PIP PCECV001
Guidelines for Application of Control Valves
PURPOSE AND USE OF PROCESS INDUSTRY PRACTICES

In an effort to minimize the cost of process industry facilities, this Practice has been prepared from the technical requirements in the existing standards of major industrial users, contractors, or standards organizations. By harmonizing these technical requirements into a single set of Practices, administrative, application, and engineering costs to both the purchaser and the manufacturer should be reduced. While this Practice is expected to incorporate the majority of requirements of most users, individual applications may involve requirements that will be appended to and take precedence over this Practice. Determinations concerning fitness for purpose and particular matters or application of the Practice to particular project or engineering situations should not be made solely on information contained in these materials. The use of trade names from time to time should not be viewed as an expression of preference but rather recognized as normal usage in the trade. Other brands having the same specifications are equally correct and may be substituted for those named. All Practices or guidelines are intended to be consistent with applicable laws and regulations including OSHA requirements. To the extent these Practices or guidelines should conflict with OSHA or other applicable laws or regulations, such laws or regulations must be followed. Consult an appropriate professional before applying or acting on any material contained in or suggested by the Practice.

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# PIP PCECV001
Guidelines for Application of Control Valves

## Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Scope</td>
<td>2</td>
</tr>
<tr>
<td>2. References</td>
<td>2</td>
</tr>
<tr>
<td>2.1 Process Industry Practices</td>
<td>2</td>
</tr>
<tr>
<td>2.2 Industry Codes and Standards</td>
<td>2</td>
</tr>
<tr>
<td>2.3 Government Regulations</td>
<td>3</td>
</tr>
<tr>
<td>2.4 Other References</td>
<td>3</td>
</tr>
<tr>
<td>3. Valve Materials</td>
<td>4</td>
</tr>
<tr>
<td>3.1 General</td>
<td>4</td>
</tr>
<tr>
<td>3.2 Valve Body</td>
<td>4</td>
</tr>
<tr>
<td>3.3 Valve Body Material Testing Methods</td>
<td>6</td>
</tr>
<tr>
<td>3.4 Valve Trim</td>
<td>6</td>
</tr>
<tr>
<td>3.5 Gaskets</td>
<td>8</td>
</tr>
<tr>
<td>3.6 Packing</td>
<td>8</td>
</tr>
<tr>
<td>4. Valve Types</td>
<td>11</td>
</tr>
<tr>
<td>4.1 General</td>
<td>11</td>
</tr>
<tr>
<td>4.2 Globe Styles</td>
<td>13</td>
</tr>
<tr>
<td>4.3 Rotary-Style Valves</td>
<td>16</td>
</tr>
<tr>
<td>5. Sizing of Valves</td>
<td>19</td>
</tr>
<tr>
<td>5.1 Sizing Methods</td>
<td>19</td>
</tr>
<tr>
<td>5.2 Sizing Guidelines</td>
<td>19</td>
</tr>
<tr>
<td>6. Inherent Flow Characteristics</td>
<td>20</td>
</tr>
<tr>
<td>6.1 Definitions</td>
<td>20</td>
</tr>
<tr>
<td>6.2 Equal Percentage Characteristic</td>
<td>21</td>
</tr>
<tr>
<td>6.3 Linear Characteristic</td>
<td>22</td>
</tr>
<tr>
<td>6.4 Quick Opening Characteristic</td>
<td>23</td>
</tr>
<tr>
<td>7. Cavitation and Flashing</td>
<td>23</td>
</tr>
<tr>
<td>7.1 Cavitation</td>
<td>23</td>
</tr>
<tr>
<td>7.2 Flashing and Erosion</td>
<td>26</td>
</tr>
<tr>
<td>8. Noise Considerations</td>
<td>28</td>
</tr>
<tr>
<td>8.1 General</td>
<td>28</td>
</tr>
<tr>
<td>8.2 Noise Reduction</td>
<td>28</td>
</tr>
<tr>
<td>9. Actuators and Accessories</td>
<td>29</td>
</tr>
<tr>
<td>9.1 General</td>
<td>29</td>
</tr>
<tr>
<td>9.2 Sizing and Selection</td>
<td>29</td>
</tr>
<tr>
<td>9.3 Actuator Forces</td>
<td>30</td>
</tr>
<tr>
<td>9.4 Positioners and Accessories</td>
<td>33</td>
</tr>
<tr>
<td>10. Valve Shipping and Storage</td>
<td>35</td>
</tr>
<tr>
<td>11. Valve Installation</td>
<td>35</td>
</tr>
</tbody>
</table>
1. **Scope**

This Practice describes the guidelines and background information for the application of pneumatically actuated control valves. Issues addressed include valve selection, valve and actuator sizing, material selection, flow characteristic evaluation, valve accessories, and consideration of the effects of flashing, cavitation, and noise.

2. **References**

Applicable parts of the following PIP Practices, industry codes and standards, and other references shall be considered an integral part of this Practice. The edition in effect on the date of contract award shall be used, except as otherwise noted. Short titles are used herein where appropriate.

### 2.1 Process Industry Practices (PIP)

- PIP PCCGN002 - *General Instrument Installation Criteria*
- PIP PCSCV001 - *Specification of Control Valves*
- PIP PNSC0001 - *Fabrication and Examination Specification for ASME B31.3 Metallic Piping*

### 2.2 Industry Codes and Standards

Applicable requirements in the latest edition (or the edition indicated) of the following standards shall be considered an integral part of this Practice:

- **American Petroleum Institute (API)**
  - API 609 - *Butterfly Valves: Double Flanged, Lug- and Wafer-Type*
- **American Society for Mechanical Engineers (ASME)**
  - ASME B31.3 - *Process Piping*
- **American Society for Testing and Materials (ASTM)**
  - ASTM A193 - *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service*
  - ASTM A194 - *Standard Specification for Carbon and Alloy Steel Nuts for High-Pressure or High-Temperature Service, or Both*
  - ASTM A216 - *Standard Specification for Steel Castings, Carbon, Suitable for Fusion Welding, for High-Temperature Service*
  - ASTM A217 - *Standard Specification for Steel Castings, Martensitic Stainless and Alloy, for Pressure-Containing Parts, Suitable for High-Temperature Service*
  - ASTM A320 - *Standard Specification for Alloy/Steel Bolting Materials for Low-Temperature Service*
  - ASTM A351 - *Standard Specification for Castings, Austenitic, Austenitic-Ferric (Duplex), for Pressure-Containing Parts*
  - ASTM A352 - *Standard Specification for Steel Castings, Ferritic and Martensitic for Pressure-Containing Parts, Suitable for Low-Temperature Service*
• Fluid Controls Institute, Inc. (FCI)
  – ANSI/FCI 70-2 - Control Valve Seat Leakage
• The International Society of Automation (ISA)
  – ANSI/ISA 75.01.01 - Flow Equations for Sizing Control Valves
  – ANSI/ISA-75.07 - Laboratory Measurement of Aerodynamic Noise Generated by Control Valves
  – ANSI/ISA 75.11 - Inherent Flow Characteristic and Rangeability of Control Valves
  – ISA 75.17 - Control Valve Aerodynamic Noise Prediction
  – ISA RP75.23 - Considerations for Evaluating Control Valve Cavitation
  – ANSI/ISA 75.25 - Control Valve Dynamic Testing
• International Electrotechnical Commission (IEC)
  – IEC 60534-8-1 - Industrial-process control valves - Part 8-1: Noise considerations - Laboratory measurement of noise generated by aerodynamic flow through control valves
  – IEC 60534-8-3 - Industrial-process control valves - Part 8: Noise considerations - Section 8: Control valve aerodynamic noise prediction method
  – IEC 60534-8-4 - Industrial-process control valves - Part 8: Noise considerations - Section 8: Prediction of noise generated by hydrodynamic flow
• NACE International
  – NACE Standard MR0103 - Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments
  – NACE MR-01-75 - Sulfide Stress Cracking Resistant Metallic Materials for Oil Field Equipment

2.3 Government Regulations

• U.S. Department of Labor, Occupational Safety and Health Administration (OSHA)
  – OSHA 1910.95 - Occupational Noise Exposure
• U.S. Environmental Protection Agency (EPA)
  – Clean Air Act (CAA), Section 112, National Emission Standard for Hazardous Air Pollutants
  – HON Rule, Article 63.168 - Valves in Gas/Vapor Service and in Light Liquid Service

2.4 Other References

• Mars G. Fontana and Norbert D Green, 1989, Corrosion Engineering, McGraw-Hill, New York, NY
3. Valve Materials

3.1 General

3.1.1 Material selection should be guided by the piping specification and by the process conditions as a minimum.

3.1.2 If uncertainty about materials selection exists, the final materials selection should be made in consultation with those specializing in materials science or with the control valve supplier.

3.1.3 For valves in a flammable hydrocarbon service, less flame resistant body materials (e.g., plastic, cast iron, bronze, and aluminum) should be avoided so that process integrity can be maintained in an emergency situation involving an external fire.

3.2 Valve Body

3.2.1 The valve body material should be as specified in the piping specification but is typically WCB or WCC carbon steel or ASTM type 300 series stainless steel (SS).

3.2.2 Valves should be designed in accordance with the design pressure and temperature.

3.2.3 All materials used in the valve should be compatible with the process for normal and abnormal conditions.

3.2.4 Table 1 provides metallurgy guidance at different design temperatures.
### Table 1. Selection Guide for Valve Body, Studs, Nuts, and Testing

<table>
<thead>
<tr>
<th>Temp °F (°C) (See Note 1)</th>
<th>Body (ASTM)</th>
<th>Bonnet Studs (ASTM)</th>
<th>Bonnet Nuts (ASTM)</th>
<th>Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>-425 &lt; T &lt; 100 ( -254 &lt; T &lt; 38 )</td>
<td>A351 Gr CF8M</td>
<td>A320 Gr B8</td>
<td>A194 Gr 8</td>
<td>Charpy at design temp</td>
</tr>
<tr>
<td>-325 &lt; T &lt; 1000 ( -198 &lt; T &lt; 538 )</td>
<td>A351 Gr CF8M</td>
<td>A320 Gr B8M</td>
<td>A194 Gr 8M</td>
<td>Charpy at design temp</td>
</tr>
<tr>
<td>-50 &lt; T &lt; 20 ( -46 &lt; T &lt; -7 )</td>
<td>A352 Gr LCB or A352 Gr LCC</td>
<td>A193 Gr L7</td>
<td>A194 Gr 7</td>
<td>Charpy (See Note 3)</td>
</tr>
<tr>
<td>-20 &lt; T &lt; 100 ( -29 &lt; T &lt; 38 )</td>
<td>A216 Gr WCB or A216 Gr WCC</td>
<td>A193 Gr B7</td>
<td>A194 Gr 2H</td>
<td>Charpy (See Note 2)</td>
</tr>
<tr>
<td>100 &lt; T &lt; 800 ( 38 &lt; T &lt; 427 )</td>
<td>A216 Gr WCB or A216 Gr WCC</td>
<td>A193 Gr B7</td>
<td>A194 Gr 2H</td>
<td>None</td>
</tr>
<tr>
<td>800 &lt; T &lt; 1000 ( 427 &lt; T &lt; 538 )</td>
<td>A217 Gr WC9 (Chrome)</td>
<td>A193 Gr B16</td>
<td>A194 Gr 4</td>
<td>None</td>
</tr>
<tr>
<td>800 &lt; T &lt; 1000 ( 427 &lt; T &lt; 538 )</td>
<td>A351 Gr CF8M (316 SS)</td>
<td>A193 Gr B8M</td>
<td>A194 Gr 8M</td>
<td>None</td>
</tr>
<tr>
<td>1000 &lt; T &lt; 1100 ( 538 &lt; T &lt; 593 )</td>
<td>A217 Gr WC9 (Chrome)</td>
<td>A193 Gr B16</td>
<td>A194 Gr 4</td>
<td>None</td>
</tr>
<tr>
<td>1000 &lt; T &lt; 1100 ( 538 &lt; T &lt; 593 )</td>
<td>A351 Gr CF8M (316 SS)</td>
<td>A193 Gr B8M (See Note 4)</td>
<td>A194 Gr 8M</td>
<td>None</td>
</tr>
<tr>
<td>1100 &lt; T &lt; 1500 ( 593 &lt; T &lt; 816 )</td>
<td>A351 Gr CF8M (316 SS)</td>
<td>A193 Gr B8M (See Note 4)</td>
<td>A194 Gr 8M</td>
<td>None</td>
</tr>
</tbody>
</table>

**Notes:**
1. T is design temperature in degrees F.
2. Consider Charpy testing.
3. If design temperature is less than -20°F (-29°C), Charpy test at -50°F (-46°C).
4. For temperatures greater than 1000°F (538°C), ASTM A193 Gr B8M Class 2 strain-hardened studs should be used.

#### 3.2.5
The following *NACE* standards should be used as applicable for selecting material for processes containing hydrogen sulfide (H₂S). These standards provide metallic material requirements for resistance to sulfide stress cracking.

- a. For oil field (upstream) applications, *NACE MR-01-75*
- b. For refining applications, *NACE MR-0103*

#### 3.2.6
Physical effects of turbulence, fluid impingement, flashing, outgassing, erosion, cavitation, changes in flow, pressure, temperature caused by maintenance (e.g., when line is steamed out), and other abnormal operating conditions may require a different material for the valve body than for the piping in which the valve is installed. Corrosion, which has minimal or acceptable effects on the pipe, can be exacerbated in the valve body. Passivation films that form under relatively quiescent conditions can be worn away by high-velocity fluids.
3.3 Valve Body Material Testing Methods

3.3.1 Control valve suppliers should have a quality control plan that includes nondestructive examination (NDE) and repair procedures. Heat treatment and repair procedures should as a minimum be in accordance with the following ASTM standards as applicable:

a. For austenitic castings, ASTM A351
b. For ferritic and martensitic castings, ASTM A352

3.3.2 Castings made from some valve body materials (e.g., Monel™, titanium, and Hastelloy®) can be prone to flaws and voids. To ensure acceptable valves, NDE of pressure-retaining parts should be completed before machining.

3.3.3 Testing methods (e.g., x-ray, ultrasonic, dye checking, hardness testing, magnetic particle, etc.) should be agreed with the facility owner’s material engineer before ordering the valves, and the provisions should be included in the purchase order. Typical NDE procedures for pipe fabrication are provided in PIP PNSC0001. The extent of NDE and acceptance requirements for pipe fabrication should be in accordance with ASME B31.3.

3.3.4 Charpy impact testing should be performed for cold service applications (i.e., less than -50°F (-46°C)). See ASTM A352 Grade LCB materials.

3.3.5 Materials of constructions and welds may be verified by positive material identification (PMI). If PMI is required, provisions for PMI should be included in the purchase order.

3.4 Valve Trim

3.4.1 General

3.4.1.1 The effects of wear, galling, erosion, and corrosion are more pronounced on valve trim than on the valve body. To minimize these effects and to simultaneously control cost, a valve trim of a different metallurgy than that of the valve body may be utilized.

3.4.1.2 Standard valve trim, typically 316 SS, should be given first consideration. Higher alloy grades (e.g., 416 SS, 17-4 PH SS) have a proven history in severe service applications. These alloys are offered as standard on some valves.

3.4.1.3 Valves in the following services should be specified with trim having a hardness of 38 Rc (hardness Rockwell C) minimum:

a. Cavitating or flashing services
b. Services containing erosive or solid-bearing fluids
c. High-pressure applications

3.4.1.4 The guidelines in Sections 3.4.2 through 3.4.4 are not exhaustive but are typically accepted. These guidelines should be compared with actual experience because the issues that impact trim material selection are complex.
3.4.2 Series 300 and 400 SS

3.4.2.1 Series 300 and 400 SS are widely used and are frequently available as standard offerings.

3.4.2.2 300 series SS (e.g., Types 304 and 316) is relatively ductile and resistant to many types of corrosion. 300 series SS cannot be hardened by heat treatment. The relative softness of 300 series SS, compared with Types 410 and 416, makes them less desirable in erosive, wear-producing applications.

3.4.2.3 400 series SS is typically less corrosion resistant than 300 series SS.

3.4.2.4 For general service, 300 and 400 series SS may be applied in processes from -20°F to 650°F (-29°C to 343°C). See valve manufacturer’s literature for limitations. As an example, cavitation trim typically has a more limited range.

3.4.2.5 Assuming compatibility with the chemistry of the process, 300 and 400 series SS components may be plated or hard-faced with materials to increase wear resistance.

3.4.3 Material Overlays

3.4.3.1 Hard-facing materials include Stellite No. 6 (CoCr), tungsten carbide, ceramic, and Ultimet®.

3.4.3.2 Hard-facing can be effective in erosive applications, in steam and water applications if pressure drops are greater than 50 psi (3.5 bar), and in general applications if pressure differentials are greater than 500 psi (34.5 bar).

3.4.3.3 The facing material can wear or corrode away over time, leaving the base, softer material unprotected.

3.4.4 Other Materials

3.4.4.1 Type 17-4 PH SS metallurgy may be specified for components (e.g., valve plugs, cages, and guide bushings) requiring greater strength, hardness, and galling resistance.

3.4.4.2 Valve trim parts may be specified with more resistant metallurgy while using a less expensive material for the body. For example, trim parts of Monel™ or Hastelloy®, Stellite, and 17-4 PH SS may be used with carbon steel bodies if the process contains trace quantities of hydrofluoric acid, sulfuric acid, or dry chlorine gas or if the process contains a maximum of 20% caustic material.

3.4.4.3 Valve trim selection can also depend on the valve body geometry. For example, streamlined bodies having high-pressure recovery coefficients are more likely to exhibit cavitation. Valves having high-pressure recovery coefficients (e.g., rotary valves) can require special or hardened trim.
3.5 Gaskets

3.5.1 The gasket and packing material should be compatible with or match the applicable piping specification and should be in accordance with the temperature and chemical requirements of the process.

3.5.2 If gaskets are not specified, the default should be a spiral-wound 316 SS gasket, combined with an asbestos-free filler (e.g., Grafoil®). These gaskets can be used in very low temperature applications (i.e., down to -400°F (-240°C)).

3.5.3 Inconel with laminated graphite can be used from -400°F to 1100°F (-240°C to 593°C).

3.6 Packing

3.6.1 General

3.6.1.1 Polytetrafluoroethylene (PTFE) is typically used as a packing material because PTFE is generally inert and has a low coefficient of friction. PTFE can be applied as packing for temperatures equal to and less than 400°F (204°C). Because PTFE can harden at low temperatures, PTFE should not be used below 0°F (-18°C) with a standard bonnet and below -50°F (-46°C) with an extended bonnet.

3.6.1.2 If an elastomer like PTFE is selected, allowances should not be taken for the cooling effects of an extended bonnet because heat is drawn into the packing material if a leak occurs.

3.6.1.3 For applications in temperatures greater than 750°F (399°C), extended bonnets should be used to protect positioners and actuators from heat. For more information on the use of extended bonnets, see Section 4.1.7.

3.6.1.4 In cryogenic services, ice should not be permitted to form on the stem because ice can destroy the packing material.

3.6.1.5 Pure graphite packing material can be used in temperatures less than or equal to 800°F (423°C) in oxidizing service and less than or equal to 1200°F (649°C) in non-oxidizing service. A corrosion inhibitor should be used if graphite packing is used. The packing manufacturer should be consulted to determine if the valve should be removed during hydrotesting. Graphite packing can corrode the stem if left wet.

3.6.1.6 Packing glands, studs, and followers should be minimum 316 SS unless 316 SS is not compatible with the process (e.g., chlorine).

3.6.1.7 For smaller valves (i.e., 1 inch (25 mm) and less), screwed packing followers should be used.

3.6.1.8 Consideration should be given to the corrosive effects of leakage through the packing. For example, dry hydrochloric acid becomes extremely corrosive if exposed to the wet atmosphere. Therefore, the stem and packing bolts should be compatible with greater corrosive demands.

3.6.1.9 Piping systems that are steamed out frequently pull a vacuum when the line cools. The valve packing should be designed for vacuum service if pulling air into the system is not desirable.
3.6.2. Bellows Seals

3.6.2.1 Bellows seals are expensive and prone to fatigue failure.

3.6.2.2 Bellow seals should be considered for lethal, toxic, pyrophoric, or cryogenic services.

3.6.2.3 The use of bellow seals should be approved by the owner of the facility.

3.6.2.4 Typically, bellows seal travel is 75% of maximum rated valve travel.

3.6.2.5 Bellow seals should be in accordance with the following:
   a. Approved for use in lethal, toxic, pyrophoric, or cryogenic services
   b. Include an anti-rotation feature to prevent twisting of bellows during normal maintenance
   c. Pressure-tested to a minimum of 1.3 times rated maximum allowable service pressure
   d. Helium leak-tested. Pressure loss should not be greater than $1 \times 10^{-6}$ cm$^3$/second of helium.
   e. Have bellows set in neutral position at 50% of valve stroke. Bellows should not be in tension or compression at neutral position.
   f. Approved by the facility owner concerning the estimated cycle life

3.6.3. Fugitive Emissions Considerations

3.6.3.1 General

1. The Clean Air Act (CAA) of 1990 and subsequent revisions and addenda have specified maximum allowable leakage rates of selected substances (i.e., hazardous air pollutants (HAP)) to the atmosphere (i.e., fugitive emissions) from chemical-handling equipment and piping, including control valves. The EPA’s final decisions on the rule, called the HON Rule (i.e., Hazardous Organic NESHAP, or the National Emission Standard for Organic Hazardous Air Pollutants from the Synthetic Organic Chemical Manufacturing Industry (SOCMI)), was signed into law on February 28, 1994.

2. The intent of this section is to provide design guidelines for control valves in chemical service that are consistent with the 1990 CAA.

3. Leakage testing of existing control valves in HON-defined HAP services and toxicity-based services is required. Repair of these valves is required as necessary to eliminate excessive leakage as defined in the HON Rule.

4. Guidelines and requirements for valve repair to reduce leakage are provided in HON Rule, Article 63.168. The following topics in the HON Rule should be reviewed:
   a. Under Article 63.168:
      (1) Paragraph (d), Frequency of monitoring
      (2) Paragraph (f), Time allowed for repair
(3) Paragraph (g), First attempts at repair  
(4) Paragraph (h), Unsafe-to-monitor exemption  
(5) Paragraph (i), Difficult-to-monitor exemption  
b. Article 63.171 (a),(b),(c), Delay of repair  
c. Article 63.180, Test measures and procedures  

5. If fugitive emissions are problematic, emissions can be minimized by the application of specifically designed packing material or bellows seals.

3.6.3.2 Valve Operation

1. Control valves provided with low fugitive emission packing should operate without leaking, as defined in the HON Rule, for a minimum service life of 2 years, with a typical maintenance frequency not greater than once per year.

2. Consideration should be given to the necessary dynamic behavior of the valve so that the low-emission packing cannot seriously impede the valve’s function as a final control element.

3. Oversized actuators should be used to overcome high packing friction to meet dead time and dead band requirements for the process.

4. Typically, for a 1% to 10% input step change, a control valve step response time (T86) of 2 to 6 seconds is suitable. T86 should be 40% of the required open loop response.

5. T86 consists of two components; the dead time (Td) and the remainder of the response time. T86 is the interval of time between initiation of an input signal step change and the moment the signal reaches 86.5% of its full steady state change. T86 is approximately twice the control valve’s time constant of a first-order response reaching 63.2% of the full steady state change. For example, assume that a closed loop response of 10 seconds is required. The T86 for the valve should be 4 seconds (i.e., 10 seconds times 40% equals 4 seconds). When subjecting the valve to a 10% input step change, the valve stem should move 8.6% of its stroke within 4 seconds.

3.6.3.3 Rotary Valves and Bellows Seals

1. Rotary control valves should be used instead of sliding-stem valves for low fugitive emissions service if feasible.

2. Bellows seals should be used only if multi-ring, low-emission packing designs are not sufficient or cannot be tolerated (e.g., pyrophoric, lethal, or toxic services).

3. Low fugitive emissions requirements mainly affect stuffing box and packing design, but for compliance, assembly joints and piping connections should also be carefully designed and maintained throughout the life of the valve.
4. Valve Types

4.1 General

The guidelines in this section should be used for globe- and rotary-style valves.

4.1.1 Valve Stem

4.1.1.1 All valves should have a mechanism to prevent stem blowout if the stem detaches from the closure member. If the stem detaches, the process fluid can expel the shaft, causing loss of containment.

4.1.1.2 The use of the actuator to retain the shaft is not an acceptable blowout prevention method because the actuator can be removed during maintenance.

4.1.2 Valve Size Less Than Pipe Size

4.1.2.1 Valve size should typically not be more than two sizes less than the pipe size. If the valve size is required to be reduced by more than two pipe sizes, the piping mechanical stresses should be validated by piping engineers.

4.1.2.2 The valve manufacturer can also provide valves with expanded inlet and outlet connections that can directly mate with the piping connections.

4.1.2.3 Using a line size globe-style valve with reduced trim has the following advantages and disadvantages:
   a. Advantages include:
      (1) Saves cost of the reducers. The installed cost can be less than that of installing a smaller valve, depending on valve size and metallurgy.
      (2) Permits increasing future throughput
      (3) Reduces risk of under-sizing valves
      (4) Permits the design of the piping system before final control valve selection
   b. Disadvantages include more costly control valve and valve manifold station

4.1.2.4 A process engineer should be consulted if the valve is greater than one size less than the downstream line size because this indicates that the pipe is possibly oversized.

4.1.2.5 The use of restricted valve trim may be considered for flow rates requiring smaller Cv coefficients.

4.1.3 Minimum Flange Rating

4.1.3.1 For sites having mainly carbon steel and stainless steel valves, ANSI class 300 flange ratings should be used to standard to minimize spare parts inventory.

4.1.3.2 The cost of ANSI classes 150 and 300 carbon steel and stainless steel valves are approximately the same depending on size. Valve
manufacturers typically use the same globe valve body castings for sizes 1 to 4 inches (25mm to 100 mm) to manufacture ANSI classes 150 through 600; the only difference is the amount of metal removed from each casting.

4.1.4 Flangeless Valves

4.1.4.1 Flanged valves should be specified in hydrocarbon services, toxic services, and hot services (i.e., greater than 400°F) (204°C) to minimize the risk of flange leaks. Flangeless (e.g., wafer-style) valves should not be used in these services. Valve end connections should be in accordance with the piping specification.

4.1.4.2 Leakage potential is heightened in flangeless valves because the exposed studs can expand in a fire.

4.1.5 Separable Flanges

4.1.5.1 Corrosion or erosion effects can indicate that the valve body should be of a higher alloy than the pipe. Cost can be saved by specifying separable flanges in a less expensive metallurgy.

4.1.5.2 Economic incentive for separable flanges is not significant unless the valve is a large 304 or 316 SS valve (i.e., greater than 4 inches) or the metallurgy is higher than 304 or 316 SS.

4.1.5.3 Typically, separable flanges should not be used because loosening the bolts can permit the valve to rotate. Separable flanges should be specified only for higher alloy or large SS valves.

4.1.5.4 If separable flanges are specified and the valve can rotate if the flange bolts are loosened, a warning tag should be affixed to the actuator.

4.1.6 Welded End Valves

4.1.6.1 Welded end valves should not be used because they are difficult to repair in line and difficult to remove for maintenance.

4.1.6.2 If the piping specification requires welded end valves, the piping engineer should be consulted to verify that welded end valves are permitted and to determine what types are permitted.

4.1.7 Bonnet

4.1.7.1 Use of extension bonnets should be minimized.

4.1.7.2 Bonnets should have a bolted design.

4.1.7.3 Bonnet bolts should not be used for attaching actuators or mounting brackets.

4.1.7.4 Extended or finned bonnets should be used for service temperatures less than 0°F (-18°C) and greater than 750°F (399°C).

4.1.7.5 Extended bonnets may be avoided in processes with temperatures greater than 400°F (204°C) and less than 750°F (399°C) if graphite-based or other high-temperature packing is used.
4.1.7.6 If extension bonnets are required, Table 2 provides guidelines:

<table>
<thead>
<tr>
<th>Temp °F (°C)</th>
<th>Graphite Packing</th>
<th>Elastomer Packing</th>
</tr>
</thead>
<tbody>
<tr>
<td>T &lt; 0 (-18°C)</td>
<td>Plain extension</td>
<td>Plain extension</td>
</tr>
<tr>
<td>0 &lt; T &lt; 450 (-18°C &lt; T &lt; 232°C)</td>
<td>No extension</td>
<td>No extension</td>
</tr>
<tr>
<td>450 &lt; T &lt; 750 (232°C &lt; T &lt; 399°C)</td>
<td>No extension (See Note 1)</td>
<td>Plain Extension</td>
</tr>
<tr>
<td>T &gt; 750 (T &gt; 399°C)</td>
<td>Plain extension (See Note 2)</td>
<td>No elastomer packing (Use graphite.)</td>
</tr>
</tbody>
</table>

Notes:
1. T is design temperature in degrees F.
2. This method should be used if graphite packing is compatible with service conditions.
3. Valve manufacturer should be consulted for a recommendation on the use of finned extension.

4.2 Globe Styles

4.2.1 General

4.2.1.1 The term “globe valve” is derived from the shape of the valve body.

4.2.1.2 Flow control is affected by positioning the closure member in relationship to a seat through the area of linear or reciprocating motion of an actuator.

4.2.1.3 The globe style of control valve includes globe, bar stock, angle, and three-way valves.

4.2.2 Globe Valves

4.2.2.1 General

1. Globe valves should have the following characteristics:
   a. Inner valve plug removable through top of valve body (push down to close)
   b. Removable non-threaded seat rings
2. Globe valves may be classified as post-guided or cage-guided plugs.

4.2.2.2 Post-Guided

1. In a post-guided configuration, the plug can be either top-guided or top- and bottom-guided.
2. Double-ported, post-guided valves are typically guided by posts at the top and bottom of the plug.
3. Post-guided, single-ported valves may be used for tight shutoff applications; however, because these valves are unbalanced, they can
require more force from the actuator to achieve shutoff if the flow is under the plug.

4. Double-ported valves cannot provide the same shutoff capability as the single-ported types because for the double-ported types, seating both plugs simultaneously is nearly impossible (ANSI Class II versus ANSI Class IV).

5. Typically, double-ported valves are not used because of higher maintenance costs and leakage.

6. Double-ported valves, because they are somewhat balanced by differential forces acting in opposite directions across the two plugs, require less positioning force than do single-ported valves. The double-ported valve actuators can be smaller than for single-ported valves in the same application or with the same shutoff requirements.

7. Post-guided valves may be a good choice for dirty service if the fluid or fluid particles can adhere to the guiding surface or clog the plug vent holes. The post and guide bushing of post-guided types, under certain conditions, can be less affected by this type of buildup.

8. For high pressure drop, incipient cavitation, or flashing services, the lower guide area is required to be hardened. Also, valve plug, seat and guides should be hard faced. For full cavitation service, the lower guide area should not be hardened.

9. For high pressure drop services, an extension, or post, on the upper side of the plug is guided by a bushing clamped in the valve bonnet or top enclosure. These valve types typically have only one port and a single seat.

4.2.2.3 Cage-Guided

1. Cage-guided valves have a cylindrical plug guided through a cage clamped in the valve body.

2. The cage is a massive, ported cylindrical spool through which a plug is axially positioned.

3. The increased guiding area is desirable for high-pressure drop, high-noise, and anti-cavitation applications.

4. Cage-guided valves may have either unbalanced or balanced plugs.

5. Unbalanced types can provide a tight shutoff if sufficient actuator force is applied.

6. For balanced styles, the plug is vented and the process pressure interacts with the top and bottom side of the plug. Therefore, relatively small pressure differentials exist across the plug throughout the valve stroke, and lower plug-positioning forces are required from the actuator.

7. Cage-guided valves should not be used in services if coke can form or if solid particles are present.
8. The cage-guided valve can achieve flow characterization with two different style variations as follows:
   a. Cage ports are contoured and the plug is cylindrical
   b. Cage ports are rectangular and the plug is contoured

9. Because of the equal flow distribution through the cage, cage-guided valves have less side load and are inherently more stable than post-guided styles.

10. Balanced styles undergo less horizontal vibration and consequently less guide, seat, and stem wear than post-guided types.

11. Because of superior stability, cage-guided valves provide greater rangeability than post-guided valves. In addition, their larger port area allows greater flow capacity compared with post-guided types of equal body size.

4.2.3 Bar Stock Bodies

Bar stock bodies may be used if any of the following apply:
   a. Special alloys required
   b. High-pressure applications
   c. Offset inlet and outlet ports required
   d. Significant cost advantage

4.2.4 Angle Valves

4.2.4.1 Angle valves should be used for the following services:
   a. Coking
   b. Solids carried in suspension
   c. Severe flashing
   d. Bottoms
   e. Drains
   f. Cavitation
   g. High pressure drop
   h. Outgassing

4.2.4.2 Side and bottom connections should be inlet and outlet, respectively.

4.2.4.3 The plugs on noncage-guided angle valves in flow-to-close applications tend to be forced into the seat as the plug nears the seat. If the valve operates at less than 20% lift at minimum flow, a volume tank with double-acting piston actuator should be used, and the piston should be adjusted to be near the bottom of the cylinder when the valve is closed.

4.2.4.4 Spring-assisted actuators should not be used.

4.2.4.5 An angle valve has a bottom-exiting venturi throat, typically of a hardened material, or a sleeve may be added to the angle valve. The
smooth entrance and exit are effective if applied to high-velocity fluids containing erosive solids.

## 4.2.5 Three-Way Valves

4.2.5.1 Three-way valves can control converging or diverging streams.

4.2.5.2 Three-way valves can provide an economical alternative to separate valves and are frequently used to bypass flow around an exchanger (i.e., diverging flow) or to mix two streams (i.e., converging flow).

4.2.5.3 Use of three-way valves can simplify failure analysis because only one actuator failure needs to be considered.

4.2.5.4 Three-way applications consisting of two valves, one actuator, and a mechanical linkage should not be used because of high maintenance costs. Two separate valves with their own actuators and other accessories should be used.

## 4.2.6 Split Body Globe Valves

Split body globe valves should not be used because of tendency to leak.

## 4.3 Rotary-Style Valves

### 4.3.1 General

4.3.1.1 Rotary-style valves have the following features:

- a. Quarter-turn rotary actuation
- b. Low weight
- c. High capacity
- d. Lower cost
- e. Simpler, more reliable, and less friction-producing packing

4.3.1.2 Disadvantages of rotary-style valves include the following:

- a. Fewer trim sizes
- b. Propensity to cavitation
- c. If high side thrust loads exist on the shaft and bearings, valve body sizes less than 2 inches (50 mm) are not suitable; although “characterized” ball valves are available in smaller sizes.
- d. Conventional butterfly valves in particular applications can require relatively high opening and closing torque from the actuator.

4.3.1.3 For fugitive emission services, rotary valves rather than reciprocating valves should be considered because of the inherent design of shaft and packing.

### 4.3.2 Butterfly Valves

4.3.2.1 Butterfly and high-performance butterfly (eccentric disk) valves have a greater valve coefficient, and the valve body size can be less than the line size.
4.3.2.2 Butterfly valves, except for high-performance (eccentric disk) types with low-torque disk designs, should be sized to control between 10° and 60° of disk opening.

4.3.2.3 For purposes of design, high-performance butterfly (eccentric disk) valves should be sized to control within a 15° to 60° range of disk opening.

4.3.2.4 High-performance valves having specially designed disks may be selected to permit operation with the disk as much as 75° open.

4.3.2.5 High-performance butterfly (eccentric disk) valves are recommended over standard butterfly valves. These high-performance valves have double and triple offset shafts to lift the disk out of the seat immediately upon actuation. This avoids wear on the seat and disk. Leakage is minimized because the disk is pressed into the seats.

4.3.2.6 Butterfly valves are available with seat designs and material that can provide a tight shutoff.

4.3.2.7 The actuator end of the valve stem should be splined. Shear pins should not be used.

4.3.2.8 Shafts should be made of one piece.

4.3.2.9 The shear safety factor should be a minimum 150% at the specified shutoff pressure drop condition.

4.3.2.10 The valve stem bearing should be designed to prevent the stem guide bushing from rotating in the valve body.

4.3.2.11 Bearing material should be selected to prevent galling of the bearing or valve stem.

4.3.2.12 The minimum disk-to-pipe clearance should be in accordance with API 609. The designer should be aware that the disk extends into the pipe and can interfere with a reducer, close-mounted instruments (e.g., thermowells, orifice plates), and another valve.

4.3.2.13 For temperatures up to approximately 450°F (232°C), tight shutoff can be achieved with sealing designs using elastomeric materials. Temperatures above approximately 450°F (232°C) require the use of metal seats. Special valves having metal seats are available for “fire-safe” applications.

4.3.2.14 Because of their higher valve coefficient, butterfly valves typically have a higher pressure recovery coefficient. The higher pressure recovery coefficient makes cavitation more likely in a butterfly valve than in a globe valve of comparable capacity.

4.3.2.15 Valve end connections should be in accordance with the associated piping specifications. For hydrocarbon and chemical services, single flanged or lugged bodies should be used for valve end connections. Wafer bodies should be used in utility or non-critical applications.
4.3.3 Ball Valves

4.3.3.1 General

1. Ball valves have a greater valve coefficient, and the valve body size can be less than the line size.

2. The designer should consider the effects of pipe reducers typically used with ball valves and apply the appropriate factors to the sizing equation.

3. Ball valves exhibit a greater potential for cavitation than comparably sized globe valves. Special anti-cavitation trims are available that can solve ball valve cavitation in some cases. Ball valves with overlays can be used for some flashing applications.

4. Ball valves are of two basic types, depending on the configuration of the rotating ball (i.e., full and segmented).

4.3.3.2 Full Ball

1. A full ball valve has a waterway or port through a solid, complete sphere.

2. Full port valves are ball valves having an opening the same diameter as that of the pipe inside diameter.

3. Reduced or normal port ball valves have a port that is typically one size less than the flange size and have much lower valve coefficient values than do the equivalent full port valves.

4. Reduced port valves are typically used as block valves.

4.3.3.3 Segmented Ball

1. In segmented ball valves, a section or segment has been removed from the ball such that the flow is “characterized” as the ball rotates.

2. Segmented balls may be cut to provide parabolic, “V,” “U,” or other contours on the leading edge of the ball.

3. The ball is supported in the valve body by stub shafts that rotate in bearings or bushings.

4.3.4 Eccentric / Rotary Plug Valves

4.3.4.1 An eccentric plug valve is a rotary motion valve with a closure member that may be cylindrical or conical.

4.3.4.2 The following are characteristics of an eccentric plug valve:

   a. Used for throttling and isolation applications
   b. Linear flow through the valve
   c. Self-cleaning characteristics
   d. Bi-directional flow
   e. Stable operation with universal flow direction
   f. Should be installed so the rotary shaft lies horizontally
g. Excellent shutoff
h. Rotary torque
i. High torque
j. Rangeability up to 100:1
k. Offer a low cost per Cv value
l. Moderate pressure recovery in the body

4.3.4.3 Reduced trim may be accomplished by changing the seat ring.

4.3.4.4 Rotary plugs valves are less susceptible to cavitation than the butterfly or ball valves.

4.3.5 Pinch Valves

4.3.5.1 Pinch-type valves may be used with limitations for plugging services and in streams with entrained solids.

4.3.5.2 Pinch-type valves have diaphragms and/or flexible liners that can be proportionally opened and closed by mechanical or pneumatic pressure on the outside line.

4.3.5.3 Pinch-type valves are zero emission-type valves.

5. Sizing of Valves

5.1 Sizing Methods

5.1.1 Generic valve-sizing methods are available in commercial PC-based electronic formats. Electronic sources provide tutorial instruction and are valuable sources of explanatory information; however, valve manufacturers’ methods should be used for the final selection of a control valve.

5.1.2 Control valves should be sized using equations from ANSI/ISA 75.01.01 - Flow Equations for Sizing Control Valves.

5.1.3 When the valve manufacturer is selected, manufacturer’s sizing should be used to verify valve size, flashing, cavitation, and noise at various flow rates and differential pressures. Alternately, the process data may be furnished to the manufacturer for sizing of the control valves. If the sizing is to be performed by the manufacturer, care should be taken to ensure that the manufacturer has all the conditions necessary (e.g., startup, shutdown, upset, etc.) to size the valve for all process conditions.

5.1.4 Viscosity should be considered because viscosity can affect capacity, especially for very small valves.

5.2 Sizing Guidelines

5.2.1 Pressure Drop

5.2.1.1 Control valves should be sized to consume a certain percentage of the total system pressure drop (typically 30% to 50% at normal design flow). If the system pressure drop is grossly overestimated, the application of the 30% to 50% guideline typically results in an oversized valve. At the
normal flow rate, the valve can throttle too near its closed position. The need to precisely predict the total system pressure drop is rarely critical because the control system corrects for errors in estimated pressure losses.

5.2.1.2 Consideration for allowable frictional pressure drop should be included in the overall system pressure drop during sizing.

5.2.2 Turndown Ratio

5.2.2.1 The valve-sizing coefficient for globe valves should be selected to limit turndown to a ratio of about 30:1. This limits the valve opening to approximately 10% of maximum for globe valves with equal percentage trim.

5.2.2.2 Greater turndown ratios should be used with caution because of the inability of the actuator to accurately position the plug near the seat, which can cause valve instability.

5.2.2.3 If greater turndown ratios are required, consideration should be given to using rotary valves with characterized trim. If turndown ratio requirements are extreme, installations with sequentially operated parallel valves may also be considered.

5.2.3 Eccentric disk valves can pop out of the seat, causing a jump in flow. This effect makes these valves unsuitable for throttling near the seat.

5.2.4 Flow-to-close valves can draw the plug into the seat if throttling near the seat. This effect makes throttling unstable near the seat. This effect can cause galling of the seat and plug.

5.2.5 Two-Phase Fluids

5.2.5.1 Cv calculations for two-phase fluids are more complex than for single fluids. Control of a two-phase, liquid-vapor combination should be avoided if possible.

5.2.5.2 For two-phase and flashing applications, the valve outlet should not be more than one size less than the downstream piping size. An expander should be located on the outlet of the valve.

5.2.5.3 A minimum of 10 diameters of straight pipe should be provided on the outlet of the valve to minimize vibration of the piping caused by the high-velocity flow from the trim.

6. Inherent Flow Characteristics

6.1 Definitions

6.1.1 The term “installed flow characteristic” refers to the relationship between the flow rate and the closure member travel as the closure member is moved from the closed position to rated travel as the pressure drop across the valve is influenced by the varying process conditions.

6.1.2 The valve manufacturer develops the “inherent flow characteristic” of the valve by measuring flow through the valve at various openings while maintaining a constant pressure drop across the valve.
6.1.3 Typically, the valve differential pressure drop changes as the valve opening changes. For this reason the installed flow characteristic provides a more meaningful representation of valve dynamic behavior. The installed flow characteristic is a more accurate representation of how flow in the system changes relative to changes in valve opening and valve and system pressure drop. However, knowing the valve inherent flow characteristic is essential to the initial sizing and application effort.

6.1.4 The primary valve inherent flow characteristics are equal percentage, linear, and quick opening.

6.1.5 **Inherent Rangeability**

6.1.5.1 Inherent rangeability is the ratio of the largest flow coefficient to the smallest flow coefficient in which the deviation from the specified inherent flow characteristics is less than the limits stated in ISA 75.11, Section 4.

6.1.5.2 Inherent rangeability is an indication of how well the valve can control the effective orifice created by the closure member-to-stroke curve.

6.1.5.3 The ratio is of limited value because the ratio does not consider the accuracy of the positioner/linkage, the instabilities of the process fluid, the inability to control areas near the seat because of bathtub effects or seat stiction, and the changing pressure drop with flow rate.

6.1.5.4 A more meaningful definition of rangeability recognizes the variation in pressure drop and is expressed as the ratio of maximum Cv at minimum pressure drop to minimum Cv at maximum pressure drop. Rangeability can vary if this definition is applied; however, rangeability is a useful tool for making initial selections. Table 3 provides typical rangeability and pressure recovery factors.

**Table 3. Representative Valve Characteristics, Rangeability, and Pressure Recovery Factors**

<table>
<thead>
<tr>
<th>Valve Type</th>
<th>Inherent Characteristics</th>
<th>Rangeability</th>
<th>Pressure Recovery Factor (F&lt;sub&gt;L&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Globe</td>
<td>= % &amp; Lin</td>
<td>20:1 to 50:1</td>
<td>0.75 to 0.92</td>
</tr>
<tr>
<td>Globe w/ cavitation trim</td>
<td>Lin</td>
<td>20:1</td>
<td>0.92 to 0.999</td>
</tr>
<tr>
<td>Angle w/ venturi</td>
<td>= % &amp; Lin</td>
<td>20:1 to 50:1</td>
<td>0.5</td>
</tr>
<tr>
<td>Ball standard bore</td>
<td>Lin</td>
<td>100:1</td>
<td>0.55 to 0.6</td>
</tr>
<tr>
<td>Segmented ball</td>
<td>Lin</td>
<td>100:1</td>
<td>0.55 to 0.85</td>
</tr>
<tr>
<td>Eccentric rotary plug</td>
<td>Lin</td>
<td>100:1 to 200:1</td>
<td>0.55 to 0.85</td>
</tr>
<tr>
<td>Ball characterized</td>
<td>= % &amp; Lin</td>
<td>100:1 to 300:1</td>
<td>0.57 to 0.75</td>
</tr>
<tr>
<td>Butterfly 60° open</td>
<td>= % &amp; Lin</td>
<td>100:1</td>
<td>0.3 to 0.7</td>
</tr>
<tr>
<td>Butterfly 90° open</td>
<td>= % &amp; Lin</td>
<td>100:1</td>
<td>0.55 to .85</td>
</tr>
</tbody>
</table>

6.2 **Equal Percentage Characteristic**

6.2.1 If a constant pressure drop across the valve is assumed, a valve with an equal percentage characteristic produces a nonlinear increase in flow as the valve opens. Equal percentage increases in valve opening cause equal percentage
increases in previous flow through the valve. For example, consider an equal percentage valve with a 30:1 rangeability over 90% of its stroke. At 50% open, the flow is 15% of maximum. If the valve is opened an additional 10% (from 50% to 60%), the flow increases 46% to 22% of maximum. If the valve is opened another 10% (from 60% to 70%), the flow again increases by 46% to 32% of maximum.

6.2.2 Figure 1 shows the relationship between valve opening and valve flow for the equal percentage characteristic.

![Figure 1. Equal Percentage Characteristic](image)

An equal percentage valve exhibits increasing gain as the valve opens and is recommended for a process in which the system gain decreases with increasing valve load.

6.2.4 As the pressure drop available to the valve decreases, equal percentage valves exhibit increasingly linear characteristics. For this reason, equal percentage valves should be used for systems in which the valve absorbs varying amounts of pressure drop or if a relatively small amount (i.e., less than 30%) of the system pressure drop is consumed by the valve. Typical process applications include pressure control and nonlinearized flow control.

6.3 Linear Characteristic

6.3.1 As shown in Figure 2, a valve with a linear flow characteristic produces a linear increase in flow as the valve opens.

![Figure 2. Linear Characteristic](image)

6.3.2 Valves with linear trim are typically required for applications in which the valve differential pressure drop is relatively constant over the valve travel range.
Typical applications include liquid level control, linearized flow control, centrifugal compressor antisurge control, pump minimum flow bypass control, depressuring, gravity flow level control, and split range.

6.4 **Quick Opening Characteristic**

6.4.1 Figure 3 shows the flow characteristic curve for the quick opening valve.

![Figure 3. Quick Opening Characteristic](image)

6.4.2 Valves with a quick opening characteristic exhibit a rapid increase in flow as the valve opens. Initial valve flows are fairly linear until the valve travel is about 50% to 70% open. Flow rate “flattens out” as the area created by the rising plug begins to equal the port area.

6.4.3 Quick opening valves are typically specified for “on-off” service and for pressure-relieving applications. Quick opening valves can be used as linear valves if their travel is restricted to the linear flow regime.

7. **Cavitation and Flashing**

7.1 **Cavitation**

7.1.1 Cavitation in a valve body’s vena contracta can occur if the pressure of the flowing liquid drops below the fluid vapor pressure and then the pressure is recovered above the vapor pressure.

7.1.2 Cavitation affects valve sizing and can damage valve parts and downstream piping, depending on valve trim design, pressure drop, flow rate, temperature, and fluid. Care should be exercised to ensure that the sizing methods are applicable for the valve being evaluated.

7.1.3 The small holes used in cavitation trim for the valve are susceptible to plugging during operation, which should be considered in the selection of valves and trim. A strainer should be installed upstream of a control valve with anti-cavitation trim.

7.1.4 Cavitation in water services is more damaging to trim components than in hydrocarbon services.
7.1.5 Sigma Index

7.1.5.1 *ISA RP75.23* describes an effective methodology for communication by defining cavitation parameters, evaluating cavitation characteristics, and providing guidelines for selecting control valves.

7.1.5.2 *ISA RP75.23* defines the sigma index as follows:

\[
\text{Sigma } \sigma = \frac{(P_1 - P_v)}{(P_1 - P_2)}
\]

7.1.5.3 The valve manufacturer should provide a recommended sigma (\(\sigma_{mr}\)). The sigma recommended should be adjusted from the reference valve to the actual application using size, pressure, and reducer factors. This adjustment results in a sigma proposed (\(\sigma_p\)). If \(\sigma_p\) is less than \(\sigma\), the valve should not experience damage. If \(\sigma_p\) is greater than \(\sigma\), a “cavitation control” trim may be selected or an evaluation may be made using the intensity index (I) described in *ISA RP75.23*, Annex C.

7.1.5.4 Nominal values of sigma recommended (\(\sigma_{mr}\)) are as follows:

a. Butterfly or ball - 2.0 to 2.3
b. Globe and angle - 2.2
c. Single-stage cavitation trim - 1.2
d. Three-stage cavitation trim - 1.025

7.1.6 Intensity Index

7.1.6.1 The intensity index is a valve-life reduction factor. The magnitude of the index represents how many times faster erosion can occur over the threshold damage rate.

7.1.6.2 The intensity index modifies sigma incipient damage (\(\sigma_{id}\)) with the following factors:

a. Velocity factor, \(F_U\) - When damage or pitting has commenced at the incipient damage sigma or velocity, the rate of pitting increases exponentially with increased velocity.

b. Fluid temperature factor, \(F_T\) - For water, cavitation damage is approximately three times greater halfway between freezing and boiling.

c. Duty cycle factor, \(F_{DC}\) - The damage for continuous, intermittent, or rare cavitation conditions is considered.

7.1.7 If cavitation is predicted, the following actions should be considered:

a. Verify that the upstream pressure is required. For example, check if the pump needs to produce the pressure. Verify the process data.

b. Relocate the valve to a greater outlet pressure (e.g., grade versus top of column).

c. Relocate the valve to a lower temperature.

d. Install a restriction orifice directly downstream of the valve if flow rate variations are small.
e. Install additional valves or use anti-cavitation trim.

f. Install a spare valve in parallel, or replace valve from available stock.

Comment: For further specifics see ISA RP75.23.

7.1.8 Mitigation Methods

7.1.8.1 The best method for eliminating cavitation is to find a successfully functioning valve in a similar application and use that design and/or consult the valve manufacturer.

7.1.8.2 For severe cavitation in water service (i.e., greater than 350 psi (24 bar) drop), an anticavitation trim should be used. Anticavitation trim valves are effective in demanding applications and can significantly reduce the capacity of the valve, and the small orifices can plug in particle-laden or viscous fluid applications. Because of the small holes (i.e., approximately 1/16 inch (1.5mm) or less) in the trim, a strainer is recommended upstream. The anticavitation trim is designed to do the following:

a. Break the flow into many small streams
b. Reduce the pressure in multiple stages
c. Force the flow through multiple turns or tortuous paths
d. Direct the jets into the center of the cage to cancel the energy force

7.1.8.3 If plugging is a concern, a multiple plug-style valve should be considered. These valves divide the pressure drop into more than one pressure drop. Two valves can be installed in series to achieve the same anti-cavitation results.

7.1.8.4 For moderate cavitation of water (i.e., less than 350 psi) (24 bar) and for most hydrocarbon-cavitating services, an angle valve with hardened venturi may be used. A sharp-edge seat port orifice to keep the discharge away from the body wall should be selected. If this design is used, the design should have the following characteristics:

a. Valve outlet not greater than one size less than the pipe
b. Immediately expand to the pipe size on the outlet
c. Provide a minimum of 10 diameters of straight pipe downstream of the control valve

7.1.8.5 For minor cavitation applications such as hydrocarbons with less than 500 psig (34.5 bar) drop, a flow-to-open standard globe valve with hardened trim is recommended. If selecting hardened trim, the cracking that can be caused by impact of repeated valve closures and thermal shock should be considered.

7.1.8.6 Hydrocarbons and especially viscous or mixed hydrocarbons cannot cause as much damage to valves as can water. Because all cavitation damage prediction data use water, the calculations can be overly conservative for these classes of services.
7.1.8.7 Rotary-style valves should not be used in cavitating services or in erosive services. A rotary-style valve has a greater recovery factor, causing more intense cavitation, and directs the flow energy at the side of the pipe, which can cause the pipe to wear.

7.1.8.8 For cavitation and erosive services if tight shutoff is required, a separate ball valve should be considered.

7.2 Flashing and Erosion

7.2.1 Flashing

7.2.1.1 If the pressure of a liquid at its flowing temperature is reduced below its vapor pressure, vapor in the form of bubbles evolves from the liquid. If the downstream pressure in the valve does not recover, but remains below the liquid vapor pressure, a mixture of liquid and vapor can exit the valve. This event is called flashing.

7.2.1.2 If vapor continues to evolve to the point that flow becomes restricted or choked, further reduction in downstream pressure serves only to cause more vapor to evolve.

7.2.1.3 Increased differential pressure caused by the lower downstream pressure has no effect in accelerating flow through the valve after the effective, or allowable, differential pressure is reached.

7.2.1.4 To determine the capacity of the valve under these choked conditions, the allowable, not the actual, differential pressure should be used in the sizing formula.

7.2.2 Erosion

7.2.2.1 Erosion is caused by high-velocity flow, particles, and corrosion.

7.2.2.2 Because high-velocity flow is associated with flashing, flashing frequently causes erosion. Flashing tends to smoothly wear away the plug and seat material, causing leaky valves and changed flow characteristics.

7.2.2.3 Particles, especially hard particles, in the moving fluid can also cause erosion. Like flashing, the seat can wear, and worse, particles can erode away the body, causing loss of fluid.

7.2.2.4 For some corrosive fluid services, the type of metal used in the piping does not corrode because the metal forms a protective surface film. However, this film can be eroded away because of high flow velocity, exposing a fresh surface to the corrosive agent in the fluid. For example, carbon steel can be used for sulfuric acid service only if the velocity is kept low.

7.2.3 Outgassing

7.2.3.1 Outgassing is the release of gas that is dissolved or entrained in a liquid.

7.2.3.2 Characteristics of outgassing are as follows:
   a. Absorption of heat is not required.
b. Corresponding states does not apply.

c. MW (molecular weight) of gas phase not constant

7.2.3.3 Consequences of outgassing are as follows:

a. Gas can form more rapidly than flashing.
b. No meta-stable state - gas may be present at the vena contracta.
c. Damage can be more aggressive than flashing.
d. Greater velocities
e. Entrained particulate can increase wear on trim and valve outlet.
f. Excess vibration can wear out instrumentation and trim causing process upsets.

7.2.3.4 Valve selection attributes for outgassing are as follows:

a. Open, streamline flow passage
b. Minimizes erosion from vapor phase and possible entrained particulate
c. Protective outlet liner (venturi)
d. Maintainable and replaceable trim components

7.2.4 Mitigation Methods

7.2.4.1 To prevent erosion, incipient cavitation, corrosion, and flashing hardened trim should be selected, and a design with streamline flow, which prevents direct impingement upon the trim, body, or pipe, should be used. An angle valve with a venturi liner should be considered. If this design is used, the valve should not be greater than one size less than the downstream pipe. A minimum of 10 diameters of straight pipe should be provided downstream of the valve. This design focuses the energy down the center of the pipe. Increasing the size of the pipe and providing straight lengths allows time to dissipate the energy of the fluid from the valve.

7.2.4.2 Sacrificial downstream piping, hardened alloys, multistage pressure reduction, and special trim designs should also be considered for solving problems associated with flashing.

7.2.4.3 If a valve is controlling feed flow to a vessel, mounting the valve directly on a vessel flange should be considered. This configuration effectively eliminates the downstream piping.

7.2.4.4 Reducing the trim exit velocity to acceptable levels (i.e., 20 ft/second (6 m/sec)) if possible, helps eliminate problems associated with erosion.

7.2.4.5 The following are recommended minimum pressure drop limits versus material for erosive service:

a. 125 psi (8.6 bar) - 17-4 PH SS and No. 6 stellite
b. 150 psi (10.3 bar) - No. 6 Colmonoy®
c. 200 psi (13.8 bar) - 440-C SS

d. Greater than 200 psi (13.8 bar) - tungsten carbide

Comment: When in doubt contact the chosen control valve manufacturer for further guidance.

8. Noise Considerations

8.1 General

8.1.1 Noise prediction is a specialized study that typically requires the use of valve manufacturer prediction methods. The valve manufacturer or the facility owner’s noise control specialist should be consulted.

8.1.2 If the noise is greater than acceptable levels as specified in PIP PCSCV001, alternate methods of noise reduction should be evaluated, and the facility owner advised.

8.1.3 The owner should be notified if the calculated noise level exceeds a value of 85 dB(A) as specified on the purchaser’s PIP PCSCV001-D Data Sheet.

8.1.4 Valve manufacturers’ noise prediction calculations are typically accurate to within plus or minus 5 dB(A).

8.1.5 OSHA 1910.95 provides a formula that calculates acceptable exposure time to the different noise levels to which a person may be exposed during a shift. For example, the allowable noise exposure for 95 dBA is 4 hours. A 115-dBA exposure is the maximum allowable noise for 15 minutes.

8.1.6 Typically, states or local governments regulate the acceptable noise level at the plant fence line, which is much less than the acceptable limits within the plant (i.e., 70 dBA for adjoining industrial facility and 55 dBA for adjoining residential area).

8.1.7 The owner’s noise reduction strategy should be determined and incorporated into the selection of valves.

8.1.8 Acceptable noise level depends on the following:
   a. Facility owner’s location and standard noise limitation practices
   b. Proximity of valve to the fence line
   c. Proximity of valve to normally attended versus isolated area
   d. Frequency of use (e.g., continuous, less than once per year)

8.1.9 The maximum acceptable noise level is specified on the purchaser’s PIP PCSCV001-D Data Sheet. This value varies between facility owners and locations.

8.1.10 Valve noise levels consistently greater than 110 dBA should be avoided because valve failure can result.

8.2 Noise Reduction

8.2.1 If noise greater than acceptable levels for human exposure cannot be mitigated by adjusting the process or piping geometry, noise reduction trim should be used.
The application of anti-noise trim is the only method that can eliminate damaging noise at its source.

8.2.2 Anti-noise trims and silencers are susceptible to plugging in some process conditions. A strainer should be provided upstream of an anti-noise trim.

8.2.3 Other solutions to reduce excess noise, while possibly less effective or more costly, may include the following path treatment methods:
   a. Acoustic lagging - Noise can reappear downstream at next device.
   b. Pipe/valve insulation - Noise can reappear downstream at next device.
   c. Thicker pipe wall - Noise can reappear downstream at next device.
   d. Silencers (e.g., plates and diffusers) - Noise cannot reappear downstream at next device.
   e. Acoustic sheds - Noise can reappear downstream at next device.

8.2.4 For a point source, doubling the distance away from the noise source, results typically in 6 dBA less noise. For a line source, doubling the distance away from the noise, typically results in 3 dBA less noise.

8.2.5 Because diffusers work by absorbing some of the pressure drop, diffusers tend to work well at the maximum flow conditions. If diffusers are used, the maximum noise is often calculated at mid-range. Therefore, diffusers are acceptable only for applications with limited rangeability.

9. Actuators and Accessories

9.1 General

9.1.1 The guidelines in Section 9 apply to spring return, diaphragm, and spring return cylinder (i.e., piston) valve actuators.

9.1.2 Pneumatic spring and diaphragm actuators should not have force-multiplying linkages.

9.2 Sizing and Selection

9.2.1 Typically, valve actuators are sized and selected by the valve supplier or manufacturer.

9.2.2 Actuators should be sized in accordance with the control and shutoff requirements, given the minimum nominal air supply pressure available at the valve. In addition, air supply pressure at the owner’s facility should be confirmed and regulated to prevent exceeding torque, thrust, and case pressure specifications.

9.2.3 Actuators that are infrequently stroked through their entire range can develop stem-packing friction problems. Additional packing friction force should be considered for these applications.

9.2.4 Actuator design should ensure shutoff capability under conditions of maximum differential pressure including abnormal conditions (e.g., start-up, shutdown, and steam-out). In some applications, the actuator needs to be sized to shut off in the
reverse flow direction. This requirement should be identified and considered in the valve design also.

9.2.5 Typically, both diaphragm-type and cylinder-type actuators should be provided with positioners. Piston-type actuators should always be provided with a positioner. However, positioners by themselves may not be suitable for fast processes (e.g., compressor surge control). For fast processes, pneumatic boosters may be required to provide the necessary actuator air volume and pressure. Typically, slow processes or processes requiring control with a wide proportional band (i.e., low gain) benefit from a positioner.

9.2.6 Diaphragm actuators typically have the following advantages:
   a. More widely used than cylinder types
   b. Wide range of adaptability to various valve sizes
   c. Available from various manufacturers
   d. Less expensive than cylinder types of comparative size

9.2.7 Because of their higher cylinder pressure ratings, cylinder actuators can accept higher instrument air pressure and can generate greater thrust than comparably sized diaphragm types. This can be a significant advantage if high thrust forces are needed because a diaphragm actuator, having comparable thrust capability, is typically larger and heavier.

9.2.8 If valves are in services that can cause a control valve stem to stick, the actuator should be sized using a 1.25 design factor as a minimum.

9.3 Actuator Forces

9.3.1 The actuator should be designed to balance the sum of the forces that act on the actuator including the following:
   a. Forces exerted on the plug by the process medium
   b. Spring forces required to stabilize the plug
   c. Seat load force exerted by the spring to close the valve tightly
   d. Seat load force exerted by the spring to position the plug in its fail-safe position
   e. Force required to overcome stem-packing friction

9.3.2 The process fluid exerts a force on the plug that tends to either open or close the valve, particularly for an unbalanced plug. The amount of unbalanced force that exists because of differential pressure across the plug is termed “static unbalance.”

9.3.3 Seat Load Forces

9.3.3.1 Seat load, the force necessary to provide valve shutoff, is dependent on valve port size and shutoff classification.

9.3.3.2 Seat loading should be in accordance with FCI 70-2 leakage criteria.

9.3.3.3 The valve manufacturer’s recommended seat load should be used to achieve the leakage class.
9.3.3.4 Table 4 provides nominal seat loadings to ensure repeatable tight shutoff for each seat leakage classification.

**Table 4. Nominal Seat Loading versus Leakage Class**

<table>
<thead>
<tr>
<th>Leakage Class</th>
<th>Nominal Port Size &lt;5 inches</th>
<th>Nominal Port Size &gt;5 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>10 lb/linear inch</td>
<td>10 lb/linear inch</td>
</tr>
<tr>
<td>Class II</td>
<td>20 lb/linear inch</td>
<td>20 lb/linear inch</td>
</tr>
<tr>
<td>Class III</td>
<td>40 lb/linear inch</td>
<td>40 lb/linear inch</td>
</tr>
<tr>
<td>Class IV metal seats</td>
<td>50 lb/linear inch</td>
<td>80 lb/linear inch</td>
</tr>
<tr>
<td>Class IV soft seats</td>
<td>50 lb/linear inch</td>
<td>50 lb/linear inch</td>
</tr>
<tr>
<td>Class V metal seats</td>
<td>250 lb/linear inch</td>
<td>400 lb/linear inch</td>
</tr>
<tr>
<td>Class V soft seats</td>
<td>50 lb/linear inch</td>
<td>50 lb/linear inch</td>
</tr>
<tr>
<td>Class VI soft seats</td>
<td>50 lb/linear inch</td>
<td>100 lb/linear inch</td>
</tr>
<tr>
<td>Class VI metal seats</td>
<td>300 lb/linear inch</td>
<td>300 lb/linear inch</td>
</tr>
</tbody>
</table>

Note: 
Seat load = seating force/port circumference.

9.3.3.5 Seat ring circumference is defined as the line of contact between the plug and the seat with the valve in the fully closed position.

9.3.4 **Friction Forces**

9.3.4.1 Friction between the packing and stem should be considered in sizing the actuator.

9.3.4.2 Friction force varies with the diameter of the stem, the type and style of packing, and the fluid characteristics.

9.3.4.3 Viscous and sticky fluids increase the packing friction forces and affect the actuator force requirement.

9.3.4.4 Graphite packing has a much greater friction load than tetrafluoroethylene (TFE) and other elastomers. Graphite also tends to bind to the stem if the stem is not moved for a long time. Therefore, graphite packing should be used only in applications exposed to high temperatures and if fire-safe applications are required.

9.3.5 **Dynamic Forces**

9.3.5.1 The actuator should be designed to compensate for the various dynamic forces acting on the control valve plug, and the effects of these forces should be considered in the various sizing methods provided by the valve supplier.

9.3.5.2 This Section discusses the dynamic forces that act on various types of valve and diaphragm actuator combinations.

9.3.5.3 An actuator bench setting is the instrument air pressure required, in the absence of service process pressure, to begin moving the stem and to fully stroke the actuator over its entire range. Bench settings are adjustments made to the actuator spring if the valve is out of service or “on the bench.” These settings are applied by adjusting the spring...
compression to compensate for the process pressures that can act on the plug area.

9.3.5.4 For an air-to-close actuator on a flow-to-open valve, both the actuator spring force and the force of the fluid against the plug are additive and are opposed by the force provided by the diaphragm case pressure. Normally the actuator is bench-set to begin moving the plug at the minimum input signal from the controller or positioner (typically 3 psi or 6 psi, (.2 bar or .4 bar). If the plug forces are large, a positioner may be required to provide the force required for complete shutoff. This type of control valve opens on loss of diaphragm case pressure (i.e., fails open).

9.3.5.5 For an air-to-close actuator with a flow-to-close valve, the dynamic plug forces oppose the actuator spring force and are additive to the diaphragm case pressure. This control valve configuration tends to be unstable and should be avoided.

9.3.5.6 For an air-to-open actuator with a flow-to-open valve, the diaphragm case pressure and plug forces are additive and oppose the actuator spring force. Typically, higher bench pressure settings are required to ensure adequate shutoff. This valve and actuator combination fails closed, assuming an adequate bench set, and requires a bench pressure setting greater than 3 psi (.2 bar) to unseat the valve.

9.3.5.7 For an air-to-open actuator with a flow-to-close valve, the process pressure on the plug and spring forces are additive and in opposition to the diaphragm force. The actuator air pressure requires less force to unseat the valve while on the bench than in service. The amount of bench-set force applied to the spring should be reduced by the plug force exerted by the process. For this actuator, the spring force becomes less as the plug approaches the seat. The reduced actuator stiffness can cause valve instability in the low lift operation region.

9.3.5.8 A rotary valve actuator applies force through a lever to exert torque on the plug, disk, or ball. Major rotary valve torque components are break-away and dynamic torque.

9.3.5.9 Break-away torque is the torque required to move the disk from its closed, fully seated position. Break-away torque is a function of seating friction and can be significant for elastomer-lined valves.

9.3.5.10 Dynamic torque is determined by applying manufacturer-specific factors to the valve differential pressure at selected valve openings. Torque requirements should be checked at appropriate angles of rotation from nearly closed to fully open. Dynamic torque is a direct function of the effective differential pressure at the various angles of valve rotation.

9.3.5.11 The total torque requirement is the sum of the break-away and dynamic torques. Determining rotary valve torque requirements involves highly valve-specific sizing procedures. Therefore, calculations should be performed in consultation with the valve supplier or manufacturer.
9.4 Positioners and Accessories

9.4.1 Electronic Components

9.4.1.1 Positioners, solenoid valves, limit switches and all other electronic components should be approved for the electrical area classification requirements by the appropriate governing agencies.

9.4.1.2 All electronic components should be able to withstand electromagnetic interference for the wiring method used (e.g., open wiring versus conduit systems).

9.4.1.3 Intrinsically safe rated instrumentation should be approved by the facility owner.

9.4.2 Positioners

9.4.2.1 A well-tuned positioner with zero slop linkage and correctly sized actuator is required for accurate control of the valve.

9.4.2.2 To achieve the economic benefit of control strategies available with distributed control, the ability to make small movements of the valve position with minimal dead band is critical. Therefore, positioners should be the default choice provided for valves tied to a distributed control system.

9.4.2.3 Valves with piston operators normally require full system pressures of 60 to 100 psig (4.2 to 6.9 bar). All piston actuators and diaphragm actuators in throttling service should be provided with a positioner. A filter regulator should be provided upstream of all positioners.

9.4.2.4 Electronic input positioners should be used instead of positioners that accept a pneumatic signal. Digital positioners (e.g., HART, Fieldbus, etc.) provide capability for valve diagnostics that are not available with analog electronic positioners.

9.4.2.5 ISA 75.25 provides a guide and specification to set dead band and response time requirements. ISA 75.25 also includes measurement techniques for dead band and response time. The valve specification should identify special dead band, response time, and testing requirements for valves that require a high degree of performance. Valves expected to have a large impact with small movements (e.g., liquid pressure control) should be designed in accordance with ISA 75.25.

9.4.3 Boosters

9.4.3.1 Boosters are one-to-one self-contained regulators that are used to increase the speed of a control valve by providing large air volumes.

9.4.3.2 Boosters are selected to provide the required capacity to stroke the valve in the required time.

9.4.3.3 If a piston actuator needs air on each side of the piston to operate (typically referred to as double acting), two boosters are required.
9.4.3.4 For applications requiring large step changes in the valve travel within short periods (e.g., compressor recycle valve for surge control), a positioner with volume boosters should be used. If the positioner is not used, accurate control is not possible during recycle operation after the quick stroke has occurred. The pneumatic boosters are required to provide necessary actuator air volume and pressure around the positioner. Oversized tubing, fittings, filters, and air regulators should also be provided. The valve stroking time should be consistent with the valve supplier’s and surge control requirements. The valve performance should be tested at the valve supplier’s shop.

9.4.3.5 The following guidelines should be used to achieve the stroking times shown:

a. For a 2-second full stroke, use volume booster, larger tubing, and quick exhaust relays.

b. For a 1-second full stroke, use volume boosters, larger tubing, and quick exhaust relays. For certain applications and with valve manufactures confirmation, failure direction can be accomplished by using a volume tank with trip and lock-up pneumatic relays.

9.4.4 Limit Switches

9.4.4.1 Valve position switches should be proximity type, enclosed in watertight dust-proof housings with terminal strips for wire connections as a minimum.

9.4.4.2 Most positioners provide a continuous signal of the valve-position feedback (e.g., HART, Fieldbus).

9.4.5 Solenoid Valves

9.4.5.1 Solenoid valves are used to force the valve to a specified position.

9.4.5.2 A solenoid valve should be the last device tied to the actuator to directly vent the air off the actuator.

9.4.5.3 Solenoid valves should be installed between the positioner and the actuator to eliminate the positioner as a source of failure.

9.4.5.4 The port size and tubing should be sized to trip the valve within the specified time.

9.4.5.5 If the solenoid valve is 24 VDC, a “low-powered” solenoid valve should be used so that the wiring used for loop-powered instruments can also be used for the solenoid valve. To provide the necessary force to move the spool, these valves typically require an auxiliary air supply to the pilot valve.

9.4.5.6 Pilot operated valves require a minimum differential pressure across the valve to operate.

9.4.6 Position Indication

9.4.6.1 Position transmitter should be approved for the electrical area classification requirements by the appropriate governing agencies.
9.4.6.2 A position transmitter may be used to provide a continuous feedback of valve position. Position transmitters are devices that are mechanically connected, or linkless (Hall Effect) to the valve stem or shaft and generate and transmit a 4 – 20 mA electrical signal representing the valve position.

10. Valve Shipping and Storage

10.1 Valves should be shipped with all valve openings (e.g., process, electrical, air) sealed.

10.2 Valves should be stored in an enclosed building that cannot flood and that provides protection from rain, blown dust, mud, etc. Climate control should not be required.

11. Valve Installation

11.1 Control valve installations should be in accordance with PIP PCCGN002.

11.2 Control valve installations should be accessible from grade or platform to aid in operation and maintenance. Valves with handwheels or bypass manifolds should be readily accessible either from grade or a permanent platform.

11.3 Special care should be taken with the piping for high-recovery valves (i.e., \( Cd > 20 \times \frac{C_v}{D^2} \)), especially butterfly and other rotary valves. The capacity of high-recovery valves can be significantly decreased by reducers and elbows near the valve ports. Further, butterfly valves and valves of similar design can require a larger actuator if installed just downstream of an elbow.

11.4 Bypass Manifolds

11.4.1 Bypass manifolds should be identified on the Piping and Instrumentation Diagrams. Bypass manifolds can affect control valve performance.

11.4.2 Bypass manifolds should not be provided in highly reactive chemical services if inadvertent valve leakage can result in an undesirable event (e.g., backflow contamination).

11.4.3 Bypass manifolds should be provided if the process cannot be shut down for repair or replacement of the valve.

11.4.4 Bypass manifolds should not be provided if manual control is impossible or if the bypass line cannot be kept in service (e.g., in slurry service, which can plug stagnant lines).

11.4.5 Manual throttle valves should be selected for control valve bypass manifolds to provide approximately the same capacity and trim characteristics as those of the control valves that they bypass.

11.4.6 Block valves used in manifolds with low-recovery control valves should have the same body size as the control valve unless known expansions or uncertain operating conditions dictate the use of line-sized valves.

11.4.7 For severe services, consideration should be given to installing redundant control valves in parallel.
11.4.8 If a bypass valve manifold is not provided, a handwheel should be specified for manual operation. Handwheels should not be used on control valves with solenoid valves.

11.5 Control Valve Piping

11.5.1 Because ports in valves with cavitation or noise reduction trim are typically less than 1/4 inch (6 mm) in diameter, an upstream strainer should be provided.

11.5.2 Bypass manifolds, if required, should be arranged to prevent the accumulation of dirt or other solids in stagnant lines.

11.5.3 Sufficient block, vent, and drain valves should be installed to enable removal of the control valve.

11.5.4 Piping should be designed to prevent accumulation of water, which can freeze. Typically, the bypass should be placed above the control valve.