

Refinery Valves and Accessories for Control and Safety Instrumented Systems

API RECOMMENDED PRACTICE 553
SECOND EDITION, OCTOBER 2012



AMERICAN PETROLEUM INSTITUTE

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Downstream Segment

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Contents

Page

1	Scope	1
2	Normative References	1
3	Terms and Definitions	3
4	Control Valves	8
4.1	General	8
4.2	Valve Body	8
4.3	Valve Actuators	23
4.4	Valve Positioner	27
4.5	Handwheels	29
4.6	Switches and Solenoids	30
4.7	Volume Boosters/Quick Exhaust Vents/Air Locks	31
5	Specific Criteria	32
5.1	Globe-Style Valves	32
5.2	Rotary Style Valves	33
5.3	Specialty Valves—High Pressure Drop and Particle Applications	35
5.4	Control Valve Performance	36
5.5	High Performance Control Valves	38
5.6	Material Considerations for Control Valves in Refining Processes	39
6	Installation/Inspection/Testing	43
6.1	Accessibility	43
6.2	Location	43
6.3	Control Valve Manifolds	45
6.4	Inspection and Testing	45
7	Refinery Applications	47
7.1	Introduction	47
7.2	Atmospheric Distillation—(Typical)	47
7.3	Vacuum Distillation—(Typical)	53
7.4	Fluid Catalytic Cracking (FCCU)—(Typical)	57
7.5	Catalytic Reformer—(Typical)	65
7.6	Hydrocracker—(Typical)	69
7.7	Hydrotreater—(Typical)	74
7.8	Delayed Coker—(Typical)	78
7.9	Gas Plant—(Typical)	82
7.10	Alkylation Unit—(Typical)	86
7.11	Sulfur Recovery Unit—(Typical)	90
8	Emergency Block Valves	94
8.1	EBV General Installation Guidelines	94
8.2	Actuator Selection	95
8.3	Fireproofing	96
8.4	Control Stations	97
9	Safety Instrumented System (SIS) Valves	97
10	Vapor Depressurizing Valves	101
10.1	General	101
10.2	Depressuring Valves and Actuator Requirements	102

Contents

	Page
11 Hydraulic Slide Valve Actuators	102
11.1 General	102
11.2 Hydraulic Power Unit (HPU)	103
11.3 Slide Valve Positioner Systems	104
11.4 Instrumentation Required	105
11.5 Performance Characteristics	107
11.6 Electrical Requirements	107
11.7 Testing and Inspection	107
11.8 Slide Valve Actuator Service	108
Bibliography	109
Figures	
1 Typical Control Valve Components	9
2 Typical Live-loaded Packing Arrangement	12
3 Resilient Seat	13
4 Inherent Valve Characteristics	14
5 Characterized Cages for Globe-style Valve Bodies	14
6A Sliding Stem Motion Valve	15
6B Rotary Motion Valve	15
7 Effect of Valve Style on Control Range	16
8 Typical System Head—Capacity Relationship	18
9 Pressure-drop through a Restriction	19
10 Cavitation Damage to Valve Plug	19
11 Cavitation Damage to Seat Ring	19
12 Flashing Damage	20
13A Slotted Noise Abatement Trim	22
13B Stacked Disc Design Cage	22
14 Diaphragm Actuator	23
15 Double-Acting Spring Return Piston	25
16 Electrohydraulic Actuator	26
17 Electrohydraulic Actuator Schematic	26
18 Conventional Valve Positioner	28
19 Smart Valve Positioner	28
20 Top Mounted Handwheel	29
21 Side Mounted Handwheel	29
22 Cam-operated Limit Switch	30
23 Beacon Type Limit Switch Housing	30
24 Proximity Switches	30
25 Single-ported Globe Valve	32
26 Double-ported Globe Valve	32
27 Lugged-style Butterfly Valve	33
28 Wafer-style Butterfly Valve	34
29 Typical Wafer-style (flangeless) Valve Installation	34
30 Multi-stage Valve	35
31 Angle Valve	35
32 Typical Control Valve Manifold	44
33 Atmospheric Distillation Simplified Flow Diagram	48
34 Vacuum Distillation Simplified Flow Diagram	54

Contents

Page

35A	Fluid Catalytic Cracking (FCCU)—Reactor Section Simplified Flow Diagram	57
35B	Fluid Catalytic Cracking (FCCU)—Fractionator Section Simplified Flow Diagram	58
35C	Fluid Catalytic Cracking (FCCU)—Vapor Recovery Section Simplified Flow Diagram	58
36	Catalytic Reformer Simplified Flow Diagram	66
37	Hydrocracker Simplified Flow Diagram	70
38	Hydrotreater Simplified Flow Diagram	75
39	Delayed Coker Simplified Flow Diagram	78
40	Gas Plant Simplified Flow Diagram	82
41	Sulfuric Acid Alkylation Unit Simplified Flow Diagram	86
42	Sulfur Recovery Unit Simplified Flow Diagram	90
43	1 out-of 1 SOV Arrangement (1oo1)	99
44	2 out-of 2 SOV Arrangement (2oo2)	99
45	Generic 2 out-of 3 SOV Arrangement (2003)	100
46	Typical Slide Valve Installation.	103
47	Typical HPU Unit	104

Tables

1	Material Designations for High Nickel Alloys.	39
2	Valve Sizing Data for Unit Feed Valve	49
3	Valve Sizing Data for Fuel Gas to Furnace	49
4	Valve Sizing Data for Heavy Bottoms Valve	50
5	Valve Sizing Data for Reflux Valve.	51
6	Valve Sizing Data for Stripping Steam Valve	52
7	Valve Sizing Data for Feed Pump Recirculation Valve	52
8	Valve Sizing Data for Charge Heater Pass Feed Valve	53
9	Valve Sizing Data for Resid Bottoms Valve	55
10	Valve Sizing Data for Top Pumparound Valve	56
11	Valve Sizing Data for Stripping Steam Valve	56
12	Valve Sizing Data for Charge Oil Valve	59
13	Valve Sizing Data for Spill Back Valve.	60
14	Valve Sizing Data for Heater Fuel Gas Valve	60
15	Valve Sizing Data for Inlet Air to Regenerator Valve	61
16	Valve Sizing Data for Inlet Air to Atmosphere Valve	62
17	Valve Sizing Data for Stripping Steam Valve	63
18	Valve Sizing Data for Steam to Reactor Valve	63
19	Valve Sizing Data for Bottoms Circulation Valve	64
20	Valve Sizing Data for Debutanizer Bottoms Valve	65
21	Valve Sizing Data for Reactor Feed Valve.	66
22	Valve Sizing Data for Recycle Hydrogen Valve	67
23	Valve Sizing Data for Net Hydrogen Valve	68
24	Valve Sizing Data for Separator Valve	69
25	Valve Sizing Data for Hydrocracker Feed Valve.	69
26	Valve Sizing Data for Reactor Letdown Valve	71
27	Valve Sizing Data for Hot Separator Valve	72
28	Valve Sizing Data for Cold Separator Valve	73
29	Valve Sizing Data for Hydrogen Quench Valve	74
30	Valve Sizing Data for Hot High Pressure Separator Valve	74
31	Valve Sizing Data for Compressor Recycle Valve	76
32	Valve Sizing Data for Depressurizing Valve	77

Contents

	Page
33 Valve Sizing Data for Quench Gas Valve	77
34 Valve Sizing Data for Unit Feed Valve	79
35 Valve Sizing Data for Furnace Feed Valve	80
36 Valve Sizing Data for Heavy Coker Gas Oil Valve	81
37 Valve Sizing Data for Reflux Valve	81
38 Valve Sizing Data for Lean Sponge Oil Valve	83
39 Valve Sizing Data for Sponge Absorber Overhead Valve	83
40 Valve Sizing Data for Absorber Deethanizer Bottoms Valve	84
41 Valve Sizing Data for Debutanizer Bottoms Valve	85
42 Valve Sizing Data for Debutanizer Reboiler Steam Valve	85
43 Valve Sizing Data for Alky Feed Valve	87
44 Valve Sizing Data for Makeup Acid Feed Valve	87
45 Valve Sizing Data for Caustic Wash Valve	88
46 Valve Sizing Data for Wash Water Valve	89
47 Valve Sizing Data for Acid Gas Valve	91
48 Valve Sizing Data for Fuel Gas Valve	91
49 Valve Sizing Data for Oxygen Valve	92
50 Valve Sizing Data for Combustion Air Valve	93
51 Valve Sizing Data for Sulfur Valve	93
52 Typical SIS Valve Response Times versus Body Size (from API RP 556 Second Edition)	98
53 Example of a Slide Valve Data Sheet	108

Refinery Valves and Accessories for Control and Safety Instrumented Systems

1 Scope

1.1 This recommended practice (RP) addresses the special needs of automated valves in refinery services. The knowledge and experience of the industry has been captured to provide proven solutions to well-known problems.

1.2 This document provides recommended criteria for the selection, specification, and application of piston (i.e. double-acting and spring-return) and diaphragm-actuated (spring-return) control valves. Control valve design considerations are outlined such as valve selection, material selection, flow characteristic evaluation, and valve accessories. It also discusses control valve sizing, fugitive emissions, and consideration of the effects of flashing, cavitation, and noise.

1.3 Recommendations for emergency block and vent valves, on/off valves intended for safety instrumented systems, and special design valves for refinery services, such as Fluid Catalytic Cracking Unit (FCCU) slide valves and vapor depressurizing systems, are also included in this recommended practice.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Publication 2218, *Fireproofing Practices in Petroleum and Petrochemical Processing Plants*

API Recommended Practice 521, *Guide for Pressure-Relieving and Depressurizing Systems*

API Recommended Practice 556, *Instrumentation, Control and Protective Systems for Gas Fired Heaters*

API Standard 598, *Valve Inspection and Testing*

API Specification 6FA, *Specification for Fire Test for Valves*

API Standard 607, *Fire Test for Soft-Seated Quarter-Turn Valves*

API Standard 608, *Metal Ball Valves – Flanged, Threaded and Butt Welding Ends*

API Standard 609, *Butterfly Valves: Double Flanged, Lug-and Wafer-Type*

ANSI, B16.34 ¹, *Valves—Flanges, Threaded, and Welded End*

ANSI 70, *National Electrical Code*

ANSI/FCI70-2 ², *Quality Control Standard for Control Valve Seat Leakage*

ASME *Boiler and Pressure Vessel Code* ³, *Section VIII, Div. 1, International Society for Measurement and Control Standard S75 Series of Control Valve Standards*

¹ American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, New York 10036, www.ansi.org.

² ANSI/Fluid Controls Institute, Inc., 1300 Sumner Avenue, Cleveland, Ohio, 44115, www.fluidcontrolsintstitute.org.

³ ASME International, 3 Park Avenue, New York, New York 10016-5990, www.asme.org.

ASME Boiler and Pressure Vessel Code, Part U-1, Section VIII, Division 1 (3.2.6.4)

EPA, US Code Title 42 Chapter 85 ⁴, *National Emission Standard for Hazardous Air Pollutants (NESHAP)*

IEC 60534-2-1 ⁵, *Flow Capacity – Sizing Equations for Fluid Flow Under Installed Conditions*

IEC 61511, *Functional Safety – Safety Instrumented Systems for the Process Industry Sector Parts 1-4*

ISA Control Valve Standard 75.01.01 ⁶, *Flow Equations for Sizing Control Valves*

ISA Control Valve Standard 75.02, *Control Valve Capacity Test*

ISA Control Valve Standard 75.17, *Control Valve Aerodynamic Noise Prediction*

ISA Control Valve Standard 75.08.01, *Face to Face Dimensions for Integral Flanged Globe Style Control Valve Bodies (Classes 125, 150, 250, 300, and 600)*

ISA Control Valve Standard 75.08.02, *Face to Face Dimensions for Flangeless Control Valves (Classes 150, 300, and 600)*

ISA Control Valve Standard 75.08.06, *Face to Face Dimensions for Flanged Globe Style Control Valve Bodies (Classes 900, 1500, and 2500)*

ISA Control Valve Standard 75.08.07, *Face to Face Dimensions for Separable Flanged Globe Style Control Valves (Classes 150, 300, and 600)*

ISA Control Valve Standard 75.25.01, *Test Procedure for Control Valve Response Measurement from Step Inputs*

MSS SP-25 ⁷, *Standard Marking System for Valves, Fittings, Flanges, and Unions*

NACE Standard MR0103 ⁸, *Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments*

NACE Publication 34103, *Overview of Sulfidic Corrosion in Petroleum Refining*

NACE Standard RP0170, *Protection of Austenitic Stainless Steels and Other Austenitic Alloys from Polythionic Acid Stress Corrosion Cracking During Shutdown of Refinery Equipment*

NACE Standard MR0175, *Petroleum and Natural Gas Industries - Materials for Use in H₂S-containing Environments in Oil and Gas Production – Parts 1, 2, and 3*

NACE RP0472, *Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments*

OSHA 1910.95 ⁹, *Occupational Noise Exposure*

⁴ U.S. Environmental Protection Agency, Ariel Rios Building, 1200 Pennsylvania Avenue, Washington, DC 20460, www.epa.gov.

⁵ International Electrotechnical Commission, 3, rue de Varembé, P.O. Box 131, CH-1211, Geneva 20, Switzerland, www.iec.ch.

⁶ International Society of Automation, 67 Alexander Drive, Research Triangle Park, North Carolina, 22709, www.isa.org.

⁷ Manufacturers Standardization Society of the Valve and Fittings Industry, Inc., 127 Park Street, NE, Vienna, Virginia 22180-4602, www.mss-hq.com.

⁸ NACE International (formerly the National Association of Corrosion Engineers), 1440 South Creek Drive, Houston, Texas 77218-8340, www.nace.org.

⁹ U.S. Department of Labor, Occupational Safety and Health Administration, 200 Constitution Avenue, NW, Washington, D.C. 20210, www.osha.gov.

3 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.1

actuator

A pneumatic, hydraulic, or electrically powered device used to supply force and motion to open or close a valve.

3.2

bonnet

That portion of the valve that contains the packing box and stem seal. It also can guide the stem. It provides the principle opening to the body cavity for assembly of internal parts.

3.3

cavitation

Is a two-stage continuous phenomenon, the first stage of which is formation of vapor bubbles within the liquid state due to the pressure at the vena contracta being equal to or below the liquid's vapor pressure. The second stage is the collapse or implosion of these bubbles back into the all liquid state as the pressure recovers at the outlet (see Figure 9 for illustration).

3.4

choked flow

Is a condition at constant inlet pressure for which no increase in flow rate is achieved for a decrease in downstream pressure.

3.5

control valve signature

Is a test that measures the position of an actuator (or actuator valve opening) against an input to the valve, such as an actuator pressure or control signal. From this information, a graphical representation (i.e. signature) is produced that depicts valve performance. Some valve performance characteristics that can be determined from a valve signature test could include, but are not limited to, valve friction, actuator torque, dead band and shutoff capability as well as actuator spring rate and bench set. Valve signatures are usually performed when a valve is new to get an initial benchmark of a valve's performance out of the factory. However, valve signatures are not limited to the factory environment. They can also be performed in the field as a predictive tool in assessing whether a valve has performance issues, possibly requiring it to be rebuilt during a unit turnaround.

3.6

dead band

The range an input signal can be varied without initiating an observable change in the output signal. Dead band is the name given to a general phenomenon that can apply to any device.

3.7

dead time

The time interval in which no response of the system is detected following a small (usually 0.25 % to 5 %) step input.

3.8

dynamic time

A measure of how long the actuator takes to get to the T63 (63 %) point once it starts moving.

3.9

emergency block valves

EBVs

Emergency block valves are designed to control a hazardous incident. These are valves for emergency isolation and are designed to stop the uncontrolled release of flammable or toxic materials. These valves should be fire-safe, if they

are within the fire zone. The valves may be referred to as type A, B, C, and D. Refer to their individual definitions within this section.

3.10

equal percentage

An inherent flow characteristic that, for equal increments of rated travel, will ideally give equal percentage changes of the flow coefficient (C_v).

3.11

fail-closed

A condition where-in the valve closure member moves to a closed position when the actuating energy source (air or signal) fails or is lost.

3.12

fail-open

A condition where-in the valve closure member moves to a open position when the actuating energy source (air or signal) fails or is lost.

3.13

fail-safe

A characteristic of a valve and its actuator which upon a loss of actuating energy supply (air or signal) will cause a valve to move to be fully closed, fully open, or remain in its last position, whichever position is defined as necessary to protect the process.

3.14

fire zone

This is an area which is unsafe to enter during an emergency situation. The area is considered to be within a 7.6 m (25 ft) radius minimum surrounding the leak source.

3.15

flammable materials

Low flash liquids [flash point below 38 °C (100 °F)] and high flash liquids [flash point 38 °C (100 °F) or higher] when handled at temperatures above or within 8 °C (46 °F) of their flash points.

3.16

flashing

Is a similar concept to Cavitation, except pressure recovery at the valve outlet remains equal to or below the vapor pressure (see Figure 9 for illustration).

3.17

flow characteristic

Relationship between flow through the valve and percent rated travel as the latter is varied from 0 % to 100 %.

3.18

flow coefficient

C_v

A constant (C_v) related to the geometry of a valve, for a given travel, that can be used to establish flow capacity. It is the number of US gallons per minute of 15 °C (60 °F) water that will flow through a valve with a one pound per square inch pressure drop.

3.19

friction

A force that tends to oppose the relative motion between two surfaces that are in contact with each other.

3.20**globe valve**

A valve with linear or rotary motion closure member, one or more ports, and a body distinguished by a globular shaped cavity around the port region. Globe valves can be further classified as: two-way single-ported; two-way double-ported; angle-style; three-way; unbalanced and balanced.

3.21**hysteresis**

During a calibration cycle, the maximum difference in output value for any single input value, excluding errors due to dead band.

3.22**inherent characteristic**

The relationship between the flow coefficient and the closure member (e.g. plug, ball or disk) as it is moved from the closed position to rated travel with constant pressure drop across the valve. Typically these characteristics are plotted on a curve where the horizontal axis is labeled in percent travel and the vertical axis is labeled as percent flow (or C_v). Because valve flow is a function of both the valve travel and the pressure drop across the valve, conducting flow characteristic tests at a constant pressure drop provides a systematic way of comparing one valve characteristic design to another. Typical valve characteristics conducted in this manner are named Linear, Equal-Percentage, and Quick Opening.

3.23**linear characteristic**

An inherent flow characteristic that can be represented by a straight line on a rectangular plot of flow coefficient (C_v) versus rated travel.

3.24**noise**

Unwanted sound that takes two forms, Aerodynamic (conversion of mechanical energy of flow into acoustic energy as fluid passes through valve) and Hydrodynamic (energy caused by cavitation and flashing of a liquid fluid as it passes through valve).

3.25**packing box**

A sealing system consisting of deformable material contained in a gland that usually has an adjustable compression means to obtain or maintain an effective seal. Commonly used to seal against leakage to outside the valve body during valve disk or stem movements.

3.26**partial stroke testing****PST**

Is a technique used in a safety instrumented system to allow the user to test a percentage of the possible failure modes of a valve without the need to physically close the valve all the way.

3.27**positioner**

A controller (servomechanism) that is mechanically connected to a moving part of a final control element or its actuator and that automatically adjusts its output to the actuator to maintain a desired position in proportion to the input signal.

3.28**process variability**

A precise statistical measure of how tightly the process is being controlled about the set point. Process variability is defined in percent as typically $(2\sigma/m)$, where σ the standard deviation of the process variable and m is the set point or mean value of the measured process variable.

3.29**quick opening characteristic**

An inherent flow characteristic in which a maximum flow coefficient (C_v) is achieved with minimal valve travel.

3.30**rangeability**

The ratio of the largest flow coefficient (C_v) to the smallest flow coefficient (C_v) for a given valve type.

3.31**rotary control valve**

A valve style that uses a flow closure member (full ball, partial ball, disk, or plug) rotating in the flow stream to control the capacity of the valve.

3.32**safety critical service**

A system composed of sensors, a logic solver, and final control elements for the purpose of taking the process to a safe state when predetermined process conditions are exceeded.

3.33**safety instrumented function****SIF**

An action with a specified safety integrity level, and whose purpose is to provide a certain amount of safety risk reduction.

3.34**safety integrity level****SIL**

Are categories based on the probability of failure on demand (PFD) of a Safety Instrumented Function. There are four levels of Safety Integrity, SIL 1, SIL 2, SIL 3, and SIL 4. Refer to IEC61511 for further details.

3.35**safety instrumented system****SIS**

A system composed of sensors, a logic solver, and final control elements for the purpose of taking the process to a safe state when predetermined process conditions are exceeded.

3.36**seat**

The area of contact between the closure member and its mating surface that establishes valve shut-off.

3.37**seat leakage**

In the fully closed position the quantity of fluid passing through a valve with pressure differential and temperature.

3.38**servo**

A control system which is used to convert a small mechanical motion into one that requires much greater power.

3.39**severe service**

Process conditions that result in cavitation, flashing, highly cyclic operations, erosive conditions, and/or high differential pressure.

3.40**T63**

The time measured from initiation of the input signal change to when the output reaches 63 % of the corresponding change. It includes both the valve assembly dead time, which is a static time, and the dynamic time of the valve assembly.

3.41**toxic material**

A liquid or vapor that can cause damage to humans and for which an exposure limit [either Material Threshold Limit Value (TLV) or Occupational Exposure Limit (OEL)] has been established by a relevant regulatory agency (e.g. the US EPA). These substances may cause significant negative impact (e.g. severe inflammation, shock, collapse, or even sudden death) if humans are exposed to sufficiently high concentrations for a sufficiently long period of time. Some examples include but are not limited to: Benzene, Xylene, Butadiene, Chlorine, Ammonia, Hydrogen Sulfide, and Hydrogen Fluoride.

3.42**trim**

The internal components of a valve exposed and in contact with the line medium, usually consisting of but not limited to the seat ring, valve stem, valve plug, ball or disk, guide bushing, and cage.

3.43**Type A EBV**

A manually operated fire-safe block valve installed at the equipment. This type of valve is installed when ignition is not expected in the event of a leak.

3.44**Type B EBV**

This fire-safe block valve should be installed at a minimum of 7.6 m (25 ft) from the leak source when ignition is expected. The Type B valve is manually operated and is limited to sizes up to and including DN 200 (8 in.), and pressure classes through ANSI CL300. For reasons of access, the valve should be accessible from ground, or if ground access is not practical, then the valve should be accessible via a platform installed no higher than 4.6 m (15 ft) above grade.

3.45**Type C EBV**

The Type C valve is a power-operated Type B valve. The valve should be power-operated if larger than DN 200 (8 in.) or if a pressure class higher than ANSI CL300 is needed. The valve should be installed outside the fire zone a minimum of 7.6 m (25 ft) from the leak source and no higher than 4.6 m (15 ft) above grade. Controls are accessible from the valve location.

3.46**Type D EBV**

This is an EBV with remote controls. There is no restriction as to where the valve may be located, but the controls should be a minimum of 12 m (40 ft) from the leak source and should be out of the fire zone. An EBV installed at an elevation greater than 4.6 m (15 ft) above grade will also come under this category. Both the actuator and that portion of the control cable and tubing which is in the fire zone should be fireproofed or designed to operate without failure during fire conditions. Specify that the conduit/tubing/cable supports are required to be fireproofed.

3.47**valve response time**

A time usually measured by a parameter that includes both dead time and time constant. (See definitions for T63, and Dead Time.) When applied to the valve, it includes the entire valve assembly.

3.48**vena contracta**

Is a point downstream of the flow restriction where the flow stream reaches its minimum cross-sectional area and thus its maximum velocity and minimum pressure (see Figure 9 for illustration).

3.49**vessel**

Any drum, column, tower, or reactor associated with the processing or handling of hydrocarbon in a refinery.

3.50**volume booster**

A stand-alone relay used as a volume booster or simply booster to boost or amplify, the volume of air supplied to the actuator.

3.51**voting**

A system that uses redundancy (at least “m” of the “n” channels or devices) to be in agreement before a SIS takes an action (e.g. 1oo1, 2oo2, or 2oo3 voting).

4 Control Valves

4.1 General

A control valve, as shown in Figure 1, consists of two major subassemblies: a valve body, and an actuator. The valve body is the portion that actually contains the process fluid. It consists of a body, internal trim, bonnet, and sometimes a bottom flange and/or bonnet flange. This subassembly should meet all of the applicable pressure, temperature, and corrosion requirements of the user's design specifications.

The actuator assembly moves the control valve in response to an actuating signal from an automatic (i.e. Basic Process Control System) or manual device (i.e. handwheel). It should develop adequate thrust to overcome the forces within the body subassembly and at the same time be responsive enough to position the valve plug accurately during changing process demands.

4.2 Valve Body

4.2.1 Valve Body—General

4.2.1.1 Process design conditions dictate the ASME pressure classification and materials of construction for control valves, provided the standard offering meets or exceeds all piping and process control requirements. The valve end connections and pressure rating should, as a minimum, conform to the piping specification and ASME B16.34. The valve material should be suitable for the process design conditions.

4.2.1.2 Nickel alloy or stainless steel valve metallurgy should be specified for process design temperatures below $-30\text{ }^{\circ}\text{C}$ ($-20\text{ }^{\circ}\text{F}$) with consideration for low temperature impact tested carbon steels. High pressure steam, flashing water applications, and boiler feed water service where differential pressures exceed 14 barg (200 psig) may require harder, chrome-molybdenum alloys. Sour service valve materials should meet the requirements of NACE MR0103. Corrosive and erosive components even in trace quantities may affect the metallurgical choice of the valve.

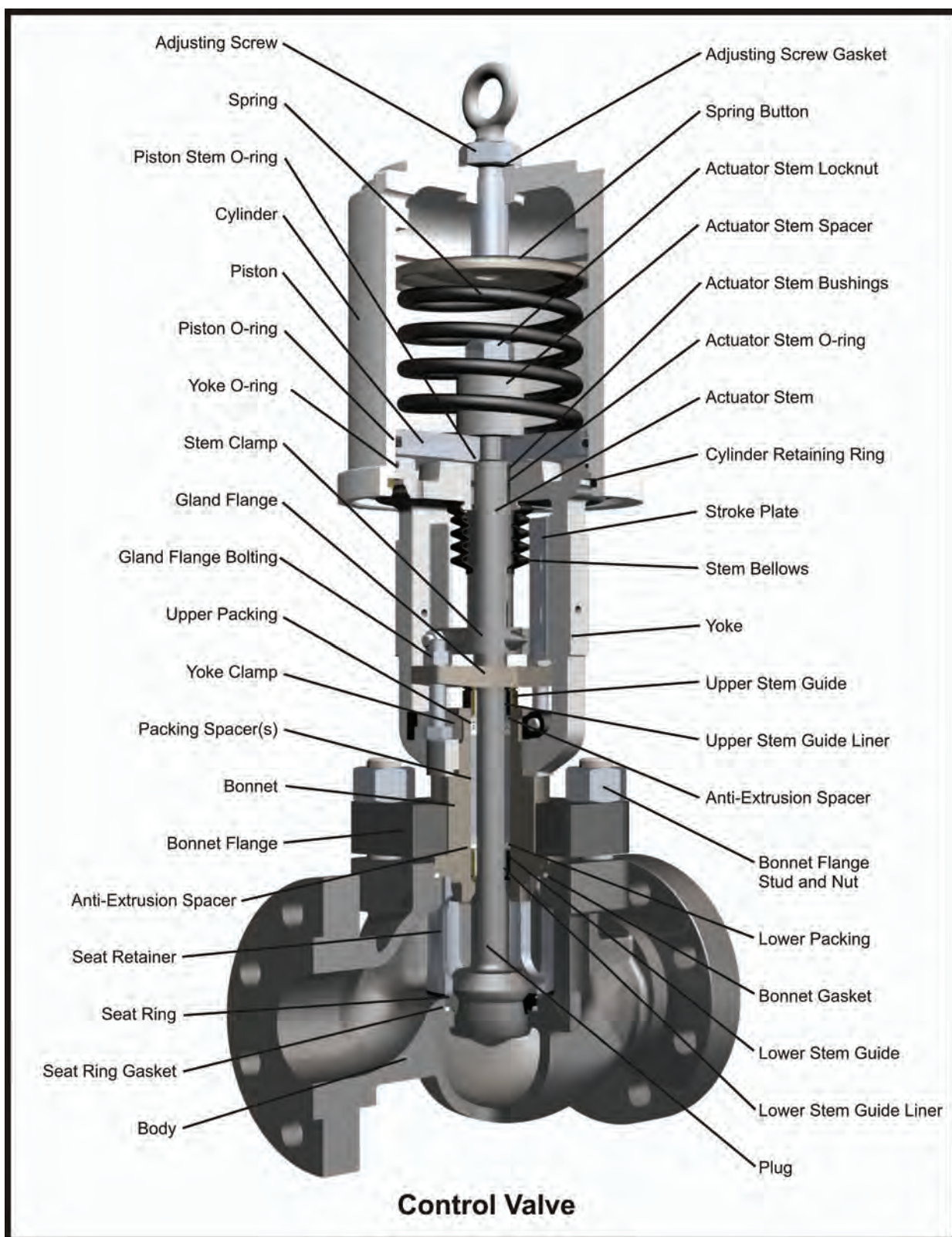


Figure 1—Typical Control Valve Components

4.2.1.3 Valve trim should be the manufacturer's standard where acceptable. Hardened trim could be required for corrosive, erosive, cavitating, or flashing service, and where valve differential pressure exceeds 14 barg (200 psig). If these conditions exist, consult the valve manufacturer for further guidance.

4.2.1.4 Flanges are the preferred end connection for globe-style valves; with butt-weld end connections acceptable for ASME CL900 and above. Threaded valves and valves with welded end connections are not recommended for hydrocarbon service and should be specified only with the end user's prior approval.

4.2.1.5 Flanged control valve bodies are available with either integral flanges (machined as part of the body casting or forging, or flanges welded to the body), or separable flanges (individual removable flanges that usually lock in place on the valve body by means of a two-piece retaining ring).

4.2.1.6 Flangeless valves have no flange connections as part of the valve body and are simply bolted or clamped between the adjoining line flanges. Flangeless valves should be avoided in hydrocarbon service, since their long bolts can expand when exposed to fire and cause leakage. The following limitations should apply to flangeless valves.

- a) Flangeless valves should not be used where the process design temperature is above 315 °C (600 °F).
- b) Flangeless valves should not be used where the process design temperature is below 315 °C (600 °F) and the service conditions meet the "dangerous" criteria defined below:
 - 1) toxic materials such as phenol, hydrogen sulfide, chlorine;
 - 2) highly corrosive materials such as acids, caustic, and similar materials;
 - 3) flammable materials (including hydrocarbons lighter than 68 °API);
 - 4) boiler feed water and steam, in systems requiring ANSI CL300 and higher flange ratings;
 - 5) oxygen in concentrations greater than 35 %.
- c) For design temperatures above 205 °C (400 °F), body material should have the same nominal coefficient of thermal expansion as the line bolting material and adjacent flanges.

4.2.1.7 Flange finish describes the depth of the grooves in the surface part of a flange which is available for the sealing gasket. If a special finish is needed for gaskets, it should be specified with the valve. The typical standard is 125 to 250 RMS, which provides a good sealing surface for the gasket.

4.2.1.8 The installed face-to-face dimension of integral flange globe style valves should conform to ANSI/ISA 75.08.01. Face-to-face dimensions of flangeless control valves should conform to ANSI/ISA 75.08.02. Face-to-face dimensions of separable flanged globe style valves should conform to ANSI/ISA 75.08.07 or 75.08.01. Butterfly valves are covered by API 609. Caution should be used when installing flangeless valves so that they will not leak in hydrocarbon service under fire conditions.

4.2.1.9 The valve body size should be no less than two pipe sizes smaller than the line size or half the line size. Smaller valve sizes should be reviewed to make sure that line mechanical integrity is not violated.

4.2.1.10 Final valve sizing and selection should be reviewed by the valve manufacturer or their official representative.

4.2.1.11 Threaded seat rings should be avoided in highly corrosive environments because corrosion may make removal difficult.

4.2.1.12 Control valves in plugging services (e.g. liquid sulfur) should be steam jacketed where steam tracing would not provide enough heat to prevent plugging.

4.2.2 Bonnets

Bonnets should be bolted. Bolting material should comply with ASTM A193/194/320 and should be compatible with the valve body and bonnet. Before replacing any valve bonnet bolting, consult valve manufacturer for limitations and torque requirements.

Extended bonnets should be considered when process temperatures are below the freezing point of water 0 °C (32 °F) or above the temperature limits of the packing materials shown in 4.2.3. The control valve manufacturer should be consulted for guidelines on temperature limitations.

Bonnet gaskets should be fully retained spiral wound, with polytetrafluoroethylene (PTFE) or graphite filler. Flat gaskets made from PTFE sheet stock are acceptable where conditions permit. Insert reinforcements should be stainless steel or other appropriate alloy, as required.

Bonnets could be tapped for the addition of lubricators and steel isolating valves for all control valves with packing other than PTFE or graphite or for all control valves with extended stems in hot service.

4.2.3 Packing

Control valves use packing to help seal the area between where the valve stem exits the valve body and where it connects to the yoke of the valve actuator. Packing is used to reduce the emissions of volatile and harmful fluids to the atmosphere. Several packing materials and designs can be used depending on the process service conditions expected and whether the application must comply with specific environmental regulations. Below are design guidelines to consider.

- a) Packing boxes should be easily accessible for periodic adjustment. The packing material should always be 1) elastic and easily deformable, 2) chemically inert, 3) able to withstand applicable process design conditions, and 4) minimize friction. Additionally, when there is an application need, the packing material may also be fire resistant and designed to meet a specific fugitive emission regulatory requirement. Valve manufacturer's packing temperature limits refer to the temperature at the packing box.
- b) PTFE has excellent inertness, good lubricating properties, and is one of the most common valve packing materials. It may be used in solid molded, braided, or turned form (V-rings) or as a lubricant for asbestos-free packing. Its temperature limit with standard packing box construction is 230 °C (446 °F). If used to meet fugitive emissions, virgin PTFE should be alternated with carbon-filled PTFE or similar minimal cold-flowing material and live loaded.
- c) Graphite laminated or preformed ring packing is chemically inert except when strong oxidizers are handled. This type of packing can be used for temperature applications approaching 540 °C (1000 °F). Increased friction is a concern when applying commercial grade graphite packing. Performance is often compromised because of significant increases in hysteresis and deadband. Packing systems with additives to reduce friction are available. Care should be exercised during actuator sizing.
- d) Asbestos packing shall not be used.
- e) Valve packing box arrangements should use anti-extrusion rings to minimize extrusion, which causes loss of packing material, and should use a minimum amount of packing to reduce effects of thermal expansion.
- f) Valve stem should be retained in a centrally aligned position via a bushing system. Otherwise, the packing load may be excessive.

4.2.4 Fugitive Emissions

Federal Regulations (e.g. EPA's US Code Title 42 Chapter 85) and state/local requirements have established strict limits on emission to the atmosphere of certain hazardous substances and/or worker exposure requirements. These substances are volatile hazardous pollutants listed in the National Emission Standard for Hazardous Air Pollutants (NESHAP).

Increased emphasis on limiting packing leaks has resulted in the development of new packing materials and methods. Individual valve manufacturers are offering increasingly effective designs. See Figure 2 for an example of one of these newer designs. The control valve manufacturer should be consulted for all applications that must adhere to a fugitive emission regulatory requirement.

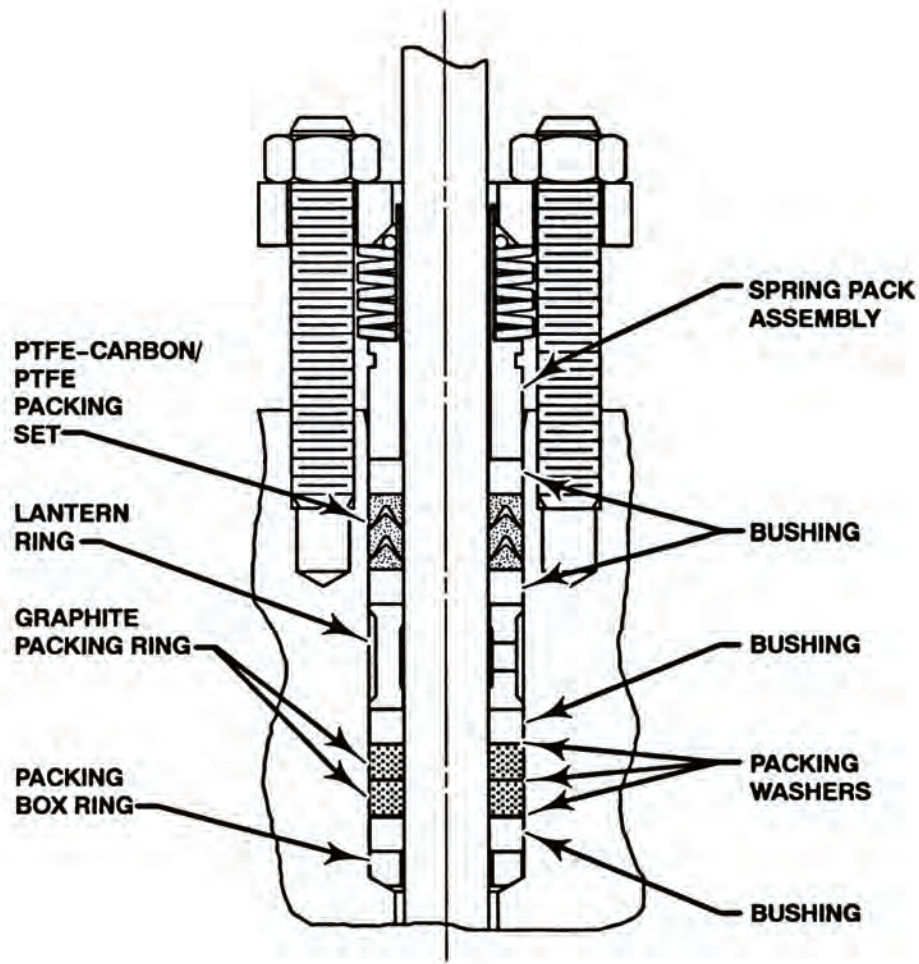


Figure 2—Typical Live-loaded Packing Arrangement

FFKM, perfluoroelastomer also has excellent inertness and good lubricating properties. It does not cold flow and therefore does not need live loading. It is available in V-rings. The temperature limit with standard packing box construction is 370 °C (700 °F).

Rotary valves, when suitable for the application, have a similar live load packing arrangement, and can provide excellent sealing for extended periods of time (300,000 cycles or more) with emissions remaining below 500 ppm. This is achievable because the shaft of a rotary valve does not move linearly across the seal, but rather rotates in place cross the seal.

4.2.5 Seat Leakage

As defined by ANSI B16.104 (FCI 70-2), seat leakage is the quantity of fluid passing through a valve when the valve is in its fully closed position at a specified process design pressure differential and temperature. Below are design guidelines to be aware of.

- a) ANSI B16.104 (FCI 70-2) establishes a series of 6 seat leakage classes for control valves and defines their associated test procedures. Worst case process design conditions should be considered for control valve leakage class selection.
- b) Metal-to-Metal seating with Class II leakage rating is expected for most process applications, especially for fluids containing abrasive particles or with design temperatures above 230 °C (450 °F). The control valve manufacturer should be consulted for guidance when better than Class II leakage is needed.
- c) For tight shutoff applications, the leakage class should be at least Class V.
- d) When better than Class V leakage is specified, composition (soft) seats may be considered as long as the valve seat materials can conform to the process design pressure and temperature, and the chemistry of the process. Composition seats are usually limited to process temperatures below 230 °C (450 °F) due to the fact that most elastomer materials begin to cold flow at this temperature. Steaming through a valve can damage or ruin a composition seat (see Figure 3) if the component pressure or temperature limitations are exceeded.
- e) Double-ported valves and 3-way valves are limited to a Class II shutoff.
- f) Single-seated unbalanced globe valves with metal-to-metal seating surfaces meet Class IV. Class V shutoff can be achieved by providing improved plug to seat ring concentricity or lapping seating surfaces and/or increasing actuator thrust. Resilient seats on single seated valves can provide Class VI shutoff.

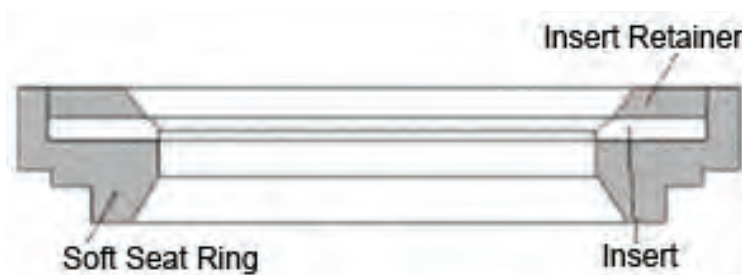


Figure 3—Resilient Seat

4.2.6 Control Valve Characteristics

A valve's trim is the heart of the valve and operates to give a specific relationship between flow capacity and the valve plug lift. This relationship is known as the valve flow characteristic and is achieved by different valve plug shape and/or cage designs.

- a) Control valve flow characteristics are determined principally by the design of the valve trim. The three inherent characteristics available are quick opening, linear, and equal percentage, as shown in Figure 4 and Figure 5. A modified equal percentage characteristics generally falling between linear and equal percentage characteristics is sometimes available.
- b) Positioners may use mechanical cams or be programmed to provide other desired characteristics.

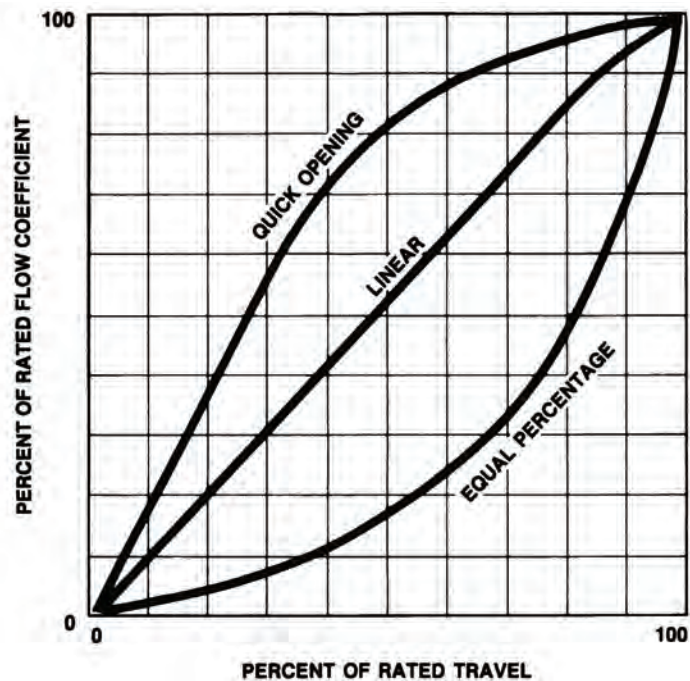


Figure 4—Inherent Valve Characteristics



Figure 5—Characterized Cages for Globe-style Valve Bodies

- c) Installed characteristics often differ significantly from inherent characteristics if the pressure drop across the control valve varies with flow. As a result, equal percentage plugs are generally used for flow control applications because most of the “system pressure drop” is not across the control valve. Linear plugs are commonly used for applications where most of the “system pressure drop” occurs across the control valve.
- d) Two-way control valves should be specified to have a equal percentage characteristic especially as noted below:
- 1) gas compressor recycle control valves;
 - 2) valves in pressure-reducing service;
 - 3) valves in level control service.

An exception to the above, are two-way valves used in pairs as three-way valves. These should be specified with a linear characteristic.

4.2.7 Control Valve Types

Today's control valves operate by one of two primary motions: sliding stem motion (see Figure 6A) or rotary motion (see Figure 6B). The selection of a valve for a particular application is primarily a function of process requirements for control performance, pressure drop, temperature, and rangeability.

Loop dynamic performance should be considered when selecting control valves. Each type of control valve (sliding stem motion or rotary motion) has different performance characteristics. Theoretically, a loop has been tuned for optimum performance at some set point flow condition. As the flow varies about that set point, it is desirable to keep the installed process gain as constant as possible over the control valve operating range to maintain optimum performance. The ratio of the incremental change in valve flow (output) to the corresponding increment of valve travel (input) which caused the flow change is defined as the valve gain and impacts the process gain. If a valve is applied which results in the wrong valve gain for the application there is danger that the process gain might change enough to cause instability, limit cycling, or other dynamic difficulties.

To maintain acceptable dynamic process performance, the process gain should not vary more than a 4-to-1 ratio.

Process optimization requires a valve style and size be chosen that will keep the loop gain within acceptable limits over the operating range. Control range varies dramatically with valve style. The example case in Figure 7 shows different installed valve characteristics and valve gain behavior.

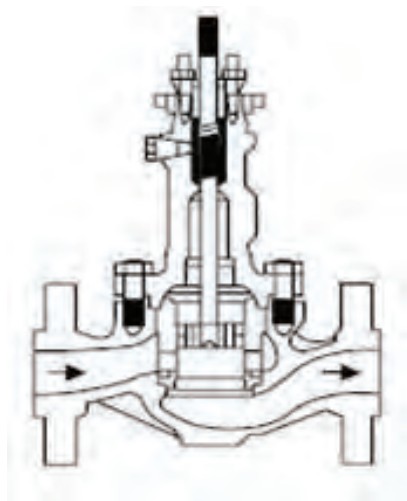


Figure 6A—Sliding Stem Motion Valve

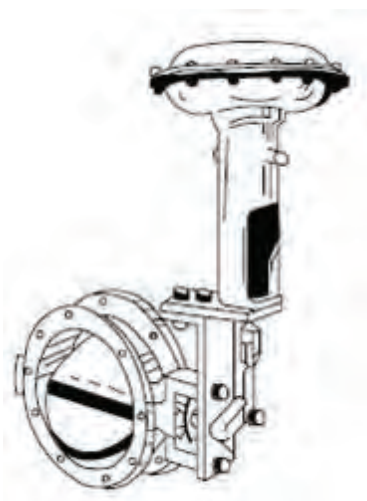


Figure 6B—Rotary Motion Valve

4.2.8 Sizing

This section discusses the methods for calculating flow through a control valve and for establishing the required capacity coefficient (C_v) for valve sizing purposes.

- a) Control valve sizing and selection is the process of determining the correct valve size and style for a specific application. The fundamental flow equations used for this process are presented in the industry standards ISA 75.01.01, *Flow Equations for Sizing Control Valves*, and IEC 60534-2-1, *Flow Capacity – Sizing Equations for Fluid Flow Under Installed Conditions*. Per the associated test standards, ISA 75.02, *Control Valve Capacity Test*, the tolerance for control valve C_v testing is $\pm 5\%$ at full opening; the tolerance for partial openings is not stated. Control valve data is typically based on water and air testing under ideal conditions for a limited set of sizes. The

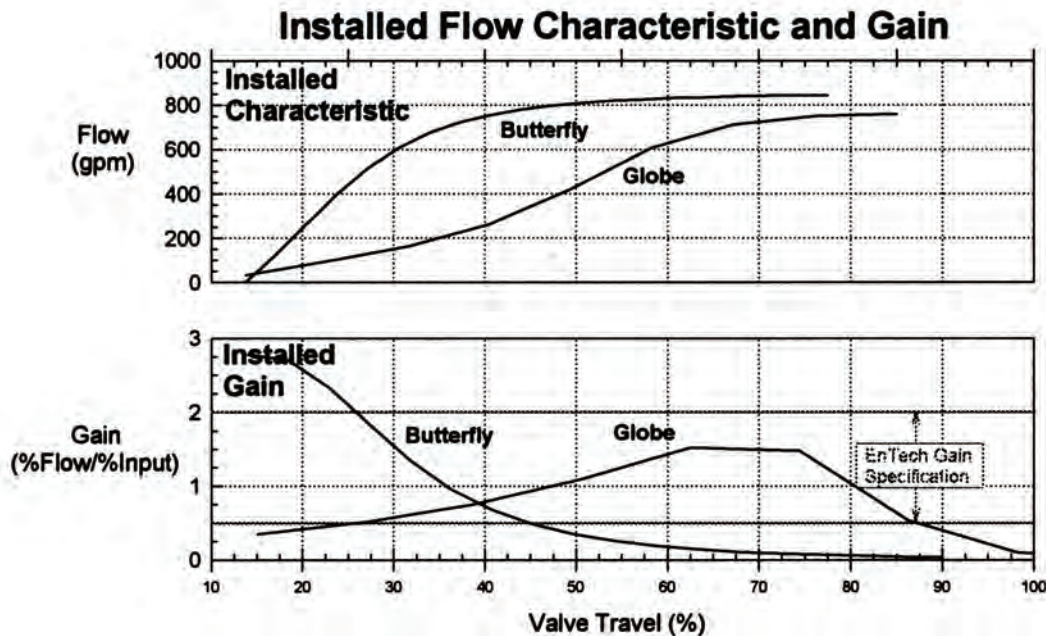


Figure 7—Effect of Valve Style on Control Range

calculations become less accurate for fluids and conditions significantly different from ideal, for very large or very small sizes, and for installed conditions significantly different from laboratory conditions.

b) The primary factors that should be known for accurate sizing are:

- 1) the fluid phase (gas, liquid, multiphase) and the density of the fluid (specific gravity, specific weight, molecular weight);
- 2) the valve inlet and outlet pressures at the flow rates being considered;
- 3) the temperature of the fluid;
- 4) cleanliness of fluid (entrained particulate/catalyst);
- 5) the viscosity (liquids);
- 6) the vapor pressure and critical pressure (liquids);
- 7) specific heat ratio (gas);
- 8) the compressibility factor (gas);
- 9) flow rates required (maximum, normal, minimum);
- 10) pressure drop at shutoff;
- 11) maximum permissible noise level, if pertinent, and the measurement reference point;
- 12) inlet and outlet pipe size and schedule;
- 13) alternate process conditions including items like start-up, regeneration, or other modes of operation;

- 14) any significant temperature differentials the valve will see in case of an upset.
- c) Control valve sizing should comply with the following criteria.
- 1) Control valve size should be selected so that at the maximum specified flow rate and corresponding pressure drop, the required travel should not be more than 90 % of full travel. In some cases travel up to 95 % may be desired, but this should be avoided, unless the process conditions present no alternatives.
 - 2) Control valve size should be selected so that at the minimum specified flow rate and corresponding pressure drop, the required travel should not be less than 10 % to 20 % of full travel. Proposals to use control valves at lower travel should be reviewed and approved by Owner's engineer and the valve manufacturer.
 - 3) Conventional butterfly valves should be sized for maximum angle opening of 60 degrees. Proposals to use angles greater than 60 degrees should be reviewed and approved by Owner's engineer and the valve manufacturer.
- d) For heat exchanger service, conventional valves used in pairs (including rotary actuated valves such as ball or butterfly) are preferred over a single 3-way valve. Valves in heat exchanger service should be sized in accordance with the following:
- 1) For globe (and characterized type three-way) valves in three-way service, the exchanger valve (port) should be sized to pass the maximum design flow through the exchanger and zero flow through the bypass valve (port). The bypass valve (port) should be sized to pass the maximum design flow with zero flow through the exchanger valve (port) subject to the limitation that the bypass valve should be no smaller than one size below the exchanger valve.
 - 2) Valves in heat exchanger service should be sized in accordance with the process design requirements. Although line size valves can generally be used, in some cases a more rigorous process/hydraulics study should be done to determine if a smaller bypass valve size is warranted due to pressure drop within the exchanger. The combination of valves will need to be able to handle the full process flow in all cases of full, partial and no bypass flow around the exchanger.
- e) As part of valve selection, the overall system in which the valve is to be installed should be considered. A typical system (in addition to the control valves) includes a pump or compressor, that provides energy, and other types of refinery equipment, such as piping, exchangers, furnaces, and hand valves, that offer resistance to flow. Note that the differential pressure between the pump head curve and the system pressure drop curve is the amount of pressure available for the control valve. If no control valve was used, the flow would always be at the rate indicated by the intersection of the two curves (see Figure 8).
- f) The presence of reducers upstream and/or downstream of the valve will usually result in a reduction in capacity because of the creation of an additional pressure drop in the system. Piping systems where both the inlet and outlet piping are larger than the valve will result in an increased valve C_v requirement. Capacity correction factors that can be applied to calculated C_v values are readily available from most manufacturers for the various styles of valves or estimated from the methods contained in ISA S75.01.01 or IEC 60534-2-1.
- g) In any flow restriction, a portion of the pressure head of the incoming fluid is changed to velocity head, resulting in a reduction in static pressure at the vena contracta. Refer to Figure 9. As the fluid leaves the flow restriction and assumes downstream velocity, some portion of velocity head is recovered as pressure head. This process is termed pressure recovery. The degree of pressure recovery is dependent upon the internal geometry of the flow restriction. The vena contracta pressure may drop to the vapor pressure of the fluid. As the pressure recovers it may stay at the vapor pressure (flashing) or it may recover above the vapor pressure (cavitation). Flashing and cavitation are indications of partial or full choked flow, which may affect sizing (see following discussions).

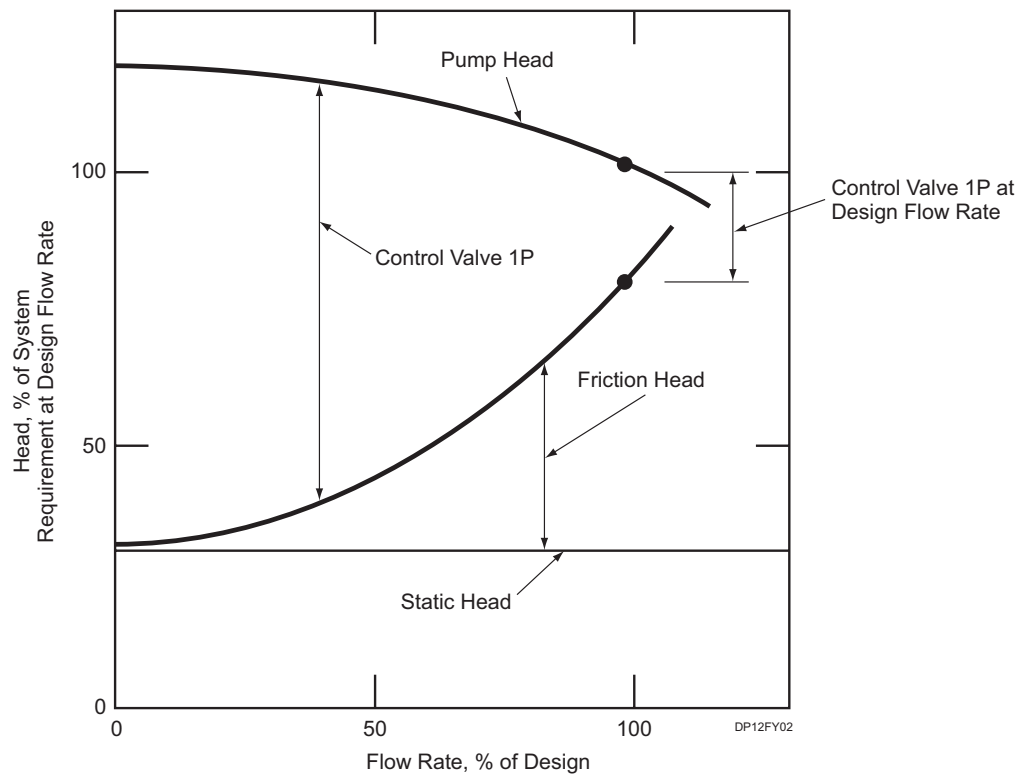
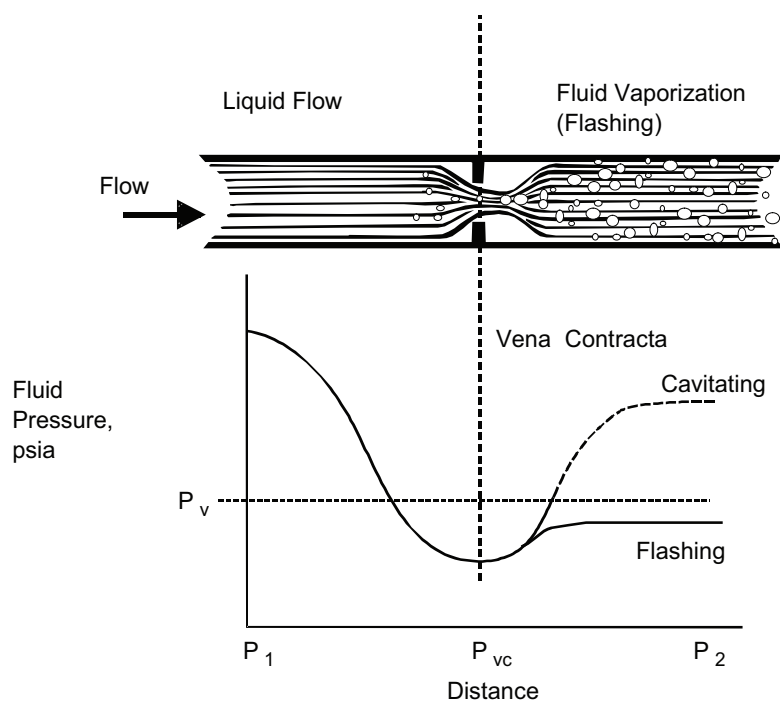


Figure 8—Typical System Head—Capacity Relationship

h) Choked volumetric flow occurs in gas or vapor service when the fluid velocity reaches the speed of sound at the vena contracta. Increasing the pressure drop (at constant inlet pressure) under a choked condition no longer increases the flow. This will affect the valve sizing by limiting the pressure drop available for sizing to the choked flow pressure drop value. Pressure recovery has the effect of achieving choked flow at a pressure drop that is less than would be predicted by the critical pressure ratio. This can become a problem for valves with high-pressure recovery, such as rotary valves. This necessitates the use of a larger valve or different valve style. Liquid flow can also experience choking when vaporization takes place and the resulting compressibility impacts the actual valve capacity.

i) Cavitation:

- 1) Cavitation is the generation of bubbles (vapor cavities) in the lowest pressure portion of the valve, and the subsequent collapse of these bubbles. See Figure 9. The bubble collapse (implosion) imparts a mechanical attack on the metal surfaces that can destroy a control valve in a short time. See Figure 10 and Figure 11. It is easily recognized by a characteristic sound described as “like rocks flowing through the valve.” High purity materials (single component) generally are the most likely to cause damage when cavitation takes place. Hydrocarbon mixtures with various vapor pressures for different components make it difficult to predict the onset or the severity of cavitation. Special cavitation control trims are offered by manufacturers that can reduce or prevent cavitation. Some of these trims are subject to plugging in dirty services and should be reviewed for suitability to each service.
- 2) Valves with low-pressure recovery should be used to minimize or prevent cavitation. In some cases it may be necessary to use special components, or stage the pressure reduction through specially design elements.



(Courtesy of Emerson Process Management)

Figure 9—Pressure-drop through a Restriction

(Courtesy of Flowserve)

Figure 10—Cavitation Damage to Valve Plug

(Courtesy of Flowserve)

Figure 11—Cavitation Damage to Seat Ring

j) Flashing:

- 1) Flashing occurs where the downstream pressure is at or below the vapor pressure of the fluid. See Figure 9 and Figure 12. Flashing, like cavitation, can cause physical damage and decreased flow capacity. Velocity is the major concern. The outlet flow increases velocity due to the fluid changing from a liquid to a gaseous state. A larger control valve body size with reduced trim and larger size outlet piping can be applied to prevent choking and excessive velocity problems. Other solutions to reduce or eliminate flashing damage are; hardened trim, flow down angle valves with sacrificial liner, and reverse flow rotary valve positioned for outlet to flow directly into a large volume (such as a tank), or sacrificial spool piece. Manufacturers should be consulted for recommendations.
- 2) Flashing damage is usually less severe than the damage from cavitation. However, restricted piping configurations at the valve outlet can cause the flashed vapor to cavitate and cause piping damage downstream of the control valve. Manufacturers should be consulted for recommendations.

k) Out-gassing:

- 1) Out-gassing appears to be identical to flashing from a macroscopic perspective; however, it is completely different in its composition and vapor generation process. Out-gassing flowing media consists of at least two separate, unique components of different molecular weights dissolved or entrained in a liquid continuum. The gas comes out of solution and becomes visible upon a reduction in static pressure. An everyday example of this is a carbonated beverage. The liquid in the sealed container has carbon dioxide gas that is entrained in it. Upon a slight depressurization, i.e. opening the container, the carbon dioxide will immediately come out of suspension, creating the familiar bubbles or fizz. Unlike flashing, out-gassing is not a thermal process in that absorption of heat is not required to generate the presence of the compressible component. In fact, out-gassing is a kinetic process like that of the carbonated beverage. A slight change in pressure is all that is needed to release the entrained gas.



Figure 12—Flashing Damage

- 2) Out-gassing cannot be sized in the same manner as you would size a flashing application. The potential existence of both a compressible (gas or vapor) element and non-compressible (liquid) element in the flowing media prior to the throttling orifice cannot be accurately modeled using the standard ANSI/ISA S75.01.01, or IEC 60534-2-1 methods. Specially developed methods and control valve sizing equations are required. The downstream flow rates and fluid properties for both the compressible component (gas/vapor) and the non-compressible (liquid) should be known. Misapplied outgassing applications can result in the application being undersized, extreme vibration, and increased trim and valve body wear. Manufacturers should be consulted to conduct proper sizing.
- 3) Typical control valve selections for outgassing service are multi-stage or sweep flow designed sliding stem “expanding area trim” or angle type control valves. The appropriate selection is based upon the pressure

temperature, flow rate, and gas volume ratio of the application. Manufacturers should be consulted for recommendations.

l) Rangeability:

- 1) The rangeability of the control valve should be considered during valve selection. Control valves are available with published C_v rangeability of 50 to 1 and even greater, at constant pressure drop, a condition that rarely exists in actual practice. Typically, valves are sized with 10 % to 20 % excess capacity at the high end and 10 % to 20 % below the minimum required capacity at the low end.
 - 2) A high rangeability is of little significance if the service conditions for the valves in question do not require it. The requirement for rangeability is to cover the maximum and minimum flow rates at the design flowing conditions.
- m) Manufacturers should analyze all valve specifications for cavitation, noise, or other detrimental factors, using the data on the data sheets as a basis. Undesirable operating situations should be brought to purchaser's attention, including noise or cavitation severity. Manufacturers should propose possible solutions to these problems within the design limits of the type of valve covered by the specification or indicate that a special design is needed.

4.2.9 Noise

- a) The predicted sound pressure level radiated from a control valve is a complex determination, and the allowable noise level in the installed location cannot be stated as one simple number to be specified in all circumstances. This is particularly true where there are other noise sources in close proximity, since they have an additive effect. The actual level depends on a number of factors, such as atmospheric discharge, physical location, proximity of other noise sources and their magnitude, piping system configuration and wall thickness, insulation on piping, presence of reflective sources, etc.
- b) Prediction of noise generated by a control valve is an inexact science. Prediction levels for a valve operation at conditions specified on the specification sheet can vary widely using various manufacturers' methods. Refer to ISA Control Valve Standard 75.17
- c) To provide a basis for allowable noise level analysis, control valves calculated to generate excessive noise levels should have alternate valves proposed that will not exceed the specified noise level within 1 m (3 ft) downstream and 1 m (3 ft) out from the pipe. For atmospheric discharge vent control valves (or system), the noise level should not exceed the specified noise level at a point three meters down from the vent exhaust and at a downward angle of 45 degrees.
- d) Allowance may be taken for insulation and/or increased pipe wall thickness.
- e) The calculated continuous noise level should not exceed 85 dBA, measured where personnel may be continuously working. This may not be within 1 m (3 ft) downstream and 1 m (3 ft) out from the pipe. The Occupational Safety and Health Administration decreases the allowable time of exposure as the sound level increases, and the user is referred to OSHA 1910.95 for specific guidelines. It is the user's responsibility to determine if the sound level will meet OSHA requirements or local site standards, whichever is more stringent.
- f) Noise levels above 85 dBA may be allowable where personnel are not working continuously.
- g) The maximum intermittent sound level should normally be limited to 110 dBA at one meter downstream and one meter out from the pipe.
- h) In no case shall the calculated sound level exceed 115 dBA within 1 m (3 ft) downstream and 1 m (3 ft) out from the pipe due to possible mechanical failure within the system (pipe welds, small lines, etc.). In this case, no allowance shall be taken for insulation.

- i) IEC and ISA industry standards exist for estimating noise levels of general service valves. However, noise prediction and mitigation is a specialized effort generally requiring the manufacturer recommendation for an effective design. It should be noted that the standards are being revised to allow for manufacturers' information to be available in a uniform format.
- j) Noise can be treated in two ways: source treatment and path treatment. Source treatment means the noise is reduced using an inline device. These devices treat noise by breaking up high velocity jets. In a control valve, this is achieved by using a cage characterized with small passageways. Three types of technology exist for these cages: slotted windows (Figure 13A), drilled holes, or stacked disks (Figure 13B). Selection of trim type for noise reduction is based on the $dP/P1$ ratio, a suitable amount of noise attenuation, and process considerations such as plugging due to pipe scale, coke particles, or other debris. Another type of source treatment is the use of inline silencers. Path treatment utilizes thick wall piping or insulation to reduce noise. However, this treatment only masks the generated noise. If piping is reduced to the standard wall thickness or insulation is removed, the calculated noise will be generated.
- k) Valves with noise abatement or cavitation control trim with small passages tend to plug with debris, particularly during startup, and should be protected with conical or T-type strainers. These devices should be used cautiously throughout refineries in applications where process streams are clean. On new construction where upstream piping is modified, special consideration should be taken to protect the control trim from being damaged during flushing activities.

4.2.10 Body Integrity

Hydrostatic testing of pressure-containing components is needed per ASME B16.34 and ISA S75.19. For special services, other non-destructive tests are sometimes specified.



Figure 13A—Slotted Noise Abatement Trim



Figure 13B—Stacked Disc Design Cage

4.2.11 Valve Assembly

The valve, actuator, and associated accessories, regardless of manufacturer(s), should be assembled, piped, aligned, tested, and shipped as a unit by the valve manufacturer. Tests may include hydrostatic, stroke test, leakage, or accessory calibration.

4.3 Valve Actuators

4.3.1 Pneumatic Valve Actuators

Pneumatic valve actuators, using air or gas, are preferred for most process control applications. Electric motor or electrohydraulic operators may be considered for special applications, particularly when pneumatic power is not available. Electrohydraulic actuators are commonly used where very high thrust forces are required or pneumatic supply is not available.

4.3.2 Direct Acting/Reverse Acting

Actuators are classified as direct acting (an increase in air loading extends the actuator stem) or reverse acting (an increase in air loading retracts the actuator stem). Some actuators are field reversible. They can be changed from direct to reverse acting with no additional parts. Most manufacturers publish tables that allow selection of actuator size based on valve size, flow direction, air action, pressure drop, packing friction, and available air pressure.

4.3.3 Diaphragm Actuators

Diaphragm actuators are one of the simplest and most common of control valve actuators.

- a) A spring-opposed diaphragm actuator is a single-acting actuator where pressure is applied against a spring or springs. Upon loss of air, or control signal the spring will move the valve to the desired failure position. Construction of a typical spring diaphragm actuator is shown in Figure 14.
- b) For installations where there is a limited supply of instrument air pressure available, the use of a higher spring range permits the use of positioners, and also helps to meet tight shutoff requirements.

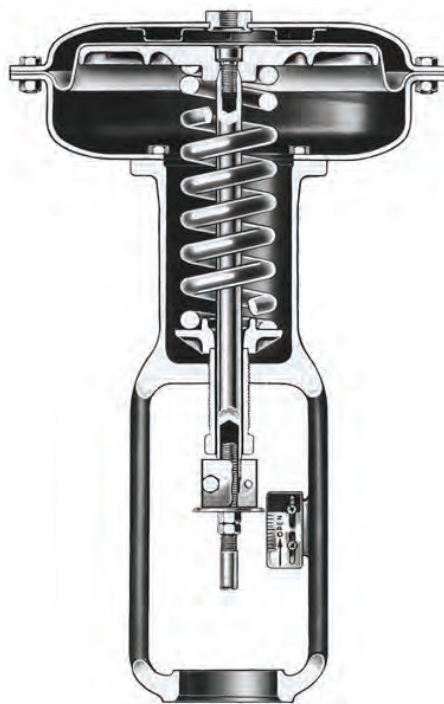


Figure 14—Diaphragm Actuator

4.3.4 Piston Actuators

The second most common control valve actuator is the piston type.

- a) Piston (or cylinder) pneumatic actuators are commonly used for control valves where high thrust is needed. Single-acting piston actuators apply air pressure to one side of the piston against a spring or springs. Upon loss of air the spring will move the valve to the desired failure position. Double-acting piston actuators are considerably stiffer than single-acting designs and can therefore be used to control higher pressure drops. Double-acting piston actuators apply air to both sides of the cylinder. Double-acting piston actuators without springs require an external volume tank and trip system to achieve the desired failure position. Springs can be added to double-acting piston actuators to provide the air failure mode. See Figure 15.
- b) Linear type piston actuators are used for globe style control valves. They are also used for rotary valves with adapter linkage. Scotch yoke or rack-and-pinion type piston actuators are normally used for on/off control, but may be used for regulatory control if control degradation is not critical.

4.3.5 Electrohydraulic Actuators

A variation of the piston actuator is the electrohydraulic, actuator which uses an electric motor to drive a pump and supply hydraulic pressure for the piston. For multiple valve installations, electrohydraulic actuators may be supplied by a common electric motor/pump skid. See Figure 16 and Figure 17.

4.3.6 Actuator Selection

4.3.6.1 Actuator selection guidelines are based on the assumption that the control valve will be required to operate against the maximum differential pressure specified. Generally, the worst case is to use the maximum upstream pressure with the downstream pressure vented to atmosphere. Utilizing this condition for selection of the actuator ensures adequate power for maximum service conditions but can dramatically affect operator size, particularly on larger valve sizes. Actuators should be sized to achieve all of the following:

- a) minimum air supply pressure expected at the valve location;
- b) force to overcome static unbalance of valve plug;
- c) to account for the frictional effects of the stuffing box packing selected;
- d) to ensure proper seat load to shutoff against the maximum differential pressure;
- e) to prevent instability of the valve plug or disk over its full travel, based on a pressure drop equal to the maximum upstream design pressure.

4.3.6.2 Stroking speed and control accuracy requirements should be reviewed and specified for critical applications, such as compressor anti-surge control, or where closing speed should be controlled to prevent hydraulic water hammer and control accuracy enables proper system start-up.

4.3.6.3 Valve failure position should be carefully analyzed in the event that supply pressure or instrument signal is lost. Generally, the valve should fail in the safe direction on loss of power or signal.

4.3.6.4 The most reliable fail-safe action is achieved with an enclosed spring. If volume tanks are required to provide reserve operating power, they should be sized to stroke the valve twice. Volume tanks should be stamped and otherwise conform to ASME Code guidelines (see Part U-1, Section VIII, Division 1, *ASME Boiler and Pressure Vessel Code*). Volume tanks should be designed with all necessary accessories to ensure the required valve action and failure position.

4.3.6.5 The actuator case should be rated for the maximum available pneumatic supply pressure. Filters or filter regulators, if required, should be supplied at the actuator inlet or the positioner inlet.

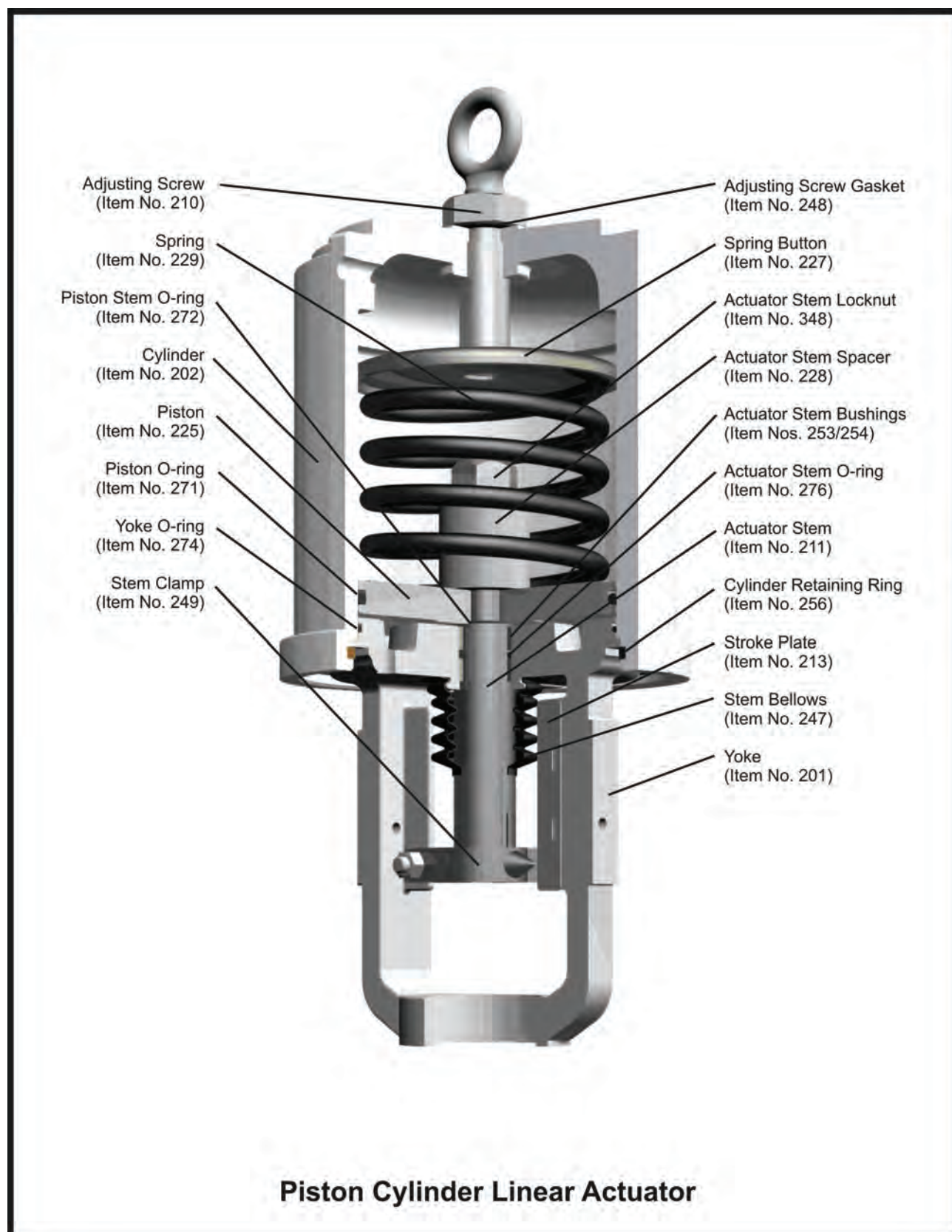


Figure 15—Double-Acting Spring Return Piston

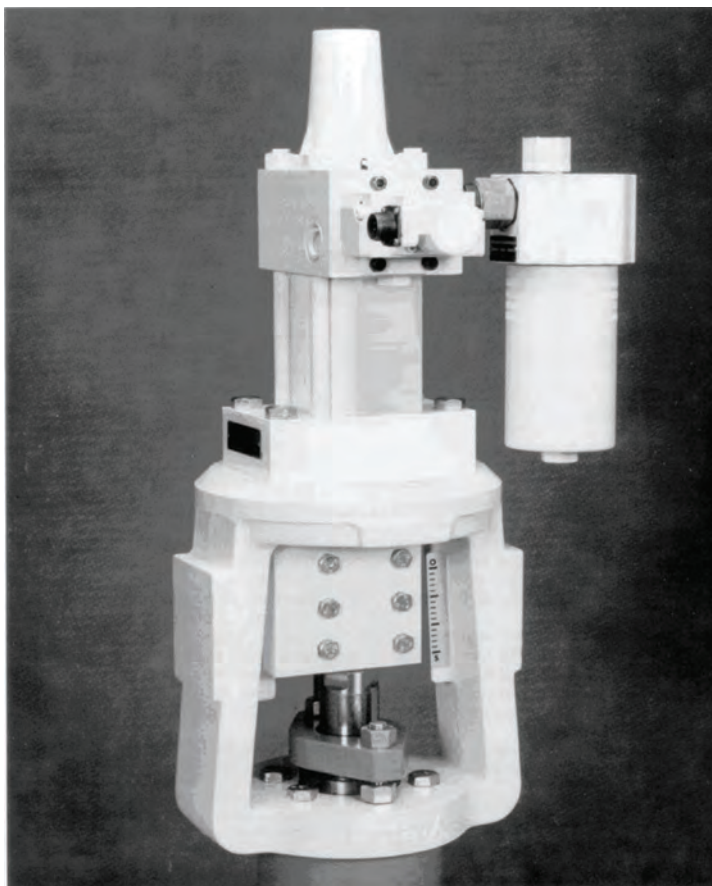


Figure 16—Electrohydraulic Actuator

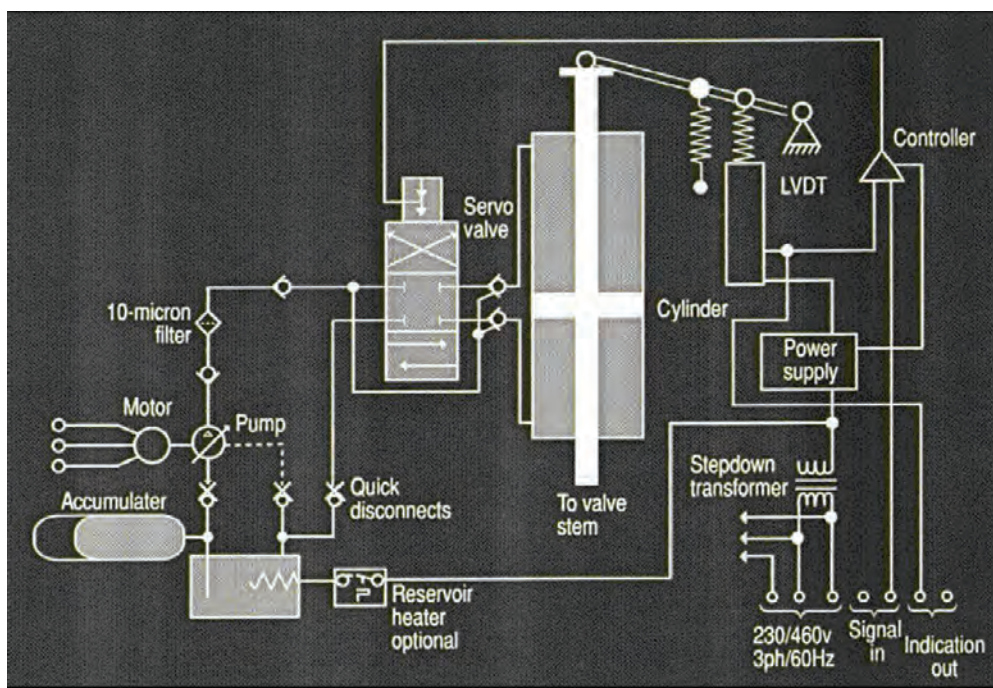


Figure 17—Electrohydraulic Actuator Schematic

4.3.6.6 The actuator should be sized to meet all control, shutoff, and valve leakage requirements. Shutoff capabilities should be investigated at conditions of maximum differential pressure.

4.3.6.7 To improve control valve performance, the effects of low frequency response and excessive deadband and hysteresis should be addressed. The valve, actuator, and positioner and accessories should be evaluated as part of the entire loop to determine loop performance.

4.3.6.8 In general, the actuator materials of construction should be the manufacturer's standard.

4.3.6.9 Sliding stem actuators should be supplied with an indicator showing valve stem position. Rotary valve actuators should have a travel indicator attached at the actuator end of the shaft, graduated in percent or degrees open.

4.4 Valve Positioner

4.4.1 Positioners are used to provide pneumatic output to the actuator to move a control valve to a specified position so that a process meets specific parameters (flow, pressure, temperature). Positioners by design have an integrated feedback mechanism that corrects for variations and ensures the valve stays in the position requested by the control system. Positioners provide air or fluid to an actuator in proportion to the input signal received from the control system.

4.4.2 The following is a list of functions a positioner can accomplish.

- a) Provide for split range operation.
- b) Reverse the valve action without changing the "failsafe" action of the spring in the actuator. (Note that this may also be done with a reversing type relay.)
- c) Increase the thrust in spring diaphragm actuators.
- d) Modify the control valve flow characteristic.
- e) Improve the resolution or sensitivity of the actuator where high precision valve control is needed. Precision is enhanced by the availability of positioners with adjustable gain.
- f) Reduce hysteresis.

4.4.3 There are two categories of positioners.

- a) Conventional mechanical or electro-pneumatic positioners (Figure 18) that receive their input setpoint from a pneumatic signal or from a DC analog signal. In older process units, it was standard practice for a mechanical positioner's pneumatic input set point to originate from an intermediate device between the Basic Process Control System (BPCS) and the positioner called a "current to pneumatic" transducer—commonly referred to as an I/P transducer. These are very rarely specified anymore with control valves. I/Ps were used to simply convert a DC analog signal (typically 4 mA to 20 mA) to a pneumatic signal (3 psig to 15 psig) that was the input to the conventional mechanical positioner.
- b) Digital Valve Controllers (Figure 19) that receive their input setpoint as a DC analog signal or as a pure digital setpoint.

4.4.4 Conventional

- a) Conventional positioners use a variety of mechanical parts to provide the position control function. Parts such as mechanical cams, springs, balance beams and bellows are commonly found in these assemblies.