6.21 Valve Types: Plug Valves


Sizes: \( \frac{1}{2} \) to 36 in. (12.5 mm to 0.96 m)

Types: V-ported, three-way, four-way, five-way, fire-sealed

Design Pressure: Typically from ANSI Class 125 to ANSI Class 300 ratings and up to 720 PSIG (5 MPa) pressure, with special units available for ANSI Class 2500. The retractable seat design is suited for 10,000 PSIG (69 MPa) service.

Design Temperature: Typically from \(-100\) to \(400\)°F \((-73\) to \(204\)°C), with special units available from \(-250\) to \(600\)°F \((-157\) to \(315\)°C)

Rangeability: Refer to Section 6.7; generally 20:1

Characteristics: See Figure 6.21a

Capacity: \( C_v = (25 \text{ to } 35)d^2 \); see Tables 6.1a and 6.21b

Leakage: Metal seats ANSI Class IV, composition seats ANSI Class V; see Table 6.1gg for definitions

Materials of Construction: Iron, forged and alloy steel, chrome plating, 302 through 316 stainless steel, Alloy 20, Ni-resist, Monel, nickel, Hastelloy B and C, and zirconium, plus rubber or plastic, including PTFE linings

Costs: Costs vary drastically with design and accessories. In general, the cost of conventional plug-type control valves is about half that of globe valves, while the cost of eccentric rotating plug valves is about the same as that of globe valves of the same size and materials. (For the costs of carbon steel and stainless steel globe valves, refer to Figure 6.19b.)

Partial List of Suppliers:

- ABB Inc. (www.abb.com)
- Anchor/Darling Valve Co. (www.flowserve.com)
- Cashco Inc. (www.cashco.com)
- Circle Seal Controls Inc. (www.circle-seal.com)
- Dezurik/SPX Valves & Controls (www.spvalves.com)
- Emerson Process Management (www.emersonprocess.com)
- FMC Fluid Control Div. (www.fmcblanding.com)
- Halliburton Services (www.hallflow.com)
- Honeywell Industrial Controls (www.honeywell.com)
- Hydril Co. (www.hydril.com)
- Jordan Valve (www.jordancontrols.com)
- Mar-In Controls (www.mar-in-controls.com)
- Nordstrom Valves Inc. (www.nordstromaudco.com)
- Offshore Technology (www.offshore-technology.com/index.html)
- Spirax Sarco Inc. (www.spiraxsarco-usa.com)
- Xomox/Tufline (www.xomox.com)
GENERAL CHARACTERISTICS

The rotary plug valves (similar to ball and butterfly valves) used to be considered only as on/off shutoff valves, but today they are also used as control valves. Table 6.1a shows how they compare in their characteristics and applications to some of the other control valve designs. Plug valves are well suited for corrosive, viscous, dirty, fibrous, or slurry services, while they are generally not recommended for applications where cavitation or flashing is expected.

Relative to the traditional globe valve, the advantages of conventional plug valves include their lower cost and weight, higher flow capacity, which can be two to three times that of the globe valve, if the plug is not characterized. In addition, they provide tight shutoff, fire-safe designs, and low stem leakage, which meets OSHA and EPA requirements.

The designs using characterized or eccentric rotating plugs provide good control performance and a self-cleaning flow pattern, which also reduces noise and cavitation. Actually, the performance of the rotating spherical segment-type valve is just as good as that of a globe valve, and for that reason some refer to it as a globe valve (Figure 6.21c).

In addition to their superior stem-sealing capability, plug valves are also suited for such corrosive applications as chlorine, phosgene, hydrofluoric acid, and hydrochloric acid. Plug valves are widely used on lethal and toxic services and can be made fire-safe by the use of Grafoil packing and can meet the external leakage requirement limits of API 607.

### TABLE 6.21b

<table>
<thead>
<tr>
<th>Valve Size-inch (mm)</th>
<th>$%_a$ (12)</th>
<th>3% (19)</th>
<th>5% (25)</th>
<th>10% (38)</th>
<th>20% (51)</th>
<th>30% (76)</th>
<th>40% (102)</th>
<th>50% (153)</th>
<th>60% (224)</th>
<th>70% (254)</th>
<th>80% (305)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>9</td>
<td>9</td>
<td>25</td>
<td>55</td>
<td>144</td>
<td>254</td>
<td>433</td>
<td>900</td>
<td>1400</td>
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<td>3100</td>
</tr>
<tr>
<td>Modified parabolic plate</td>
<td>33</td>
<td>51</td>
<td>115</td>
<td>201</td>
<td>402</td>
<td>625</td>
<td>940</td>
<td>1385</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modified linear plate</td>
<td>12</td>
<td>20</td>
<td>46</td>
<td>81</td>
<td>162</td>
<td>252</td>
<td>380</td>
<td>560</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three-way</td>
<td>7</td>
<td>7</td>
<td>20</td>
<td>40</td>
<td>70</td>
<td>100</td>
<td>175</td>
<td>350</td>
<td>475</td>
<td>650</td>
<td></td>
</tr>
<tr>
<td>Equal-percentage cage</td>
<td>20</td>
<td>44</td>
<td>97</td>
<td>178</td>
<td>307</td>
<td>641</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Modified parabolic cage</td>
<td>12</td>
<td>33</td>
<td>51</td>
<td>115</td>
<td>201</td>
<td>402</td>
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<tr>
<td>Modified linear cage</td>
<td>5</td>
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<td>20</td>
<td>46</td>
<td>81</td>
<td>162</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V-ported</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

*Courtesy of Xomox Corp./Tufline and DeZurik.
Plug Valve Features

The plug valve is a type of quarter-turn valve that is among the oldest designs known in engineering. Wooden plug valves were used in the water distribution systems of ancient Rome and probably predate the butterfly valve. Although no longer as popular as ball or butterfly valves, they lend themselves to special designs that work very well in specific control applications.

Conventional plug valves are usually lower cost and lighter weight than comparable gate or globe valves. Plug valves afford quick opening or closing with tight, leakproof closures under conditions ranging from vacuum to pressures as high as 10,000 PSIG (69 MPa). Some, including the various characterized and Y-ported or diamond design, can be used for throttling, while others, like the multiport, are used for diverting and bypass applications.

Plug valves are used on gas, liquid, and nonabrasive slurry services. Lubricated plug valves can also be used for abrasive slurries, and eccentric plugs are also used on applications involving sticky fluids. Plug valves are also used for applications requiring the contamination-free handling of foods and pharmaceuticals. In general, plug valves can handle applications with the following requirements:

- High flows at low pressure drops
- Low flow control
- Flow diversion
- High- or low-temperature applications
- Vibration-free operation
- Throttling control, only with eccentric and V-ported characterized designs.

The conventional plug valves are generally undesirable for the following types of applications:

- Flow modulation or continuous, exact flow throttling
- Maintenance-free operation (occasional lubrication is usually required and plugs may wear)

Throttling and Actuator Considerations

When used for throttling service some of the above-mentioned advantages of rotary valves, such as their high-capacity, can become disadvantages. Their high flow capacity can result in installations where small valves are mounted in large pipes. This results in a substantial waste of pumping energy, as the pump has to overcome the reducer pressure drops.

Also, the high-pressure recovery provided by most plug valve designs results in low vena contracta pressures, which in turn increase the probability of cavitation and noise. These problems, which are even more pronounced with pinch, butterfly, and ball valves, have been reduced by various means. In case of ball valves, perforated parallel plates have been inserted into the ball valve openings (Figure 6.16o) or flutes have been added to the butterfly disc (Figure 6.17s); however, the cavitation problems associated with high recovery valve designs have not been fully resolved.

In operating rotary valves, the linear movement of cylinder or spring-and-diaphragm actuators must be converted by linkages, which introduces hysteresis and dead play. In addition, a nonlinear relationship exists between actuator movement and the resulting rotation. These considerations make the use of positioners essential, which on fast processes can lower the quality of control. The torque characteristics of these valves are nonlinear (Figure 6.4v), and because of the high "break-torque" requirements, the actuators can be oversized relative to the torque requirements in the throttling range.

Design Variations

The first plug valves consisted of a tapered or straight vertical cylinder containing a horizontal opening or flow-way inserted into the cavity of the valve body (Figure 6.21d). They have developed through time into numerous shapes and patterns, depending on the application, but almost all are adaptations of the cylindrical or tapered plug. Within that plug, however, the ports may be round, oval, rectangular, V-, or diamond-shaped, and can be the flow-through type two-way valves or multiport. These make up the special designs described in subsequent paragraphs.

Plug valve designs can be categorized as lubricated or nonlubricated. In the lubricated type, the thin film of lubricant serves not only to reduce friction between the plug and the body, but also to form an incompressible seal to prevent gas or liquid leakage. Because the seating surfaces are not exposed in the open position, gritty slurries may be handled. The lubricant hydraulically lifts the plug against the resilient packing to prevent sticking. A special lubricant must be injected periodically while the valve is either fully open or fully closed.

FIG. 6.21d
Conventional, lubricated plug valve with tapered plug.
The plugs of nonlubricated plug valves are treated with coatings such as Teflon or are specially heat-hardened and polished to prevent sticking. Often they are constructed so the tapered plug may be lifted mechanically from the seat for easier operation.

**Characterized Plug Valves**

Plug valves can be characterized by the use of characterizing cage or plate inserts (Figure 6.21e). The resulting characteristics are a function of the shape of the opening on the cage or plate.

Some examples of available plug valve characteristics are illustrated in Figure 6.21f. Rotation of the plug is inside a TFE sleeve, which is locked into the body in such a way that recessed areas minimized. Although a rangeability of 20:1 is claimed, this is made possible only if the valve can be fully open in order to provide full flow. The valve is available in \( \frac{1}{2} \)–12 in. (12.5–300 mm) sizes and up to 600 PSIG ANSI (4.1 MPa) rating for use up to 400°F (204°C).

**V-Ported Design**

The V-ported plug valve (Figure 6.21g) is used for both on/off and throttling control of slurries and fluids containing solid concentrations in suspensions greater than 2%. These applications occur principally in the chemical and pulp and paper industries. A diamond-shaped opening is created by matching a V-shaped plug with a V-notched body.

Straight-through flow occurs on 90° rotation, when the plug is swung out of the flow stream. Shearing action and a pocketless body make the valve applicable for use on fibrous or viscous materials. The opening develops a modified linear flow characteristic with \( C_v \) capacities approximating 17d\(^2\). Valves are flanged from 3–16 in. (75–400 mm) in bronze, corrosion-resistant bronze, or stainless steel. The body may be rubber-lined with a rubber-coated plug. A cylinder actuator and valve positioner are used for throttling control.

A variation is the true V-port opening (Figure 6.21h). It is obtained by a rotating segment that is closing against a...
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straight edge. The valve can be smoothly throttled on thick
stock flows without the stock packing or interfering. The
valve is available in sizes from 4–20 in. (100–500 mm) and
with \( C_v \) stated as more than 20d. The valve is available in
many body and trim materials for use in the chemical or pulp
and paper industries. A cylinder-operated rack and pinion is
used for on/off service with the addition of a valve positioner
for throttling services.

Adjustable Cylinder Type

In another form of quarter-turn valve, flow is varied by rotat-
ing the core and by raising or lowering a “curtain” with an
adjusting knob (Figure 6.21i). Proportional opening at any
curtain position is made with the control handle, which may
be attached to an actuator for automatic control. Various
openings are obtained by these manipulations.

The valve is used for combustion control and for mixing
applications, in which case valves are “stacked” on a common
shaft or operated by linkages from the same actuator. To
obtain linear flow with constant pressure drop, a port adjust-
ment technique is used. After installation, the curtain is closed
until the pressure drop across the valve is one sixth of the
total pressure drop of the system using the control handle in
wide open position. This provides a flow characteristic approx-
imating linear without decreasing sensitivity by limiting valve
stroke. The percentage of flow is equalized by manipulation
of the linkage to the actuator.

Semispherical Plugs for Tight Closure

Various designs have been developed to obtain tight closure
while eliminating the continuous friction of the seals during
rotation, as with most ball valves. The valve design illustrated
in Figure 6.21j uses an eccentric ball. In the closed position,
the rectangular end of the stem protrudes into the ball and
the closure face is wedged toward the seating surface. As the
stem is rotated to open the valve, the closure surfaces separate
and the pin moves into a vertical slot so that rotation occurs.
A nonlubricated seal can be provided with a primary Teflon
seal enclosed in a body seat retainer ring. The valve is adapted
for automatic operation by connecting the stem to a dia-
aphragm actuator.

Expanding Seat Plate Design

As shown in Figure 6.21k, metal-to-metal or resilient seats
can be provided in two seating segments. These segments are

FIG. 6.21h
Illustration of how throttling is provided by a V-ported plug valve.

FIG. 6.21i
Illustrations of both the curtain and the core openings of an adjust-
able cylinder-type plug valve.

FIG. 6.21j
The semispherical plug in this plug valve design provides tight clo-
sure. (Courtesy of Offshore Technology, formerly Orbit Valve Co.)
carried on a rail that is tapered so that downward stem movement forces the plates against the inlet and outlet ports. When the valve is being opened, the first few turns of the actuator cause the retraction of the plates and then plug rotation proceeds. These plates can be removed by merely removing the bottom plate of the valve V-body.

Retractable Seat Type

Positioning a movable seal after a spherical plug is in the closed position creates tight closure with sliding friction. In the retractable seat plug valve, a trunion-mounted partial sphere is operated by spur or worm gears (Figures 6.21l). The gear system rotates the plug until it is in a closed position, at which point additional rotation of the drive creates a camming action to compress the packing ring.

When the valve is being opened, the packing ring is released before the rotation of the plug occurs. Although also applicable to low-pressure service, this valve is particularly useful up to API 5000 PSI (34.5 MPa) rating for 10,000 PSI (69 MPa) service. It is used mostly in oil fields.

Overtravel Seating Design

By fabricating a cylindrical flow passage within a tapered cylindrical plug, a plug valve can be built at least up to the 60 in. size, without undue weight and attendant inertia to rotation. In the overtravel seating design shown in Figure 6.21m, the rotation of the inner valve is caused by a rod operated by a piston pushing down on a rotator. Continuous movement of the rod closes the plug, but leaves a small crescent, because the plug is slightly raised from seating. For tight closure, the rod contacts a seating adjustment to force the plug into a tapered seating surface.

In this design, the restriction of the flow area is rapid; 30% rod travel causes about 65% closure. Complete rotation of the plug occurs at about 65% stroke, with the additional stroke being utilized for seating. If rapid closure to about 20% opening does not create serious surge pressures, this valve can be used for emergency closure without much consideration of the piston speed. The rangeability of the valve exceeds 50:1 for proportional control. Free rotation and relatively low plug weight contributes to lower power requirements.
6.21 Valve Types: Plug Valves

Multiport Design

As shown in Figure 6.21n, a three-way plug valve is obtained by providing the plug with an extra port at 90° from the inlet, so that flow can be directed in either of two destinations. A multitude of directions can be achieved by nesting combinations of the simple multiport valves or by using more complex designs. These include a multistoried arrangement with the plug extending upward to connect to a series of tiered outlets. In such multistoried configurations, the plug has a long, vertical passageway connecting the horizontal ports.

Another method of increasing the number of flow-directions is to design the plug with a diameter that is sufficiently larger than the ports so that intermediate ports can be placed at 45° or even 30 and 60°. In that case, the actuators can be programmed to serve a variety of process applications.

Bibliography