Control Valve Sizing and Considerations

In a process control system the valve is considered the final control element. Where once sliding stem valves such as globe or cage guided valves dominated control applications, design materials enhancements of today’s rotary valves have made them more widely accepted for such use. Heavier stems, new bearing designs, characterized control elements, higher flow capacity, and overall compactness have all contributed to this trend. Another advantage of a rotary stem control valve is the improved performance obtained because the valve stem does not move through the packing. Sliding stem movement tends to drag along some of the line fluid, creating a leak, or to react with the moisture in the atmosphere, causing corrosion. In addition, improvements in actuators and positioners and the need for more valve status feedback have made rotary valve performance and economy an attractive benefit and incentive for their use. For the control valve user there are two general categories of rotary valves available for control applications: standard and characterized. For our purpose here a standard rotary valve is considered one that is used primarily for on-off service but that may be fitted with an actuator and positioner for modulating service. One of the benefits of using standard valves in control service is that they may also provide full shut off if necessary. Care must be taken, however, to insure that the control service does not cause damage to the seat.

A characterized valve has a specially designed closure element that may be a V-notch, segmented ball, or other such modification. The application and design of sliding stem valves in control service is well documented, so we shall limit our coverage to the above mentioned rotary style valves.

Process system analysis

Before a control valve is selected, a thorough analysis of the process system should be performed. To be considered are flow and fluid characteristics; system extremes, such as minimum and maximum flow disturbance and power or signal failure; toxicity, an even the piping system.

The following questions should be considered.

1. What is being control (pressure, temperature, pH, flow rate, etc.)?

2. What is the control range? How closely must it be controlled?

3. Is a valve the best choice for control or should a metering pump or variable speed drive be considered? Will a simple regulator do?

4. What other properties of the fluid (corrosive, abrasive, toxic, flammable, viscous)?

5. What are the maximum and minimum pressures (and pressure drop) and temperatures? Is there a vacuum?

6. For valve sizing, what are the density and specific gravity (gas, vapor, or liquid)?

7. What are the best end connections and pressure ratings (flanged, welded, threaded, etc.)?

8. Should the valve provide bubble tight shut off?

A very important consideration in the selection of the best control valve based on performance and economy is the degree of control. If it is determined that a very slight deviation from the
optimum control point will result in very undesirable consequences, then it is likely that a characterized rotary or sliding stem control valve is the best choice. However, as industry attempts to upgrade all aspects of process systems there are more situations where a standard rotary valve can provide an acceptable degree of control as required. Some less expensive valves are even being considered sacrificial in applications where severe abrasives or excessive temperatures exist.

Like automated valves, control valves should also be selected based on the actuator's compatibility with the system and the environment. This should include power source, area classifications, physical size, seismic activity, and inherent atmospheric corrosion.

The best way to collect all the necessary information is to use a control valve data collection sheet similar to the one developed by the Instrument Society of America (ISA). From this information the necessary flow coefficient (Cv) of the valve to be used may be calculated.

Control valve terms

Before discussing the valve types used in control applications a review of control valve terms is important.

Valve capacity. Valve manufacturers have adopted a common basis for rating capacities of control valves. The yardstick accepted for this purpose is termed flow coefficient Cv and has been in use since the middle 1940s.

The valve coefficient is defined as:

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Cv = \frac{Q}{\sqrt{\frac{Sg}{P1 - P2}}}
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Where; Q = volumetric flow rate through valve in gallons per minute (GPM)

P1-P2 = pressure drop across the valve (including inlet and outlets losses) in pounds per square inch (PSI)

Sg = specific gravity of the flowing fluid

Stated another way, it is the number of gallons per minute of water at room temperature which will pass through a given flow restriction with a pressure drop of one pound per square inch.

For example, a control valve which in the full open position passes 25 gallons per minute of water with a one pound per square inch pressure drop has a maximum flow coefficient of 25. The flow is similarly determined at various increments of valve rotation, and the Cv at each increment may be calculated. A plot of these values reveals the characteristic curve of the valve. The curve is made by plotting the percent of maximum travel against the percent of maximum flow. The characteristic curve thus obtained reflects the control characteristic of that particular valve and determines whether it or another type of valve is best suited for a particular application.

Flow characteristics. All rotary control valves modify the flow of the fluid that passes through the varying flow opening (orifice) as the valve closure element (ball, plug, disk) rotates in response to a control signal. Depending upon the design of the valve the change in flow may be defined in one of the following ways:
**Equal percent.** Equal percentage is an inherent flow characteristic in which a given percentage change of travel will produce an equal percentage change in the existing flow coefficient.

**Linear.** The linear flow characteristic is an inherent characteristic where equal increments of travel produce equal increments of flow change at a constant pressure drop.

**Quick opening.** A valve with a quick opening flow characteristic provides a maximum change in flow rate at low travel. These valves are often used where significant flow rate must be established quickly as a valve begins to open.

Plant experience and analysis indicate that if there is doubt about what flow characteristic to choose, a valve with equal percentage flow is the better choice. Fortunately most common ball valves are inherently equal percentage.

When other than the inherent flow of a valve is required for a particular application, characterized cam positioners are often used. These devices feature a cam and position feedback mechanism that allows variations in the valve position at a given input signal.

**Rangeability.** The maximum flow capacity of a control valve is provided in the full open position. This is, of course, when the flow opening is at its maximum. Optimum control of the flow through a control valve is exhibited in a range that is generally between 30 to 70 percent of rotation. Full port ball valves give sluggish performance beyond 70 percent, but reduced port designs have increased resistance to flow and allow good throttling characteristics to near full valve capacity.

Rangeability of a control valve may be defined as the ratio of maximum controllable flow to the minimum controllable flow. Stated another way, it is the ratio of maximum to minimum usable sizing coefficient. It is obtained by dividing the minimum usable sizing coefficient in percent into the maximum usable sizing coefficient in percent.

**High recovery.** In some valve designs, particularly butterfly valves, the downstream pressure can recover to a pressure substantially higher than the pressure at the vena contracta, or smallest cross-sectional area, of the flow stream. This high recovery characteristic may lead to valve damage through cavitation and should be considered.

**Cavitation.** Cavitation is defined as the noisy and potentially damaging formation and collapse of vapor cavities formed when the pressure of a liquid drops below its vapor pressure at the vena contracta and then recovers to a pressure level above its vapor pressure downstream of the control valve. Since rotary valves are generally considered high recovery valves, one should be aware of their cavitation potential. Most modern sizing techniques will indicate when this potential exists.

**Pressure drop ratings.** Sometimes more limiting then the ANSI class rating is the pressure drop rating. Pressure drop is defined as the difference between the inlet and outlet pressures of the valve. Pressure drop capabilities are generally a function of a valve's internal parts: closure members, shafts, bearings, and so forth. The ability of a ball valve to handle pressure drop is largely dependent upon the support of the throttling member, the bearing sizes and locations, and the sealing member design.

**Fluid Properties**

Compressibility is probably the most important fluid property. It determines whether the fluid behaves as a liquid or a gas. Flow equations for liquids and gases are radically different in most
cases. Accordingly, the flow is compressibility determines what flow equations should be used in the flow analysis.

Fluid type is of tremendous importance when dealing with liquids. Fluid types are divided into **Newtonian and and non-Newtonian liquids**. The distinction involves how a liquids and viscosity changes with temperature and pressure. All other fluids are considered non-Newtonian. Newtonian liquids are typically pure or low molecular weight liquids such as water, alcohol, oils, or cryogenic liquids. Non-Newtonian liquids include polymers, high molecular weight liquids, slurries, greases, drilling muds, printers ink, foods such as ketchup and ice cream, crude oils at low temperature, paints and glue. Special flow equations must be used for non-Newtonian liquids for accurate analysis results.

**Chemical reactivity** or toxicity often demands the highest attention in valve selection. The two factors that determine a valves leak integrity are its materials of construction and the valves design. Unfortunately, all man-made valves leak, regardless of their materials of construction or design. It is merely a question of how soon a leak will occur, taking into account the leak rate, time and service, pressure, fluid properties, and so forth. This is the realistic view that all experienced valve design or application engineers have regarding the subject of valve leak integrity. Please note temperature and pressure can greatly increase the reactivity, corrosion potential, or toxicity of some chemicals -- even those which are considered harmless at ambient temperature and pressure.

**Abrasiveness** of the flow media is usually a minor factor in valve selection. However, it can cause serious problems if not properly dealt with. Abrasion occurs when the flow media contains solid particles which are harder than the materials from which the valve is made. This type of flow media is commonly known as a slurry. The resultant damage depends upon the velocity of the particle, size, impact angle, and relative hardness with respect to the valve components. Abrasion can also accelerate corrosion if the surface layer of a component part is damaged.

**Flashing and cavitation** merit special consideration in valve selection. Both phenomena may damage fluid systems, and valves often contributes to this problem. Evidence of these include vibration, an intermittent ticking, hiss, roar, or the worst-case of a churning gravel sound. Cavitation is especially dangerous if the liquid flow stream contains sand or metallic particles. Decreasing the pressure drop or the inlet pressure sometimes reduces the potential of flashing or cavitation.

**Flashing and cavitation** are associated with gas bubbles in a liquid flow stream. They occur in high-speed liquid flow when bubbles form around the valve seat area. An energy balance exists between the liquid velocity and pressure in the flow stream. If the velocity increases, the pressure usually decreases. The velocity increase reduces the available energy required to maintain the flow pressure. Subsequently, the flow pressure drops as it is starved of energy. Bubbles form if the flow pressure falls below the liquids vapor pressure, literally causing the liquid to boil. Flashing and cavitation are often apparent immediately down stream of a valves seat area. The reduction in flow area sharply increases the speed of the liquid flow stream, which reduces the pressure and causes bubbles to form as the liquid boils.

Flashing means the bubbles simply drift down stream, causing minor erosion, noise or vibration in the fluid system. Cavitation is potentially more dangerous. The bubbles violently collapse after a short period of time. All of the energy stored in the bubbles surface tension implodes to the bubbles center, but is then reflected back in a powerful micro-jet of energy. These millions of destructive bubbles literally blast away pieces of the valves components. Pitting and accelerated corrosion often accompany cavitation. Super cavitation occurs when the down stream fluid line is almost filled with bubbles. Violent vibration may result when these bubbles explode downstream. Air aspiration (the introduction of atmospheric air into the flow stream) will not prevent cavitation, but sometimes reduces the bubbles destructive explosion.
Standard ball valves for control

Depending upon the degree of precision and the severity of the control application, standard on-off rotary valves are often adequate for flow control. They are economically priced, small, and lightweight and also provide bubble tight shut off if required. Though each of the most popular rotary valves have various design features, a basic understanding of their performance should be useful for process control selection.

Floating ball designs use upstream pressure to force the ball into the seats for shut off. Therefore, the drive shaft and ball must be loosely connected so that the ball is free to seat. At the same time the shaft must be able to transmit positive motion to the ball. This is often accomplished using a drive tang. The tang is arranged so that the ball is free to move toward the seat when the valve is closed.

To prevent erratic control due to deadband, the shaft and ball should function as a single unit. For example, if a ball is loosely connected to the shaft, there is no response to a small change in control signal. In control applications such valves are provided with a matched ball and stem to minimize the machined tolerance in the fit.

Ball valves exhibit equal percentage flow characteristics which is a natural result of the orifice configuration. Some of the advantages of the ball valve in control are:

- It is not subject to hydrodynamic torque as are butterfly valves.
- Its Cv is generally higher than for equivalent globe valves.
- It is available in a wider range of sizes.
- It provides two stages of control as the fluid passes around the inlet and outlet edges of the ball port opening.

The ball valve will handle a wide spectrum of control applications. There are, however, limiting conditions under which the valve should be utilized. For instance, the valve should not be used when the temperature of operation is above 500°F.

Characterized rotary ball valves for control

When standard rotary valves are not adequate for control service because of flow characteristics, pressure drop, or even material compatibility, some manufacturers offer specially engineered versions of their valves to satisfy special requirements. These characterized valves include V-seated ball valves. Often more costly than their standard counterparts, these valves play an important role in total valve selection for the process engineer.

V-seated ball valve. V-seated control valves incorporate a characterized metal seat with a standard quarter turn ball valve design. The V-seated control valve is adaptable to a range of pressure and control applications generally not achievable with soft seated rotary control valves. These valves are used in industries such as chemical processing, pulp and paper, and mining and can be installed anywhere characterized control is required. The characterized 30-degree V-seat is made from graphite impregnated stainless steel alloy and offers abrasion resistance, temperature capability to 1000 degrees F, and pressure capability to 1000 pounds per square inch. The metal seat is capable of performing in high pressure drop applications where standard rotary ball valves do not last and exhibit seat foldout. With the metal seat now down stream and
resilient or optional metal seat up stream, these valves exhibit high pressure drop capability, accurate control, and meet the shut off requirements of ANSI B16.104, Class VI.

**Selecting a control valve**

The following information is necessary to consider when choosing a rotary control valve.

**Service conditions**

1. Fluid
2. Flow rate minimum and flow rate maximum
3. Flow rate normal
4. Pressure in (P1) and pressure out (P2)
5. Sizing pressure
6. Temperature maximum and normal
7. Specific gravity (at flow temperature)
8. Viscosity
9. Line size

**Valve**

10. Line size
11. Pressure rating
12. Maximum temperature

**Pneumatic actuator and positioner**

13. Air pressure available
14. Action
15. Failure position
16. Actuator size
17. Positioner type
18. Control signal
19. Standard or reverse acting
20. Characteristic flow requirement

**Electric actuator and positioner**

21. Enclosure rating (weather proof, hazardous, etc.)

22. Voltage supply

23. Cycle time

24. Control signal

**In general, the selection of a control valve requires three steps: controllability, compatibility, and actuation.** Controllability means the ability of the valve to handle the pressure, temperature, flow rate, and medium. This leads to the flow characteristics, noise, cavitation, and flow capacity.

Compatibility is basically material selection. Corrosion, excessive temperatures, and even the requirement for bubble tight shut off all require careful material selection. Some users tend to over specify shut off requirements. Few control valves are actually required to perform the function of a block valve.

Actuation is important for performance as well as system compatibility. Pneumatic and electric actuators are capable of providing long, accurate service life if properly selected and applied. Positioners are available for unfiltered air, harsh environments, hazardous areas, and even with specially engineered cams for unique needs.

Of course the cost of a control valve both initially and over its performance life should always be considered. Overspecifying is a conservative means of ensuring control, but this may lead to a high purchase price, wasted energy, and excessive operating costs.

Actuator selection and sizing should involve the experience of both the user and the manufacturer.