the turbulence directly into the downstream piping, creating more vibration and noise than would be created using a flow-through body. The downstream side of the flow-through body is quite stiff, handling some of the flow's energy conversion in an unyielding vessel before the flow proceeds into downstream piping. Angle valves also have a higher pressure recovery than other types of globe valves, resulting in a lower σ value (the cavitation index, Sec. 9.2), which means an increased chance of cavitation.

A variation of the globe straight-through style is the *expanded-outlet* style, which is basically a straight-through design except that the end

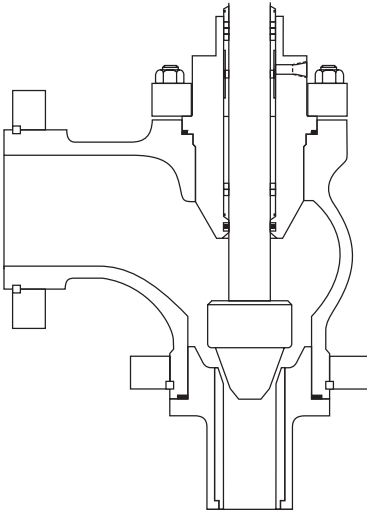


Figure 4.14 Sweep-angle body subassembly.
(Courtesy of Valtek International)

connections are a larger pipe size than the trim is designed for. For example, a 4×2 -in expanded outlet valve would have 4-in end connections (for mounting to a 4-in pipe), but would have the full-area trim for a 2-in valve. Expanded-outlet valves are used to lower the cost of welding or installing piping increasers to the valve body. The expanded-outlet body's face-to-face is also shorter than a normal globe straight-through valve with increasers, which may be important in piping systems with limited space. This style is also a cost-saving measure when a larger valve size is required with reduced trim. The smaller trim size may also act as a reduced trim—although technically it is considered a full-area trim for the smaller valve size.

Another variation of the globe straight-through style is the *offset body* style, which provides for straight-through flow except that the inlet and outlet ports are parallel and not in-line with each other (Fig. 4.15). The seat is placed in a center position between the two piping centerlines. Offset valves are used for unique piping configurations because the flow passages do not shift up or down to bring the flow above and below the seat. Unlike the T-style globe body, less pressure drop occurs with the offset body.

The *split-body* style involves a body made of two separate parts: the upper body half and the lower body half (Fig. 4.16). These two body parts connect at the center of the valve body with the seat ring sand-

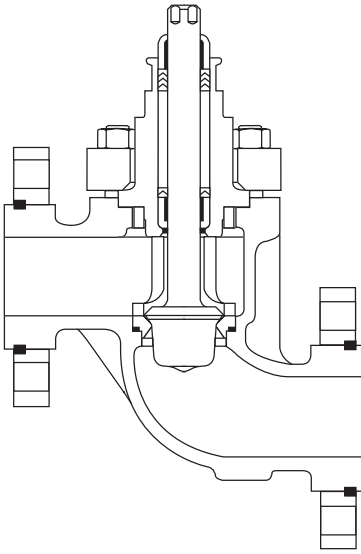


Figure 4.15 Offset globe-body subassembly.
(Courtesy of Valtek International)

wiched between the two body parts. Body bolting is used to secure the two body halves together. Two gaskets are used on both sides of the seat ring to ensure pressure retention. The bonnet can be integrally connected to the upper body half. This is preferred, since a good design should minimize potential leak paths—having a separate bonnet would add another potential leak path. Using a split-body design offers several advantages. First, the seat ring is retained in place without a seat retainer or cage to center or hold the seat ring in place, in effect, combining the advantages of both retained and threaded seat rings. If the application is such that the plug and seat ring must be inspected or replaced often, such as in chemical services that are highly corrosive, the simplicity of construction and disassembly permits frequent inspections. The split-body design also reduces the trim by one part, which may be a factor if the valve body is made from an exotic alloy. It also avoids any flow difficulties associated with a cage or retainer, such as galling or noise. Second, the seat ring can be removed with minimal disassembly, although the lower body half would need to be removed entirely from the line. And third, in some designs, the two body halves can be disassembled and turned 90° in either direction to provide a right-angle valve, perpendicular to the rising stem, as opposed to a true angle valve where the lower port is

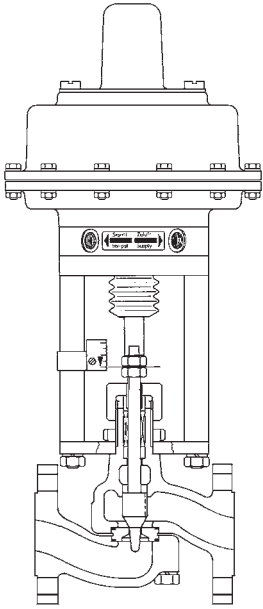


Figure 4.16 Split-body control valve. (Courtesy of Kammer Valves)

in-line with the rising stem. With a split body, the actuator or manual handwheel could remain upright. With a true angle valve, the actuator would be on its side. The split-body valve has some limitations. For example, it is usually only specified with flanged end connections. It cannot be used in steam or other high-temperature services where buttweld or socketweld end connections are required for welding the valve into the line, since the body could not be disassembled to access the seat ring. If process leakage occurs at the body connection, the body bolting is located where fluid could cause corrosion, making disassembly difficult.

Another unique body style is the *Y-body* style, which is a body where the rising stem is inclined 45° (or sometimes 60°) from the axis of the inlet and outlet ports, which are in-line with the piping (Fig. 4.17). Y-body valves are the best type of globe control valve for passing the largest C_v possible with minimal pressure drop—short of using a globe body with an integral seat and an oversized plug. Also, because the body avoids the right-angle turns and the plug pulls nearly out of the flow stream, less turbulence is generated through the body, which may reduce noise. Y-body valves are also commonly applied in piping sys-

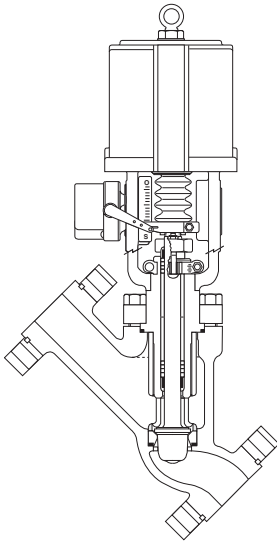


Figure 4.17 Y-body control valve. (Courtesy of Valtek International)

tems with piping set at 45° , allowing the valve body to be in-line with the piping, while the top-works is vertical to the ground. This allows easier maintenance and better operation. Because the body, when placed at a 45° angle, has little if no pockets for a fluid pool, the Y body is often applied in self-draining applications.

A *three-way body* style has three ports: two ports in-line with the piping centerline and one port in-line with the rising stem. This design uses a plug head featuring an upper and lower seating surface and two matching seats (Fig. 4.18). Depending on the position of the plug or the orientation of the piping, the process flow can be diverting, splitting, or mixing. With diverting flow, the flow enters a side port and, if the plug is fully extended into the lower seat, the flow is diverted out the opposite side port. If the plug is fully retracted into the upper seat, the flow is diverted through the bottom port. When the plug remains in a throttling position between the two seats, flow is diverted to both the side and bottom ports for when the flow needs to be split. Combining two separate flows can be accomplished with the same body style, except that the opposite side port and the bottom port both receive the upstream process flow. When the plug is placed in midposition, both processes flow together and combine before exiting the side port.

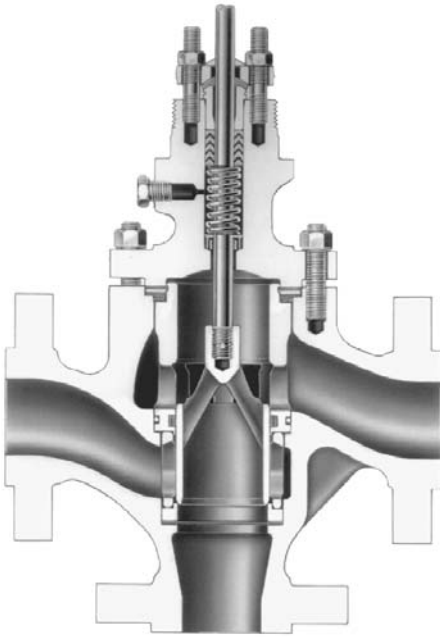


Figure 4.18 Three-way body subassembly with integral three-port body and pressure-balanced trim. (Courtesy of Fisher Controls International, Inc.)

Another optional design with three-way valves involves the use of a *three-way adapter* with a conventional globe straight-through body (Fig. 4.19). The adapter consists of an upper-body extension that is mounted above the body where the bonnet normally sits. An upper seat ring is sandwiched between the body and the adapter. The adapter is equipped with a side port, which can be mounted in any one of four quadrants if the end connection can be used without interfering with another port. One exception is flanged end connections, which can only be possible at right angles since the flanges would interfere with the in-line piping or other flanged connections. The bonnet sits above the adapter and a special three-way, dual-seating plug is used to divert, mix, or separate process flow. The obvious advantage to this type of design is that a valve can be converted to three-way service without a new body—only a new adapter, upper seat ring, and plug are required. The disadvantage is that an additional possible leak path is added to the body subassembly.

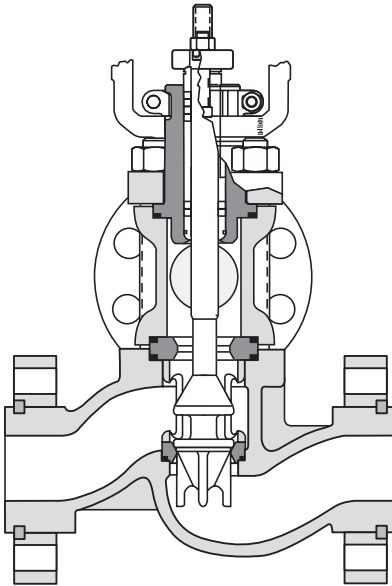


Figure 4.19 Three-way body subassembly with three-way adapter. (Courtesy of Valtek International)

4.3 Butterfly Control Valves

4.3.1 Introduction to Butterfly Control Valves

Although the butterfly valve has been in existence since the 1930s, it was used mainly as an on-off block valve until the past two decades, when it began to be used for throttling services. In the late 1970s, design advancements were made to the butterfly valve that not only made it more applicable for throttling service, but also made it preferred over globe valves in some applications. Such butterfly control valves are differentiated from their on-off block cousins by the name *high-performance butterfly valves*. In simple terms, the high-performance butterfly control valve is a quarter-turn (0° to 90°) rotary-motion valve that uses a rotating round disk as a regulating element. Typically, butterfly control valves are available in sizes 2 through 8 in (DN 50 through DN 200) from ANSI Classes 150 to 600 (PN 16 through PN 100); 10 and 12 in (DN 250 and DN 300) in ANSI Classes 150 and 300 (PN 16 and PN 40); and 14 through 36 in (DN 350–900) in ANSI Class 150 (PN 16).

When fully open, the disk actually extends into the pipe itself, which makes butterfly valves distinct from other valve designs. Butterfly-valve bodies have very narrow face-to-face dimensions compared to other types of valves, allowing the body to be installed between two pipe flanges without any special end connections. This type of arrangement is called a *through-bolt connection* and is only permissible with certain bolt lengths. If the bolt length is too long, the bolting may be subject to thermal expansion of the process or during an external fire, causing leakage.

Initially, butterfly control valves were designed as automatic on-off block valves. However, with recent improvements to rotary-valve actuators and body subassemblies, they can now be used in throttling services with the addition of an actuator or an actuation system. As detailed in Sec. 3.4, the family of butterfly valves is classified into two groups. *Concentric butterfly valves* are normally used in on-off block applications, with a simple disk in-line with the center of the valve body. Generally, concentric valves are made from cast iron or another inexpensive metal and are lined with rubber or polymer. Because of their lower performance, they are normally equipped with manual operators. In some applications, the manual operators are replaced with an actuation system for throttling service. In most applications, however, simple concentric butterfly valves are used strictly for on-off service. Even when used in throttling applications, they do not lend themselves as well to automatic control as other butterfly designs specifically designed for throttling control. This is because the initial development was for blocking service. Concentric butterfly valves have poor rangeability, while throttling-specific butterfly valves have design modifications to allow for better flow control through the entire stroke.

Eccentric butterfly valves are valves designed specifically for high-performance throttling services, using a disk that is offset from the center of the valve body. The majority of butterfly valves used as control valves feature the eccentric design. For the most part, eccentric butterfly valves are specified in common valve materials, such as carbon, stainless, or alloy steels. When equipped with actuators and positioners, they are much more precise than concentric butterfly valves that have been automated.

Compared to other types of throttling valves, eccentric butterfly valves are one of the fastest growing types of control valves today for a number of reasons. Because of the increased dead band associated with the mechanical conversion of linear motion to rotary motion, globe valves are more precise in high-pressure-drop applications than

butterfly valves. However, the control provided by today's butterfly valves is more than adequate for many low-pressure-drop applications and other standard services.

When compared to globe control valves, butterfly control valves are much smaller and lighter in weight because the butterfly valve's body subassembly weight can be anywhere from 40 to 80 percent of a comparable valve and less than half the mass of the globe body subassembly. In addition, smaller actuators can often be used with butterfly valves since the weight of the regulating element is not a critical factor in factoring the necessary actuator force. The difference in regulating-element weight between butterfly and globe control valves becomes much more evident as sizes become larger, as shown in Table 4.1. This means that butterfly valves are preferred in applications where limited space or weight is a consideration.

Table 4.1 Weight Comparisons between Globe and Butterfly Valves*

Valve Size	Flanged Globe Valve <i>Standard Valve with Actuator, ANSI Class 150</i>	Flangeless Butterfly Valve <i>Standard Valve with Actuator, ANSI Class 150</i>	Percent Reduction
2-inch DN 50	75 pounds 34 kilograms	40 pounds 18 kilograms	47%
3-inch DN 80	160 pounds 73 kilograms	46 pounds 21 kilograms	71%
4-inch DN 100	240 pounds 109 kilograms	52 pounds 24 kilograms	78%
6-inch DN 150	360 pounds 163 kilograms	96 pounds 44 kilograms	73%
8-inch DN 200	590 pounds 268 kilograms	110 pounds 50 kilograms	81%
10-inch DN 250	1050 pounds 477 kilograms	267 pounds 121 kilograms	75%

*Data courtesy of Valtek International.

Another major benefit of using a butterfly control valve is that, size for size, it has a larger flow coefficient, producing a greater flow than comparable globe valves. Because the shaft of the butterfly valve moves in a rotary motion instead of a linear motion, the frictional forces are far less than a linear-motion valve, requiring less thrust and permitting a smaller actuator. A butterfly valve has a naturally high pressure-recovery factor (Sec. 7.2.9). This factor is used to predict the pressure recovery occurring between the vena contracta and the outlet of the valve. The butterfly valve's ability to recover from the pressure drop is influenced by the geometry of the wafer-style body, the maximum flow capacity of the valve, and the service's ability to cavitate or choke. Overall, because of the high-pressure recovery, a butterfly valve works exceptionally well with low-pressure-drop applications.

The largest drawback to using a butterfly valve is that its service is usually limited to low-pressure drops because of its high pressure recovery. Although flashing is normally not associated with a butterfly-valve design, cavitation and choked flow occur easily with a butterfly valve installed in an application with a high-pressure drop. Although some special anticavitation devices have been engineered to deal with cavitation, users prefer to deal with cavitation in a globe valve because of its design versatility in allowing the inclusion of an anticavitation device. Another disadvantage is that a butterfly valve has a poor-to-fair rangeability of 20 to 1 because of the difficulty the disk has in holding a position close to the seat. The process pressure applied to the butterfly disk creates a significant side load, which can only be remedied by using a larger-diameter shaft. Another drawback to the butterfly control valve is the increased hysteresis and dead band associated with the mechanical transfer of linear action from the actuator to the rotary motion needed for the regulating element. Valve manufacturers have utilized splined shafts or other secure linkages to minimize this problem, although a globe valve avoids this problem altogether with its direct linear motion. The sizes of butterfly valves are also limited to 2 in (DN 50) and larger because of the limitations of the rotary regulating element. Because of the side loads applied to the disk, the maximum size that a high-performance butterfly can reach is 36 in (DN 900).

4.3.2 Butterfly-Control-Valve Design

The butterfly body typically involves one of two styles. The *wafer body* (sometimes called the *flangeless body*) is a flat body that has a minimal face-to-face, which is equal to double the required wall thickness plus

the width of the packing box (Fig. 4.20). Within this dimension, the disk in the closed position and the seat must fit within the flow portion of the body. Because the wafer-style body has a minimal face-to-face, straight-through bolting using the two flanged piping connections is possible without fear of thermal expansion causing leakage. Wafer-style bodies are more commonly applied in the smaller sizes, 12 in (DN 300) and less. The other body style is the *flanged body*, which is used with larger butterfly valves [14 in (DN 350) and larger] that require a longer face-to-face (Fig. 4.21) when a higher degree of thermal expansion is expected or when the regulating element cannot fit within the wafer-style body. The flanged style has integral flanges on the body that match the standard piping flanges.

As shown in Fig. 4.22, another body style is the *lug-style body*, in which the butterfly body has one integral flange that has an identical hole pattern to the piping flanges. Each hole is tapped from each direction, meeting in the center of the hole. This arrangement allows the body to be placed between two flanges. Studs are then inserted through the piping flange and threaded into the valve's integral flange. After the stud is securely threaded into the integral body flange, a nut is threaded to the stud to secure the piping flange to the body. Lug bodies are used in

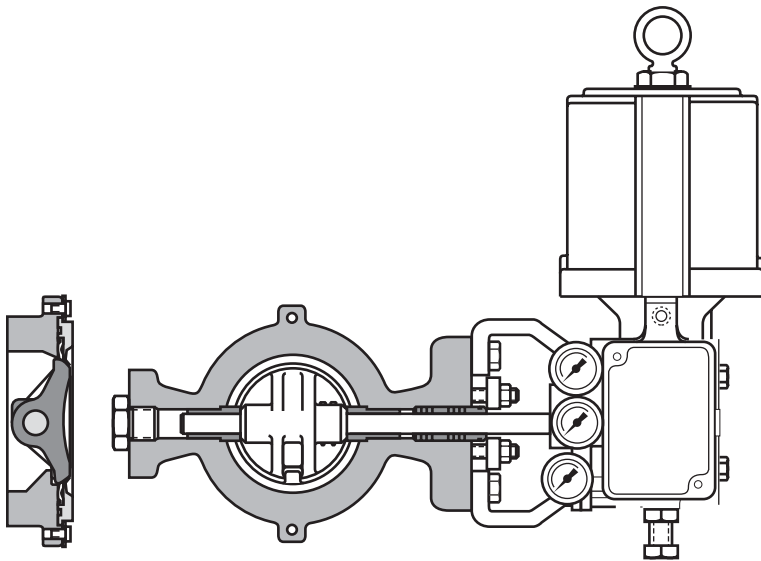


Figure 4.20 Flangeless butterfly control valve (wafer style). (Courtesy of Valtek International)

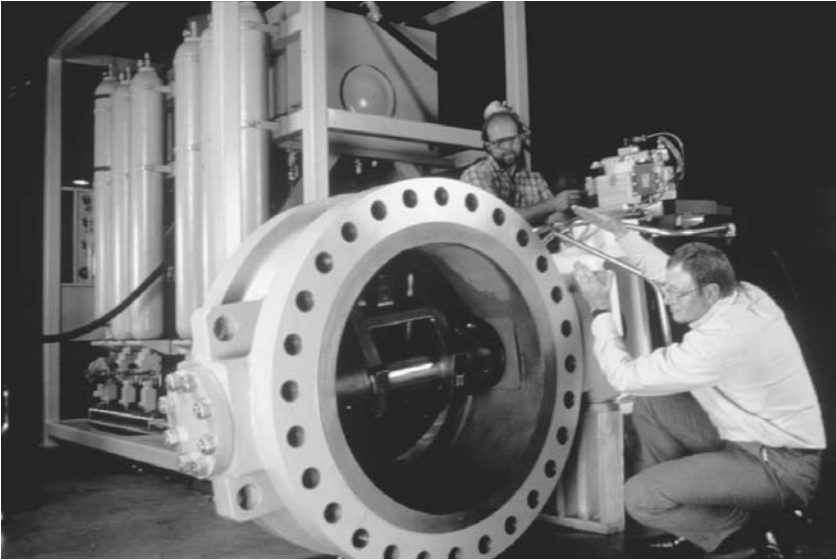


Figure 4.21 Flanged butterfly control valve. (Courtesy of Valtek International)

applications in which the risks of straight-through bolting cannot be taken—such as with thermal expansion—in smaller valve sizes that do not permit the use of two integral flanges.

The faces of the butterfly-valve body are often serrated to fix and secure the location of the flange gaskets between the pipeline and the valve. The inside diameter of the butterfly valve is close in size to the inside diameter of the pipe, which permits higher flow rates as well as straight-through flow. Perpendicular to the flow area of the valve is the shaft bore, which is drilled from both sides. Drilling from one side through the entire body is extremely difficult without the wandering associated with using a long drill bit.

The regulating element of the butterfly valve is the called the *disk*, which rotates into the *seat*. The disk is described as a round, flattened element that is attached (usually by tapered pins) to the rotating shaft. As the shaft rotates, the disk is closed at the 0° position and wide open at the 90° position. As explained earlier in Chap. 3, if the shaft is attached to the disk at the exact centerline of the disk, it is known as a *concentric disk*. When the disk is offset both vertically and horizontally (refer to Fig. 3.14), it is referred to as an *eccentric cammed disk*.

The disk is designed to minimize interruption of the flow as the process fluid moves through the valve. Slight angles and rounded sur-



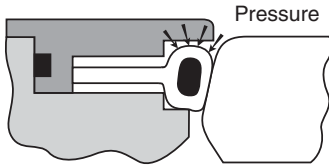
Figure 4.22 Lug-style butterfly control valve.
(Courtesy of Automax, Inc. and The Duriron Company, Valve Division)

faces are characteristic of a common disk design. When closed, the flat side (facing the seat) is called the *face*, while the opposite side is called the *back side*. The face is often designed slightly concave so that maximum flow can be achieved in the open-flow position. On the backside, sometimes a *disk-stop* is provided that matches up with a similar stop inside the body's flow area. This stop prevents the valve from over-stroking. Overstroking can cause the disk to drive through the seat, irreparably damaging the seat. The circumference of the seat wraps around the entire inside diameter of the body's flow area and is installed at one end of the body. If a polymer is used for the seat, it is called a *soft seat*. When a flexible metal is used as the seating surface, it is called a *metal seat*. The seat is installed in the end of the body and is held in place by a *seat retainer*, using screws or a snap-fit to keep the seat and retainer in place. After the seat and seat retainer are in place,

the face of the retainer usually lines up with the face of the body. In some designs, the seat-retainer design protrudes slightly from the body face, allowing some gasket compression when the body is installed in the line.

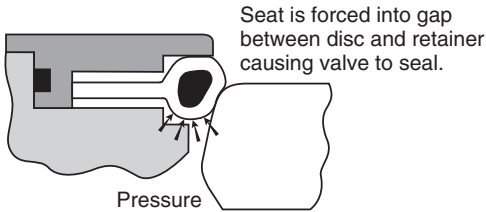
The disk is attached to the shaft with the use of one or more tapered pins. The shaft is supported by close-fitting *guides* (sometimes called *bearings*) on both sides of the disk, which are installed in the shaft bore to prevent lateral movement of the shaft and disk that can cause misalignment. Thrust washers may also be placed on both sides of the disk, between the disk and the body, to keep the disk firmly centered with the seat.

A number of different resilient seat designs exist for eccentric butterfly control valves, which are designed to handle higher pressures and temperatures—most of which operate by similar principles. One of the most common soft-seat designs is the seat that utilizes the *Poisson effect*, which states that if an O-ring or an elastomer is placed in a seating situation with a greater pressure on one side, the soft material will deform away from the pressure. In other words, deformation takes place when the pressure pushes the softer material against the surfaces to be seated (Fig. 4.23). With the Poisson effect, the greater the upstream pressure compared to the downstream pressure, the greater the seal. Because of their flexibility, O-rings encased in a polymer work exceptionally well with the Poisson effect. Related to the Poisson effect is the *jam-lever* or *toggle effect*, which uses a hinged elastomer that is designed to be thinner in the midsection than at the outside or inside diameter. This design permits the outside diameter of seat to flex and seal against metal surfaces when process pressure is applied (Fig. 4.24). A third resilient seat design uses the *mechanical preload effect*, which calls for the inside diameter of the seat to slightly interfere with the outside diameter of the disk. As the disk approaches the seat to close, it makes contact with the seat. As the disk moves further into the seat, the seat physically deforms because of the pressure applied by the disk, causing the polymer to seat against metal surfaces. In some cases, a manufacturer may use both the mechanical preload and Poisson effects to achieve the correct shutoff (Fig. 4.25). When a soft seat is used, it also has a secondary purpose, acting as a gasket between the body and the retainer. Metal seats are typically applied to high temperatures (above 400°F or 205°C). Metal seats are integral to the seat retainer—with a gasket placed where a soft seat is normally inserted (Fig. 4.26). In some designs, both a soft and metal seat can be used in tandem, allowing the metal seat to be a backup in case of failure of the soft seat (Fig. 4.27). When butterfly valves are specified for fire-safe applications, the tandem seat is



Seat is forced into gap between body and disc causing valve to seal.

Poisson Effect with Pressure Upstream



Seat is forced into gap between disc and retainer causing valve to seal.

Poisson Effect with Pressure Downstream

Figure 4.23 Poisson effect on a butterfly seal for both upstream and downstream pressures. (Courtesy of Valtek International)

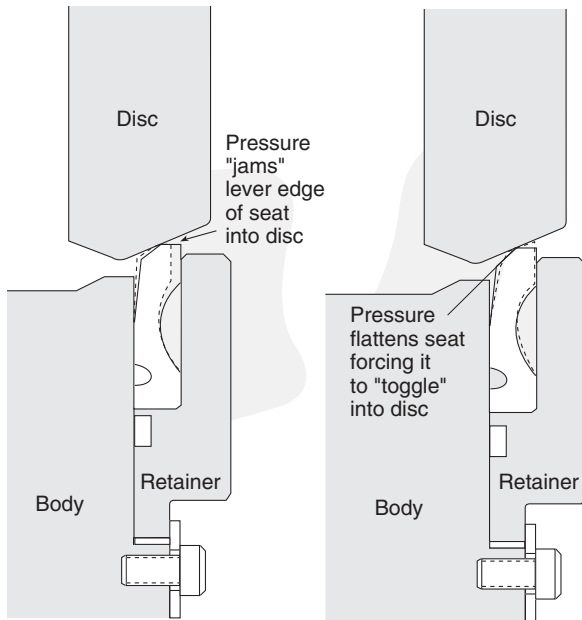


Figure 4.24 Jam lever or toggle effect on the butterfly seal. (Courtesy of Valtek International)

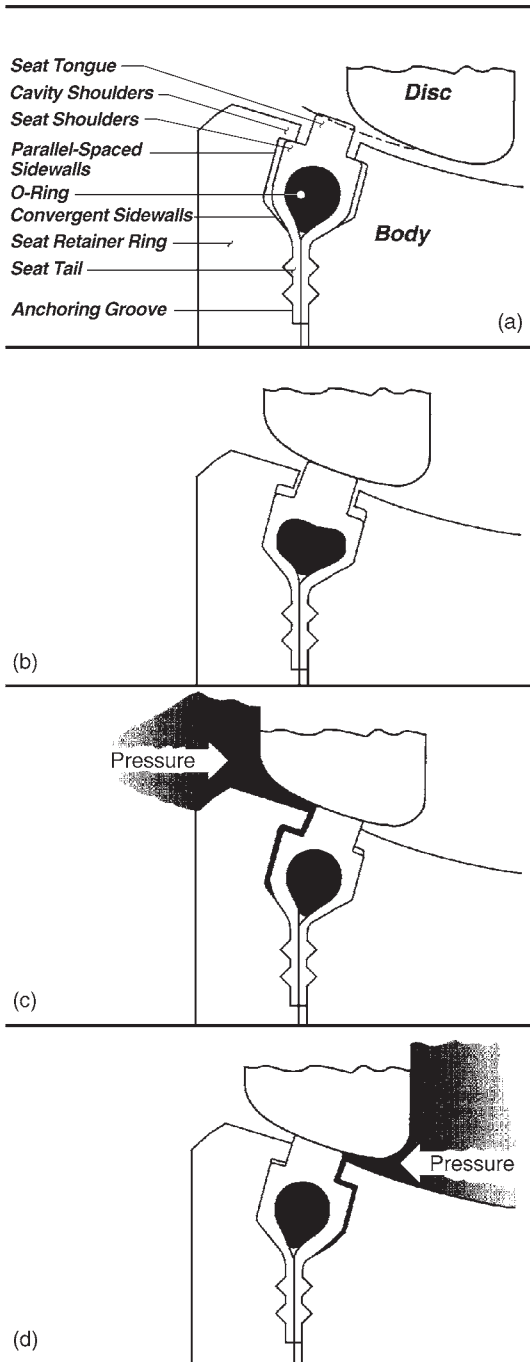


Figure 4.25 Butterfly seal using both mechanical preloading and the Poisson effect. (a) Basic seal design, (b) preloading effect on the seat caused by disk seating (with minimal pressure effects), (c and d) Poisson effect on the seat caused by increased upstream or downstream pressures. (Courtesy of Flowseal, a unit of the Crane Valve Group)

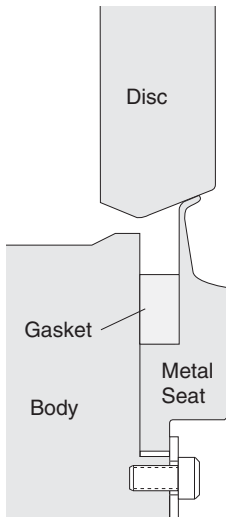


Figure 4.26 Butterfly metal seat design.
(Courtesy of Valtek International)

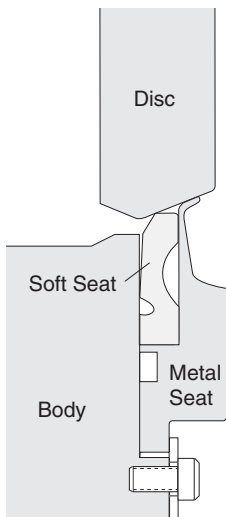


Figure 4.27 Butterfly dual soft- and metal-seat design.
(Courtesy of Valtek International)

installed. In pure throttling applications, where the valve is intended to remain in midstroke at all times and never close, the valve can be built without a seat as a cost-saving measure.

A butterfly valve's packing box is similar in some regards to the globe valve's packing box. The packing box has characteristics similar to all packing boxes: a polished bore and a depth to accommodate various packing designs. One major difference, however, is that a butterfly valve does not require a lower set of packing. Because of the rotary-motion design, the stem rotates and never changes linear position. In other words, the packing always remains in contact with the same region of the stem. Since the stem never moves its linear position, a "wiper" packing set is not necessary. All that is required is an optional spacer, the packing, and a packing follower. An upper guide or bearing is not needed at the open end of a butterfly-valve packing box as the shaft has its own guides on each side of the disk. The shaft can also be guided by a bearing in the actuator's transfer case. A gland flange and packing follower are used to compress the packing.

Because the shaft bore is normally machined from both ends, a plug or flange cover can be used to cover the bore opening opposite the packing box. To retain the body pressure, a gasket or O-ring is required. If a threaded plug end is used, it should not come in contact with the shaft, since the quarter-turn action of the shaft could possibly rotate the end plug, causing process leakage to atmosphere.

On the packing box side of the body, mounting holes are provided allowing the transfer case to be mounted. The *transfer case* contains the linear-motion to rotary-motion mechanism that allows a linear-motion actuator to be used with a quarter-turn valve. The end of the shaft that fits into the transfer case is either splined or milled with several flats to allow for attachment of the linkage. The designs of common rotary actuators, actuation systems, and handwheels are detailed in Chap. 5.

4.3.3 Butterfly-Control-Valve Operation

As the process fluid enters the butterfly body, it moves in a straight direction through the flow passage. The only obstruction to the flow is the disk itself. In the open position, the gradual angles and smooth, rounded surfaces of the disk allow the flow to continue past the regulating element without creating substantial turbulence. However, some turbulence should always be expected because the disk is located in the middle of the flow stream. In closing the valve, as the signal is received by the actuator or actuation system, the force is transferred to rotary motion, turning the shaft in a *quarter-turn motion*, which is defined any-

where between 0° (full-closed) and 90° (full-open). As the disk approaches the seat, the full pressure and velocity of the process fluid are acting on the full area of the face or back side of the disk (depending on the flow direction), which makes stability difficult. This instability may be compounded when diaphragm actuators are used, since they do not generate high thrust to begin with. Because the rangeability of butterfly valves is so poor (20 to 1), the final 5 percent of the stroke (to closure) is not available to the user. As the disk makes contact with the seat, some deformation takes place, allowing the resilient elastomer or flexible metal strip to mold against the seating surface of the disk.

To open the valve, the signal causes the disk to move away from the seating surfaces. Because of the mechanical and pressure forces acting on the disk in the closed position, a certain amount of rotary-motion force, called *breakout torque*, must be generated by the actuator or handwheel to allow the disk to open. The designs with the greatest requirement for breakout torque are those designs that require a great deal of actuator thrust to close and seat the valve. Therefore the greater the actuator force for closure, the greater the breakout torque. When fluid pressure is utilized to assist with the seat, less actuator force is required and thus less breakout torque.

In principle, the opening disk is nearly in a balanced state, since one side is pushing against the fluid forces, while the other side is pulling with the fluid forces. However, because both sides of the disk are not identical—the shaft is connected on one side, while the opposite side is more flat—flow direction has a tendency to either push a disk open or pull it closed. In most cases, when the shaft portion of the disk is facing the outlet (downstream), the process flow tends to open the valve. On the other hand, when the shaft portion is facing the inlet side (upstream), the flow tends to close the valve. The failure mechanism of the actuator must complement the flow direction, so that the proper failure mode will occur.

With concentric disk-seat arrangements (the center of the disk and the shaft are exactly centered in the valve), a portion of the disk always remains in contact with the seat in any position. At 0° open, the seating surfaces are in full contact with each other. In any other position, the seating surfaces touch at two points where the edges of the disk touch the seat. Because of this constant contact, the concentric disk-seat design has a greater tendency for wear, especially with automated control applications. During throttling, a butterfly valve may be required to handle a small range of motion in midstroke, causing wear at those two points of contact. Although the wear will not be evident during throttling, it will eventually allow leakage at those two points when the valve is closed. To

overcome this problem of constant contact between the seating surfaces, some butterfly-valve manufactures prefer to use the eccentric cammed disk-seat configuration, which allows for the disk and seat to be in full contact upon closure, but when the valve is open the disk and seat are no longer in contact. Such designs allow for the center of the shaft (and disk) to be slightly offset down and away from the center of the valve. When the valve opens, the disk lifts out of the seat and slightly away from the seating surfaces—enough to avoid constant contact.

Because of the design limitations of the disk and seat arrangement, a flow characteristic is not easily designed into the body subassembly, unlike the trim of a globe valve. Thus, a butterfly valve must use its inherent flow characteristic, which is parabolic in nature. To achieve a flow characteristic, an actuator with a cammed positioner must be used to provide a modified flow characteristic.

A feature unique to high-performance valves is the ability to mount the valve on either side of the pipeline so that the shaft orientation (shaft upstream or shaft downstream) and the failure mode (fail-open and fail-closed) can operate in tandem with the air-failure action of the actuator. Figure 4.28 shows the four common orientations [(1) fail-closed, shaft upstream, air-to-open; (2) fail-open, shaft upstream, air-to-close; (3) fail-open, shaft downstream, air-to-close; and (4) fail-closed, shaft downstream, air-to-close].

4.4 Ball Control Valves

4.4.1 Introduction to Ball Control Valves

Similar in many respects to the butterfly control valve, ball valves have been used for throttling service for the past two decades. As control valves, they have been adapted from the automation of simple on-off valves to automatic control valves designed specifically to accurately control the process. Improved sealing devices and highly accurate machining of the balls have provided tight shutoff as well as characterizable control. For the most part, they are used in services that require high rangeability. Ball control valves typically handle a rangeability of 300 to 1, notably higher than butterfly control valves that offer 20 to 1. Such high rangeability is permitted by the basic design of the regulating element, which allows the ball to turn into the flow without any significant side loads that are typical of a butterfly disk or a globe-valve plug.

Ball control valves are also well suited for slurry applications or those processes with fibrous content (such as wood pulp). The rotary

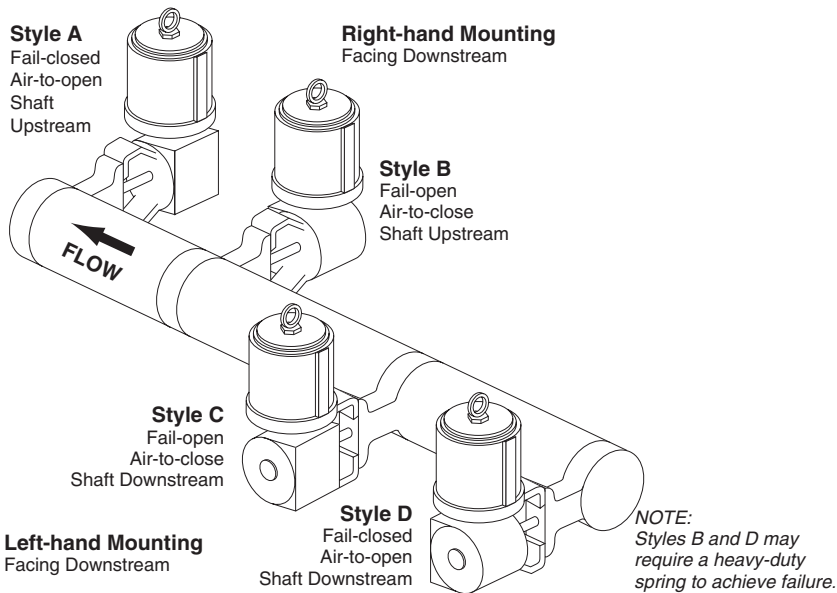


Figure 4.28 Rotary actuator mounting orientations. (Courtesy of Valtek International)

action of the ball provides a shearing action against the seal, which allows for clean separation of the process during closure. The same process would clog or bind in a butterfly or globe control valve (which uses a regulating element or trim directly in the path of the process flow). Similar to the butterfly-valve design that features straight-through flow, a ball valve can be installed in a vertical pipeline (Fig. 4.29) to avoid the settling or straining of fibrous or particulate matter. A globe valve, on the other hand, allows heavier portions of the process to settle at the bottom of the globe body (horizontal line installations) or in the body gallery (vertical line installations).

Tight shutoff is a characteristic of ball control valves, since the ball remains in continual contact with its seal. With soft seals, ball control valves can achieve ANSI Class VI shutoff (bubble-tight) but have a limited temperature range. For higher-temperature ranges, metal seals are used although they permit greater leakage rates (ANSI Class IV). Ball valves are also capable of higher flow capacity than globe valves, and even butterfly valves where the presence of the disk in the flow stream can restrict the flow capacity. Because the flow capacity of a typical ball valve can be two to three times greater than that offered by

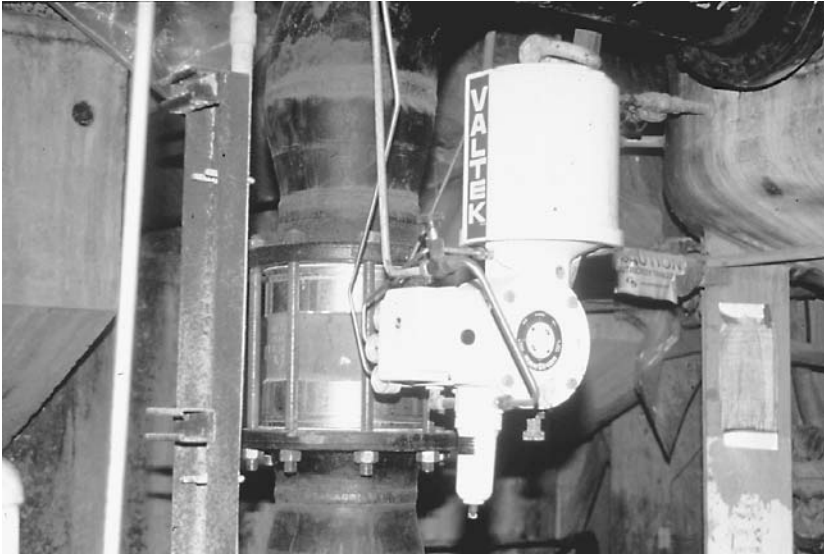


Figure 4.29 Ball control valve mounted in a vertical line. (Courtesy of Valtek International)

a comparably sized globe valve, a smaller-sized ball valve can be used, which may be a significant economic consideration. Table 4.2 shows a comparison of flow capacity between globe (both T and Y styles), butterfly and ball valves.

One major disadvantage of ball control valves is that as the valve throttles the geometry changes dramatically, providing lower pressure differentials, higher pressure drops, and an increasing chance of cavitation, although the straight-through flow style of ball valves provides a minimal pressure drop. Therefore if the service conditions are likely to result in cavitation, larger-sized ball valves may be required to provide higher differentials and to prevent a high-pressure drop from developing—defeating one of the purposes of ball valves, which is to use a smaller-sized valve with a large C_v . Using a larger ball valve also means that a good portion of the valve stroke will not be available for control purpose, utilizing the portion of the stroke closest to the closed position.

Two basic ball-valve designs are used today: the *full-port ball valve* and *characterizable-ball valve*. Similar in design to a manually operated on-off block ball valve, a full-port ball valve uses a spherical ball as the regulating element, characterized by a hole that is bored to the same inside diameter as the pipeline (Fig. 4.30). When the full-port ball

Table 4.2 C_v Comparisons Globe vs. Ball Valves*

Valve Size	Globe Valve (T-body style, flow-over-the-plug, full area trim, 100 percent open)	Ball Valve (Wafer-style, shaft downstream)	Percentage Increase
2-inch DN 50	46	104	126%
3-inch DN 80	104	275	164%
4-inch DN 100	179	445	149%
6-inch DN 150	355	844	138%
8-inch DN 200	606	1338	121%
10-inch DN 250	897	3180	255%
12-inch DN 300	1310	4150	217%

*Data courtesy of Valtek International.

valve is wide open, the flow continues unimpeded through this hole. Therefore, the flow does not impinge on a regulating element or trim, creating little (if any) pressure drop as well as minimal process turbulence. Although best utilized for on-off services, a full-port valve is rarely used for a pure throttling service because the sharp edges associated with the ball's bore may create noise, cavitation, erosion, and an increased pressure drop. Although a full-bore ball valve is often associated with on-off services, it is also applied where a pig or cleaning rod is used to clean out the interior of the pipeline. (This requires using a valve with straight-through flow that does not have a regulating

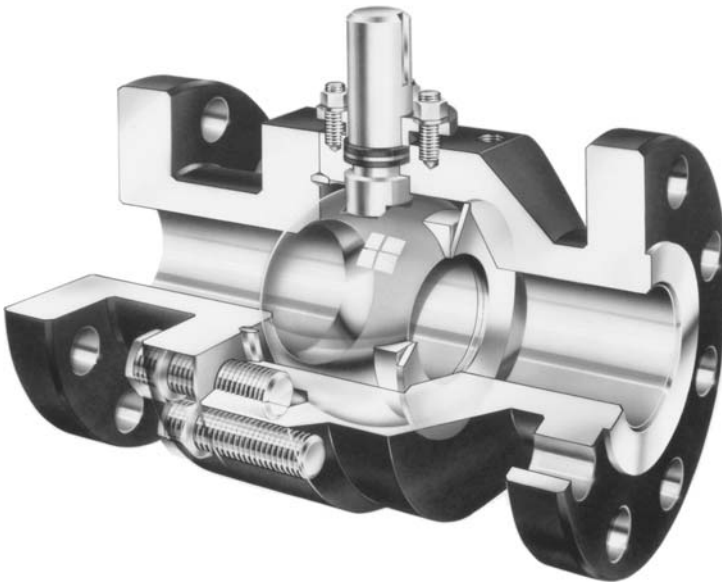


Figure 4.30 Full-port ball valve with floating seal. (Courtesy of Vanessa/Keystone Valves and Controls, Inc.)

element in the flow stream.) Because of the design limitations of full-port ball, a flow characteristic cannot be designed into the ball. The machining of orifice shapes other than circular is exceptionally difficult and expensive. The inherent flow characteristic associated with full-port valves is close to the equal-percentage characteristic, and any flow characteristic modifications must be made with a positioner cam.

The characterizable-ball valve (Fig. 4.31) does not use a spherical ball. Instead, it uses a hollow segment of a sphere that, when full-open, is turned out of the path of the process flow. This allows reasonably smooth flow through the valve body, although the contours of the body and geometry of the characterized ball will take a small pressure drop and may create some turbulence. However, as the valve moves to a midstroke throttling position, the characterized ball moves into the flow path. The flow characteristic is cut into the ball with either a V-notch or a parabolic curve to provide the necessary flow per position. As the valve continues through the quarter-turn motion, this notch or curve becomes progressively smaller until the entire surface of the ball is exposed to the flow area, providing a full-closed position. The V-notch provides an inherent linear flow characteristic, which can

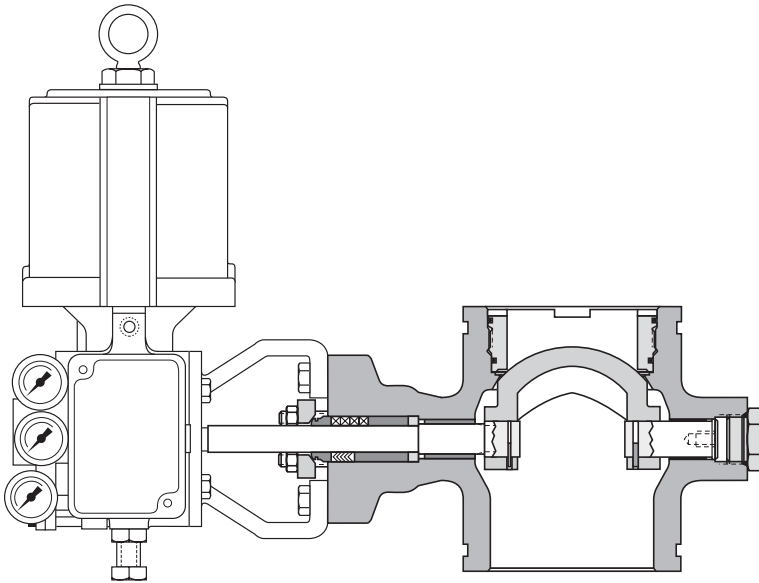


Figure 4.31 Characterizable-ball control valve. (Courtesy of Valtek International)

become close to the equal-percentage characteristic when installed. The parabolic notch can be modified to meet specific flow requirements.

Ball control valves are typically found in sizes 1 through 12 in (DN 25 through DN 300) in pressure classes up through ANSI Class 600 (PN 100).

4.4.2 Ball-Control-Valve Design

Outside of the regulating element, ball control valves are similar in many regards to butterfly control valves: quarter-turn motion, rotary-action actuators, and packing boxes without wiper (lower) packing.

As described in Sec. 4.4.1, two basic ball-valve styles exist: the full-port ball valve and characterizable-ball valve. The regulating element of the full-port body subassembly features a spherical ball that is supported by one of two methods. The first is a *floating-seal* design (Fig. 4.30), similar to most manual ball-valve designs, where two full contact seals are placed on both the inlet and outlet ports, in which the

ball is fully supported by these two seals without coming in direct contact with the body. The ball is connected to the shaft using a slip fit or other comparable connection. This connection must be extremely tight to avoid any mechanical hysteresis, especially in light of the continuous seal friction evident in this design. The basic advantage of this design is that a blind end bore is not required to support the nonshaft end of the ball. The disadvantage is that the sphere must have extremely tight tolerances to ensure constant contact at both seals. These seals are designed for more rigorous, heavy-duty service since they must both seal the flow and support the ball. Because this design is dependent upon the support of the seals, it is specified for general services featuring moderate pressures and temperatures.

The characterizable ball is typically *segmented*, meaning that only a portion of the sphere is used instead of an entire sphere. The segmented ball includes only enough of the sphere to entirely close off the flow area plus enough ball surface to provide a seal. A segmented ball is normally *trunnion-mounted* (Fig. 4.32). With trunnion mounting, the ball is supported by both the shaft and the side opposite the shaft using another shaft or post, which can be separate or integral to the ball. Because support is not handled by a seal, trunnion-mounted balls are normally designed with one seal (although two-seal designs are available), which provides less friction between the ball and seal. Trunnion-mounted designs are best for more severe services where higher pressures and temperatures are involved.

Ball valves can be provided with either soft or metal seals. With soft seals, the elastomer seal is provided with a metal or hard-elastomer backup ring to apply continual pressure to the sealing surface, act as a backup in case the elastomer fails, and to provide additional wiping of sealing surfaces. With highly corrosive or nonsparking services—such as an oxygen application—metal backup rings are prohibited in favor of hard elastomers. If a metal seal is required because of temperature extremes, care must be taken to provide complementary metals so that galling or scoring does not take place. Metal seals require heat treatment and/or coating of the ball.

The style of the body determines how the seals are held in place in relation to the ball. With one-piece bodies, the ball is installed followed by the seal, which is held in place by a retainer. Most retainers are threaded into the body, allowing for minute adjustments of the retainer to increase or decrease the compression of the seal against the ball. This design balances the integrity of the seal versus increased ball–seal friction. Ideally, the retainer should not encompass the entire gasket region surface of the body face but should share it with the body. If the

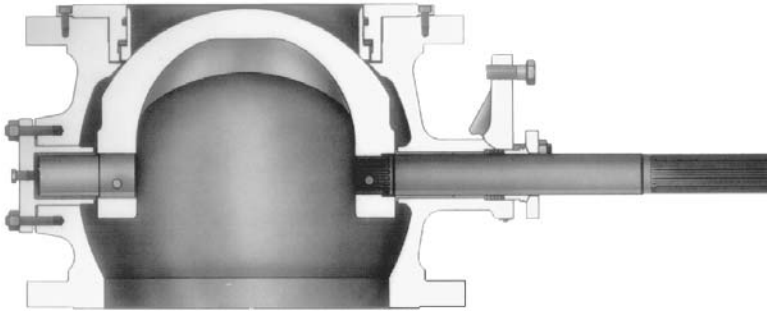


Figure 4.32 Trunnion-mounted segmented-ball valve. (Courtesy of Fisher Controls International, Inc.)

retainer does handle the entire seal, its compression of the seal will be affected by the piping forces. With uneven piping forces, they can create an uneven seal. To ensure uniform seal tightness, shims of varying width are often used between the retainer and the seal.

A few ball-valve bodies use two-piece designs in which the body is divided in half (much like a split-body globe valve), allowing for easier assembly and the use of a floating ball. The major drawback to using the two-piece design is that piping forces or process temperature can alter the seal tightness. As with all split-body designs another potential leak path is created at the joint between the two body halves.

Because the body's face-to-face is dependent upon the design of the body subassembly, that dimension varies from manufacturer to manufacturer. No overall standards have been established that all manufacturers adhere to, as opposed to ANSI/ISA Standard S75.15 or ANSI/ISA Standard S75.16 for globe-style valves. Because the ball-valve face-to-face is larger than the thin wafer-style body of the butterfly valve, yet smaller than the globe body, its body can be installed between piping flanges in some applications. When high temperatures or thermal cycling are present, the longer bolting between the piping flanges can result in lost compression through thermal expansion and cause leakage. Also, even if temperatures are moderate, the bolting associated with larger valves [8 in (DN 200) or larger] can stretch over time and cause leakage. For those applications in which a flangeless design is not practical, ball valves are also available with integral flanges or separable flanges. Integral flanges offer solid, one-piece structure integrity, while separate flanges offer lower cost (with alloy bodies) as well as easier installation when piping does not match up with the valve flanges.

The packing box is nearly identical to that found in butterfly control valves. Similar to other packing boxes, the bore is polished and deep enough to accommodate a wide variety of packing designs. As is the case with butterfly valves, the rotary quarter-turn action of the ball valve does not require a lower set of packing to wipe the shaft of any process. A typical packing box will include the packing set, an optional spacer and a packing follower (which is used to transfer the force of the gland flange to the packing). Unlike globe valves, an upper guide or bearing is not needed at the open end of a ball-valve packing box as the shaft is normally guided on each side of the ball. In some automated rotary-motion valves, the shaft is also guided by a bearing in the actuator's transfer case.

For machining simplicity of the trunnion-mounted design, the shaft bore is machined from both ends of the body, and a plug or flange cover (plus a gasket or O-ring) can be used to cover the bore opening opposite the packing box. If a threaded plug is used, it should not come in contact with the shaft, since the quarter-turn action of the shaft could unthread the plug, causing process leakage to atmosphere. Mounting holes are provided on the packing-box side of the body, allowing the transfer case of the actuator to be mounted. As with all automated rotary valves, the transfer case contains the linear-motion to rotary-motion mechanism that allows a linear-motion actuator to be used with a quarter-turn valve. The end of the shaft that fits into the transfer case is either splined or milled with several flats to allow for attachment of the linkage. The designs of common rotary actuators, actuation systems, and handwheels are detailed in Chap. 5.

4.4.3 Ball-Control-Valve Operation

As with all rotary-action valves, the ball valve strokes through a quarter-turn motion, with 0° as full-closed and 90° as full-open. The actuator can be built to provide this rotary motion, as is the case with a manual handlever, or can transfer linear motion to rotary action using a linear actuator design with a transfer case.

When full-open, a full-port valve has minimal pressure loss and recovery as the flow moves through the valve. This is because the flow passageway is essentially the same diameter as the pipe inside diameter, and no restrictions, other than some geometrical variations at the orifices, are present to restrict the flow. The operation of throttling full-port valves should be understood as a two-stage pressure drop process. Because of the length of the bore through the ball, full-port valves have two orifices,

one on the upstream side and the other on the downstream side. As the valve moves to a midstroke position, the flow moves through the first narrowed orifice, creating a pressure drop, and moves into the larger flow bore inside the ball where the pressure recovers to a certain extent. The flow then moves to the second orifice, where another pressure drop occurs, followed by another pressure recovery. This two-step process is beneficial in that lower process velocities are created by the dual pressure drops, which is important with slurry applications. The flow rate of a full-port valve is determined by the decreasing flow area of the ball's hole as the valve moves through the quarter-turn motion, providing an inherent equal-percentage characteristic with a true circular opening. As the area of the flow passageway diminishes as the valve approaches closure, the sliding action of the ball against the seal creates a scissorslike shearing action. This action is ideal for slurries where long entrained fibers or particulates can be sheared off and separated at closing. On the other hand, globe-valve trim and butterfly disks do not have this shearing action and can only attempt to separate the fibers by pinching them between seating or sealing surfaces. In many cases, the fibers stay intact and do not allow for a complete seal, creating unplanned leakage.

At the full-closed position, the entire face of the ball is fully exposed to the flow, as the flow hole is now perpendicular to the flow, preventing it from continuing past the ball.

With the characterized segmented-ball design, only one pressure drop is taken through the valve—at the orifice where the seal and ball come in contact with each other. When the segmented ball is in the full-open position, the flow is restricted by the shape of the flow passageway. In essence, this creates a better throttling situation, since a pressure drop is taken through the reduction of flow area. As the segmented ball moves through the quarter-turn action, the shape of the V-notch or parabolic port changes with the stroke, providing the flow characteristic. Like the full-port design, the sliding seal of the characterizable ball provides a shearing action for separating slurries easily.

4.5 Eccentric Plug Control Valves

4.5.1 Introduction to Eccentric Plug Control Valves

One control valve design that is growing in demand is the *eccentric plug valve* (sometimes called *eccentric rotating plug valve*), which combines many of the positive aspects of the globe, butterfly, and ball

valves. In simple terms, the eccentric plug valve is a rotary valve that uses an offset plug to swing into a seat to close the valve, much like an eccentric butterfly valve. However, the eccentric movement of the plug swings out of the flow path, similar to a segmented-ball valve. Overall this design provides minimal breakout torque, as well as tight shutoff without excessive actuator force. Figure 4.33 shows the internal construction of an eccentric plug valve.

Eccentric plug valves can typically handle pressure drops from 1450 psi (100 bar). The eccentric motion also avoids water-hammer effects and the poor rangeability inherent with butterfly valves. Unlike a ball valve where the ball is in constant contact with the seal, the plug lifts off the seat upon opening. Seat contact and partwear only occur when the valve is closed (Fig. 4.34)—a feature similar to globe-valve trim. Because the plug swings out of the flow area—as does a segmented-ball valve—it allows for greater flow capacity and avoids erosion from the process.

With the stability of the plug design, eccentric plug valves provide exceptional stability, providing rangeability of greater than 100:1, compared to 50:1 for globe valves and 20:1 for butterfly valves. Only the ball control valve has better rangeability (up to 400:1). Because the shaft and plug do not directly intersect the flow, the flow capacity is slightly less than ball valves but is better than most high-performance globe and butterfly valves. Its design permits a reasonable pressure drop to

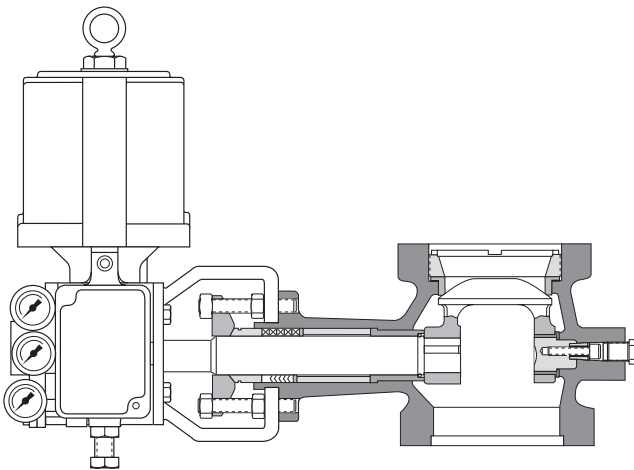


Figure 4.33 Eccentric plug valve. (Courtesy of Sereg/Valtek International)

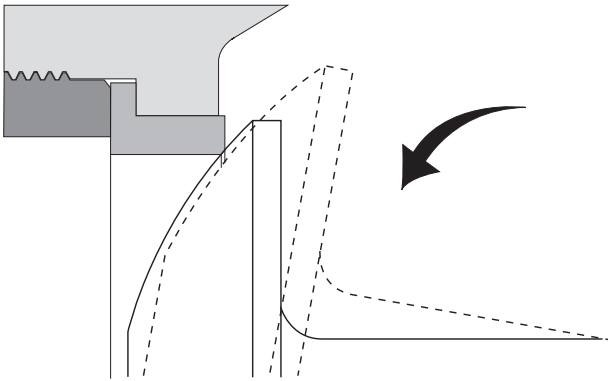


Figure 4.34 Seating path of eccentric plug design.
(Courtesy of Sereg/Valtek International)

be taken across the valve. Eccentric plug valves are best applied in applications with moderate pressure drops. In normal applications, the eccentric plug valve operates equally well in either flow-to-close or flow-to-open applications. The design of the plug permits the flow direction to assist with the closure or opening of the valve. As the eccentric plug valve opens, the flow characteristic is an inherent linear characteristic. With the regulating element outside on the outside boundaries of the flow, very little process turbulence is created.

Eccentric plug valves are typically available in sizes from 1 in (DN 25) to 12 in (DN 300), in ANSI Classes up through Class 600 (PN 100), and handle temperatures typically from -150°F (-100°C) to 800°F (430°C).

4.5.2 Eccentric-Plug-Control-Valve Design

The body design of an eccentric plug valve is very similar to a characterizable segmented ball valve in many aspects. The valve body and packing box are similar in shape and function, although the shaft alignment with the seal is different. With a ball valve, the centerline of the shaft is aligned exactly with the seal so that the ball is always in direct contact with the seal, whereas the shaft of an eccentric plug valve is slightly offset from the seat. This offset keeps the rotating plug away from any seating surfaces until closure occurs. Overall, this is similar in concept to the offset of an eccentric and cammed disk in high-performance butterfly valves. With fail-closed situations, the off-

set design positions the plug correctly upon failure, reducing the actuator failure spring requirements.

Although a segmented ball and an eccentric plug look similar at first appearance, each is designed differently. Where the ball is spherical in design, the plug is designed more like the plug head of a globe valve that is attached at a right angle with the shaft. The contour of the face of the rotary plug is similar to a modified quick-open plug contour in a globe valve, although the major difference is that the contour of the eccentric plug is also the seating surface. The seat construction is similar to the seat retainer in a ball valve, which can be threaded in place. Newer designs use a two-piece construction featuring a floating, self-centering seat with a threaded seat retainer that, when tightened, fixes the seat in place. On the other hand, one-piece seats have difficulty achieving tight shutoff because of the possibility of misalignment between the plug and seat. Seats can be either metal (providing ANSI Class IV shutoff) or provided with a soft seat elastomer (providing ANSI Class VI shutoff).

One design attribute of the eccentric plug valve that is similar to globe valves is its ability to provide reduced trims by simply changing the seat to one with a smaller opening. Because the eccentric plug has one large seating surface, it can be used with a variety of smaller seats, providing a reduced trim option that is not normally available in other rotary valves.

Eccentric plug valves utilize straight-through bolting or flanged end connections.

4.5.3 Eccentric-Plug-Control-Valve Operation

The eccentric ball valve strokes through a quarter-turn motion, with 0° at full-closed and 60° to 80° at full-open. Maximum rotation (80°) is preferred because it provides increased controllability and resolution. When less than full rotation is required, some actuators have limit-stops that can prevent the full motion.

When the valve is in the full-open position, the plug is located nearly perpendicular to the seat (Fig. 4.35) and parallel to the flow. As the flow moves through the body, it is restricted by the diameter of the seat and geometric shape of the plug, taking a reasonable pressure drop.

In fail-open applications, the flow assists the opening of the plug since the shaft is downstream from the flow and the plug swings with the flow until it is perpendicular to the seat. The process flows through

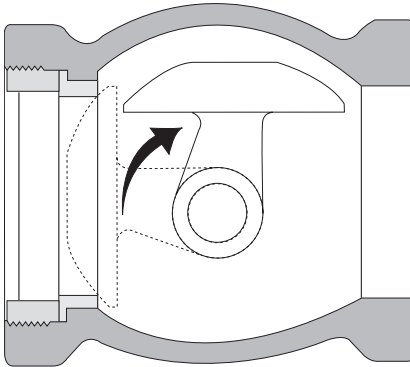


Figure 4.35 Eccentric plug in the open position. (Courtesy of Sereg/Valtek International)

the seat, taking a small pressure drop, and then slightly recovers inside the body. The majority of the flow moves through the center of the valve body and the horseshoe-shaped opening of the plug, encountering minimal flow resistance. As the flow exits the valve body, the pressure recovery is completed. As the valve begins to close, the plug moves against the flow, restricting the flow by degrees until the plug is approaching the closed position. At that point, the offset shaft aligns the plug exactly with the seat, seating surfaces meet, and the valve closes.

In fail-closed applications, the shaft is upstream from the flow and the plug must open against the flow, moving perpendicular to the seat. Flow moves through the body and the plug opening to the seat, taking a small pressure drop at the plug opening and a larger pressure drop at the seat, with pressure recovering in the downstream piping. As the valve fails, the direction that the plug swings to close is the same as the flow, using the flow pressure to assist with the closure. A feature unique to automatic rotary valves in general is the ability to mount the valve on either side of the pipeline so that the shaft orientation (shaft upstream or shaft downstream) and the failure mode (fail-open and fail-closed) can operate in tandem with the air-failure action of the actuator. Figure 4.28 is a good reference illustration for showing the four common orientations (fail-closed, shaft upstream, and air-to-open; fail-open, shaft upstream, and air-to-close; fail-open, shaft downstream, and air-to-close; and fail-closed, shaft downstream, and air-to-close).

