Abstract

“Large size quarter turn control valves can improve safety in pipelines”

Most control valve applications in pipelines are related to system start-up and shut down, emergency operations, delivery control, fluid speed control for pipeline internal examination. Selection of the right control valve is a key factor for long term successful performance for large applications where the safety and security of supply are important considerations.

This document presents considerations for control valve selection to improve the safety and operation of oil and gas pipelines.

Axial control valves are used when high pressure drop, high flow coefficients, low noise levels and bubble tight shut-off are required. Common applications include compressor start-up, shut-down and High Integrity Pressure Protection Systems (HIPPS).

Triple offset valves (TOV) are used for large volume flow control, bubble tight shutoff, pressure drops of less than 30%. Typical applications include delivery point and controlled blow down.

Ball valves are used for speed control for intelligent pig travel during pipeline examination and cleaning operations.

Tyco Flow Control has researched, developed and supplied devices for a range of applications to assure the safe and reliable operation of critical control valve systems.

Paper

1. Introduction to Control Valves and Fluid Flow

The following factors have to be considered when performing a Cv value calculation: flow value, characteristic, choked and critical flow, and regulation ratio.

**Cv or Kv flow value**

Kv is the flow of water at 15°C in m³/h and at a pressure drop of 1 bar at constant conditions within the valve.

Cv is the flow of water in gpm at 60°F and at a pressure drop of 1 psi at constant conditions within the valve.

Cv: 1.1675 Kv
1.1 Characteristic according to IEC 534-2/ISA S75.01 and S75.02. Cv/Rated Cv values

The flow characteristic represents the flow in relation to the opening position of the valve at constant pressure drop.

1.2 Choked and critical flow
The choked and critical flow is the maximum possible flow of compressible and incompressible media through the valve at operating conditions. Choked flow is a condition that takes place in a valve when the static pressure of the liquid drops below the vapor pressure, causing the liquid to flash to a vapor. The vapor bubbles occupy more volume than the same mass of liquid, resulting in restriction of the flow through the device. When fully choked flow occurs, fluid flow through the valve will not increase when the downstream pressure decreases. Choked flow results in high noise levels, vibration, pipe stress, and erosion and pitting of the valve internals. Choked flow may result from a wrong sized control valve or if an unsuitable type of valve for that application was specified.

\[ \text{Bernoulli: } p + \frac{1}{2} \rho V^2 + \rho gh = \text{constant} \]

Figure 1

1.3 Regulation ratio
Cv min/Rated Cv
The regulation ratio is the ratio of max. and min. flow (Cv or Kv) adjustable without any practical variation. Calculation programs according to IEC 534 are available to calculate the Cv value. The noise level is calculated according to VDMA 24422 (liquid) and IEC 534-8-3 (gas).

FL liquid pressure recovery factor is an important characteristic of a control valve, which shows the pressure recovered from the vena contracta to the valve outlet relative to the general pressure drop across the valve. The FL for butterfly and ball
valves, is in the range of 0.55 to 0.7, as per in the ISA Standard S75.01. Globe valves, have a higher FL in the range of 0.85 to 0.9.

\[ F_L = \frac{\Delta p}{\sqrt{Y}} \]

Figure 2

2. Large size and High Capacity Control Valves

By rule of thumb, globe-style valves larger than 12-inch, ball valves over 24-inch, and high performance butterfly valves larger than 30-inch fall in the special valve category. As valve sizes increase arithmetically, static pressure loads at shutoff increase geometrically.

In consequence, unbalance forces, shaft robustness, bearing loads, and available actuator torque all become more significant with increasing valve size. Even with lowered working pressure ratings, the flow capacity of some large-flow valves remains terrific.

Noise levels have to be carefully considered in all large-flow installations due to sound pressure levels increase proportionally direct to flow magnitude.

To keep the noise behind tolerable threshold solutions include large cast or fabricated valve body designs, usually cage-style construction, with a great number of small flow openings through the wall of the cage, labyrinth design and axial flow nozzle design.

Actuator requirements are also severe, double acting pneumatic pistons are commonly specified for large-flow applications but there is an increased trend to use spring return actuators for safety issues and ESD. The size and weight of the valve and actuator components cause difficulties during installation and maintenance procedures.

Quarter turn valves are more compact than linear valve facilitating the installation into the pipeline, removal and replacement of major trim parts. The non-rising stem is preferred for fugitive emissions compliance since wetted components never go outside the pressure vessel.

Closed to open transients are critical in large size valves, not exclusive of control valve, even for on-off applications have to be considered and studied.
2.1 TOV in pipeline controls Application

TOV are typically utilized in suction line, turbine trip, delivery lines in oil, gas light hydrocarbons and water applications. Due to the valve design, incorporating a small face-to-face dimension and lower weight than most valve types, the TOV is an economical choice for larger line sizes (i.e. 12” and above). Additional advantages of this valve are standard face-to-face dimensions, relatively high coefficient of flow (Cv), zero leakage metal to metal seat inherently fire safe, non-rubbing (frictionless) 90 degrees rotation, which minimize hysteresis and dead band, wear of sealing elements even during heavy duty modulating services, and to achieve high speed of operation for emergency
shutdown applications (ESD), thus combining in one valve control and isolation (ESD) capabilities.

The same as the ball valve, the TOV complies with ASME pressure ratings and face-to-face dimensions. This enables the valve to be easily retrofitted inline regardless of the manufacturer. In addition, the small face-to-face dimension facilitates piping design. The ASME pressure classes adhered to by most manufacturers include up to class #1500 allowing a maximum pressure of 250 bar. The TOV is considered a high recovery valve, since only the disc obstructs the valve flow path. The Cv is comparatively high; the pressure drop across the valve is relatively low. Hence the pump size is minimized and system wear reduced compared to that of low recovery valves.

![Cv curve]

The characteristic values and the Cv values may differ slightly depending on the flow direction. By selecting the most suitable direction of installation and by means of an appropriate actuator selection it is possible to configure the product to assist protective functions. Figure 5 shows some pictures resulting from post-processing of a CFD analysis.
Disadvantages of the TOV are inability to handle slurry applications. As with ball valves, the cavities and leak paths around the disc stem where the stem attaches to the body are potential entrapments for fluids and slurries. The result is unwanted increased operating torque in slurry services, loose of seat tightness and erosion. Conceptually the TOV has similar sealing effect that globe plug valve (Figure 6)

The valves have to be sized to operate between 30% to 70% of travel, obtaining an optimal control response and avoiding the cavitation zone and high noise.

Cavitation can be prevented through:
- Use of an orifice flange
- Two TOV in series
- Reduce $\Delta p$ by considering another spot of installation
2.1.1 TOV in transmission application
Empowering the features of TOV, this application at the pipeline head or end shows the advantage of right selection after several options evaluation, obtaining the required control performance, low weight, tight shut-off and the best cost position.

A delivery point supply natural gas at 80 bar, two main consumers require at maximum 60 bar in lines of 16" and 24" #600 (Figure 8 and 9)

Large size globe valves, segmented ball valves, and TOV were evaluated. Since the supplier assured that the gas wells never provide more than 80 bar, the sizing exercise results indicate that the TOV will work between 30% to 70% travel in the optimal control zone, avoiding the high noise region. Extra overpressure protection is provided with additional ESD valves and HIPPS.

2.2 Pipeline Ball Valves (API6D)
Readily available in a variety of configurations, 3-piece, side entry (Figure 10), top entry (Figure 11) and fully welded, these valves range from commodity type valves to high performance valves.

Advantages of ball valves include ease of operation, standard face-to-face dimensions, high flow capacity, and high pressure/temperature capabilities. The quarter turn operation is desirable to most operators and fairly easy to automate.
and the added feature is to be Bi-stable, even without actuators remain open or close under pressure without the need of locking devices.

Ball valves, available in reduced port and full port designs are considered high recovery valves, meaning a low pressure drop and relatively high Cv. The benefits of these desirable flow parameters are reduced pump size and less system wear due to lower velocity.

Ball valves act primarily as isolation valves only, although they have certain capability to throttle flow. On the other hand, exists ball valve designs specifically for throttling service including divided or split flow passages and “V” shaped ports. Many ball valves have a reduced bore with a Venturi-shaped flow passage. Ball valves are used in applications where a full-bore valve is needed. Ball valves operate by rotating a ball with a through-bore a quarter turn from full open to full closed. This makes for a very quick acting closure. The flow-control characteristic arises from two circle ports moving across a circular seat and from having double pressure drop across the two seats. Ball valves are normally bi-directional and have the same pressure drop as an equal length of straight pipe.
Pipeline ball valves are trunnion-mounted design that has the ball supported on a bearing trunnion. The differential pressure load is carried by the trunnion, thereby reducing the operating torque of the valve. Due to low friction forces, ball valves have been known to open gradually after a long exposure to vibration. Ball valves feature, together with the through conduit gate valves, the highest flow coefficient Cv values. Of course, a full bore valve has a higher Cv value than the reduced bore of the same DN. Moreover a FB valve provides a higher Cv value than the RB valve of the one step larger DN valve (for the same ball bore). That’s due to the flow restriction creating turbulences and producing pressure loss.

Throttling applications - When spherical valves are used in throttling applications, high velocity flow can impinge against a focused area of the ball and seals, making premature deterioration of the seating material. Special checking of working conditions or modifications to the standard design are required for ball valves to be used for throttling, including the use of metal seats, hard coatings, different speed of actuator travel and, sometimes, modifications to the ball, to give a characterized flow pattern.

Figure 11

Figure 12 shows different type of seat from right to left: thermoplastic seat, elastomeric seat, metal seat.

High pressure drops are not driven well due to the ball causing high velocity jets of fluid directed into the seat and body inducing erosion. Wrong selection will impact in the control performance and in the sealing tightness. Ball valves physically have a good control characteristic and give high turndown of 100:1 for standard ball valves and up to 500:1 for “V” ported valves (not pipeline valves). High pressure valves are available to ANSI 2500# and higher. Sizes range reach up to 72"
Metal seats, hardened surfaces are selected to work with high temperatures or/and abrasive fluids.

Full ball valves are not recommended for slurries due to the solids settling out in the body cavity. Slurries tend to solidify or clog inside the cavities, greatly increasing the operating torque of the valve and in some cases rendering the valve inoperable. Therefore, most manufacturers do not recommend exceeding trace amounts of solids of more of 3%.

Figure 13 shows a conceptual simplified Ball valve CV characteristic

![Equal percentage graph](image-url)
Figure 13

Figure 14 shows the CV value and Torque as % of break torque over valve travel for a ball valve of 24", the control zone is limited and for a large size valve the effects of choke flow and temporary cavitation is reflected by the overtorque during the first 20% of travel.

The pressure and velocity profile inside the valve structure is shown in Figure 15.

CFD calculations are required to predict the performance of the valve under throttling applications and transient in on-off service, unexpected high flow speed could potentially damage the seat.
Figure 14

Pressure and Velocity Profile across ball valve

Closed

20%

50%

75%

Open

P

Conditioned

Vapor pressure

P

Vapor pressure

P

Vapor pressure

P

Vapor pressure

V
In the tight shut-off operation, the maximum allowable fluid velocities should not be exceeded, the recommended maximum fluid velocities are:

<table>
<thead>
<tr>
<th>Liquids</th>
<th>Gas/Steam</th>
</tr>
</thead>
<tbody>
<tr>
<td>DN</td>
<td>m/S</td>
</tr>
<tr>
<td>&lt;50</td>
<td>12</td>
</tr>
<tr>
<td>80-150</td>
<td>10</td>
</tr>
<tr>
<td>200-400</td>
<td>6</td>
</tr>
<tr>
<td>&gt;400</td>
<td>3</td>
</tr>
</tbody>
</table>

Ball valves features useful for control service under well delimited conditions.

The valve has to be sized to operate between 30% to 80% of travel, obtaining good control response and avoiding the cavitation zone and high noise. It is recommended a short travel time below 30% of the stroke, avoiding to remain in this zone for long time, specially in elastomeric and thermoplastic seated valves. By the use of FEA and CFD software, CV’s over the stroke could be accurately calculated, avoiding the ancient mistakes of modeling simplification and obtaining transient analysis.

Figure 16 shows FEA for a high pressure top entry ball valve.

Figure 15

Figure 17 shows through a graphic method the deviation radius by 2D two circumference modeling vs. spatial modeling.
Figure 16

Ball valves also feature:
- good rangeability
- high flow rate with low pressure drop
- high Cv values
- good pressure recovery

That makes ball valves suitable for control service with high flow rate at low pressure drop, like for instance tank level control. Due to the high pressure recovery capability, the ball valves are susceptible to cavitation at low load for liquids or choked flow at sound velocity in gases.

Care must be taken when using a ball valve on control service, to correctly size the valve to recognized standards IEC 60534 / EN 60534.

2.2.1 Standard API 6D ball valve in throttling application

An application of API 6D ball valves is the speed control for intelligent pigs.
In order to obtain detailed data of pipeline status, these devices run a lower speed than the pipeline design, in existent pipelines appears the need of regulate the flow to obtains speeds of 3m/s to 5m/s.

**Figure 17**

Figure 18 shows typical pig trap installation.

The pig must fit loosely in the launcher/receiver so the barrel of the launcher/receiver must have a greater diameter than the pipe itself. When the pig is received the fluid has to pass around the pig in the barrel, so it is a good design rule to give the barrel a cross sectional area of almost double that of the linepipe. The barrel have to be sized considering that the flow velocity around the pig is less than 20m/s when flowing gas and 4m/s when flowing liquid.

The launcher/receiver must have an isolation valve between the barrel and the pipeline. That valve is a full bore valve to allow the pig to pass unrestricted into or out of the barrel. It is very important that this valve have high quality sealing. It must be either a soft seated ball valve or a ball valve with metal to metal seating. This valve is the only existent barrier between the line contents and the operator when the closure is open, the barrel must have a good drain valve if it is a liquid system, or a good vent valve if it is a gas system. Both are required to depressurize the barrel before opening it.

A bypass line is required around the barrel isolation valve. This is called the kicker line. It generally tees off from the branch line from the main tee and connects to the launcher or receiver barrel. The kicker must have at least one isolation valve with the same excellent isolation capabilities as the barrel isolation valve for the same reasons as the barrel isolation valve. It is generally sized for a maximum flow velocity of 4m/s for liquid and 20m/s for gas. The kicker line valve is used to throttle the flow from full pipeline pressure to zero pressure. This valve (or a valve array) is used not only for isolation but also throttling temporary.
2.2.2 Application of control valve in centrifugal compressor system

Typical pipeline applications are Anti-surge / recycle control, discharge control (Figure 19).

To protect expensive aero-derivative compressor equipment from operating in surge, many pipeline companies will have both a surge line and a surge control line for their compressors. When compressor operation passes the surge line the compressor is shut down to avoid equipment damage. When compressor operation crosses the surge control line, the unit/station recycle valves open to increase the unit/station flow. When compressor operation crosses the surge control line, the unit/station recycle valves open to increase the unit /station flow

![Diagram](image)

The surge control valve must provide accurate control, wide flow rangeability, and quick action; this control valve is critical to the protection of the centrifugal compressor.

Typical requirements are:

- High flow capacity with minimum pressure differential
- Low flow controllability
- Wide flow rangeability
- Quick stroking times of less of a second
- Controlled noise

Valves required for this service exceed the performance of standard ball valves

Some solutions in quarter turn devices are segmented ball valves, caged trims and axial flow control valves.
2.2.3 Segmented ball

Liquid cavitation and aerodynamic noise concerns can be solved employing the principles of dividing the pressure drop into a series of small pressure drops and of separating the flow stream into many small jet streams. The use of these principles combined with the rotation of the attenuator elements provides a combination of cavitation/noise abatement with good rangeability, high capacity and certain capability to handle fluids with particle content.

![Diagram](image)

Figure 19

Figure 20 shows the effects and benefits in pressure and velocity profile smoothing them.

2.3 Plug valve

The plug valve has the same considerations as the ball valve. It born as top entry/bottom entry valve that allows in line maintenance.

The pass through area modeling is relatively simpler than ball valve.

The sealing contact surface design doesn’t allows seal tightness across the time.

2.4 Axial Flow Control Valve

Axial valve design gives the fluid symmetrical flow path characteristics without any disturbance preventing erosion and abrasion due to this process downtime and maintenance costs are reduced.
The intrinsic capacity of the axial valve is high compared to the conventional globe control valve and enables selection of smaller valve size. Simultaneously the higher capacity can be used to minimize pressure loss or to provide for stringent control features.

The design allows the highest efficiency for almost any applications

- High flow coefficient
- High pressure drop
- Low noise levels
- Reduced maintenance
- Compact Design
- Very low operating torques
Axial design allows the pressure balanced of the piston from closed to open position, resulting in the use of smaller actuators than conventional control valves and reduced stroking time making it capable of HIPPS applications. The sizing of this type of control valve is made by computerized sizing software, including FEA and CFD analysis, which selects the best solution – technical and economical - to suit the application request and to give a full guarantee for the performance after installation regarding noise generation, flow capacity and cavitation. The axial design and the use of suitable gages give to this type of valve higher pressure recovery coefficients than the conventional control valves. These high coefficients reduce the possibility of cavitation. The valve body provides dramatic weight reduction compared to globe valves. This feature is even more striking combined with quarter-turn spring-return actuators.

3. Conclusions

- The right selection of control valve improve the safety of installation.
- There is nothing definitive about selecting a type of valve.
- Valve replacements, failures, repairs, downtime and lost product can be significantly minimized by selecting the right valve.
- Evaluate your system criteria relative to each valve type.
- Utilize the expertise of a consultant or the factory expert.
- Utilize valve selection software programs provided by various serious valve manufacturers.
- Consider the opening- closing transient time
- Balance controllability, rangeability, maintenance issues and seat tightness when select the valve type.
- Having good knowledge and well delimited conditions allows the use of standard valves and piggable isolation valves for limited amount of time or temporary control applications.

Classification/Tags

Pipeline and Facilities Integrity, Pipeline Components, Compressor and Pumps Stations

Flow Control, HIPPS, Valves, Actuators, Safety