Manual on Installation of Refinery Instruments and Control Systems

Part I—Process Instrumentation and Control
Section 6—Control Valves and Accessories

Refining Department

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Part I—Process Instrumentation and Control

SECTION 6—CONTROL VALVES AND ACCESSORIES

6.1 Scope

This section presents recommended practices for the installation and maintenance of control valves and related accessories such as positioners, boosters, and transducers. It also outlines control valve design considerations, discusses control valve sizing and noise, and defines types of commonly used control valves and their actuators.

A number of instruments and accessories can be mounted on and used in conjunction with control valves. Other sections of this manual will be referred to for installation, piping, and electrical practices covering those devices.

6.2 General

6.2.1 ACCESSIBILITY

All control valves should be installed so that they are readily accessible for maintenance purposes and for operation of a handwheel, if one is provided. They should generally be located at grade unless pressure head or other design conditions make such an arrangement impractical. When located above grade, control valves should be installed so that they are readily accessible from a permanent platform or walkway with ample clearances for maintenance purposes.

6.2.2 LOCATION

Where there is a choice of location, it is desirable to have the control valve installed near the piece of operating equipment that must be observed while on local manual control. It is also desirable to have indication of the controlled variable readable from the control valve.

6.2.3 INSTALLATION CLEARANCES

If a control valve is to be maintained in place, sufficient clearance should be provided above, below, or on the side so that the valve trim and the valve actuator may be removed from the valve body.

Extra clearance is required where extension bonnets or accessories are used. Clearance should always be provided on the side of the valve for maintenance of positioners and other devices.

6.2.4 PRECAUTIONS

Control valves that handle combustible fluids should be kept away from hot pumps, lines, or equipment. This practice reduces the possibility of such fluids contacting hot lines or equipment if the control valve manifold is drained and the valve is removed, or if leaks develop.

Certain rotary-motion control valve types utilize low-friction plastic lined bearings and as a result are susceptible to static electricity and should be grounded. Follow the manufacturer's recommendations.

Users should be aware that long bolts used with flangeless valves can expand when exposed to fire and cause leakage. A fire deflection shield and/or insulation is recommended. In addition, high-tensile-strength bolting is required.

Similarly, control valves used in process lines or fuel lines to fired heaters should be located outside the firewall around the heater. If no firewall is provided, the control valves should be located on the sides of the heater away from the burners or at a sufficient distance from the heater so that the line may be drained and the control valves removed without danger of a flashback. An alternate method is to pipe the drain or bleed connection a safe distance from the heater.

Because high temperatures can cause premature failure of diaphragms and electrical or electronic components, control valves should be located so that topworks are not adjacent to hot lines or equipment or in an area where temperature may be excessive. Consult the manufacturer's literature for maximum permissible ambient temperature.

Electrically operated items—motor actuators, solenoid valves, transducers—should be approved for use under the applicable hazardous area classification.

Control valves are normally protected with covers for flanged openings and threaded plugs for threaded openings during shipment and storage prior to installation.

During startup of any new facilities, care should be taken to keep scale, welding rods, and other foreign material from plugging or damaging control valves. One method is to remove the valve and substitute a spool piece during flushing operations.

6.3 Control Valve Design Considerations

6.3.1 GENERAL

A control valve, as shown in Figure 6-1, 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. This subassembly must meet all of the applicable pressure, temperature, and corrosion requirements of the connecting piping.

The internal trim controls the process fluid, provides the flow characteristic, and can accomplish the process shutoff requirements. The trim components vary depending upon valve style. Globe valves have internal trim consisting of plug, seat ring(s), plug stem, plug guide(s), and sometimes a cage. Rotary-motion valves have internal trim consisting of a ball, or eccentric plug, or vane, and seal ring, rotary shaft, and bushings.

The actuator subassembly moves the control valve in response to an actuating signal from an automatic or manual device. It must develop adequate power 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.

6.3.2 MATERIALS OF CONSTRUCTION

Materials of construction are very important in control valve design since control valves are required to handle all types of fluids. These fluids can vary from clean, dry air to corrosive chemicals at temperatures ranging from near absolute zero to well above 1000 F (538 C) and pressures from near vacuum to 50,000 pounds per square inch (345 megapascals) or higher.

Most control valve materials can be placed in two categories: (1) the pressure containment materials for the valve body, bonnet, bottom flange, and bolting; (2) the valve trim materials.

For pressure containment components, there are many materials available. Some services require the use of exotic alloys and metals to withstand corrosive fluids. However, for the majority of applications carbon steel is the most common material used. Some of the other materials used are chromium-molybdenum, stainless steel, cast iron, and bronze.

Selection of valve trim material is generally influenced by the factors of corrosion, erosion, wear, galling, pressure drop, and temperature, instead of pressure containment considerations. Commonly used materials are AISI Types 304, 316, 416, and 440, and 17-4 PH (precipitation hardened) stainless steels. Other materials such as aluminum-nickel alloy[1], cobalt-chromium alloy[2], and nickel-based alloys[3] are sometimes required. A common practice is to utilize a base material, such as Type 316 stainless steel, faced with cobalt-chromium alloy at points of expected wear such as seating surfaces and guide posts.

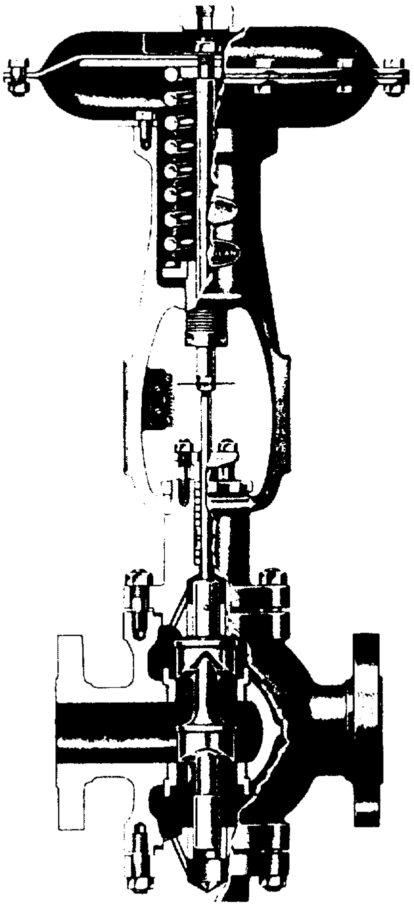

Figure 6-1—Control Valve Assembly

6.3.3 PRESSURE CONTAINMENT

Pressure and temperature ratings for the pressure containment parts have been established for the more common materials by the American National Standards Institute (ANSI).

Since the allowable working stress of most materials decreases at elevated temperatures, the pressure-temperature rating must be considered in the choice of materials.

A control valve must have a pressure-temperature rating compatible with the system in which it is employed. In smaller sizes, it is often more economical to standardize on a minimum rating (such as ANSI Class 300).

6.3.4 END CONNECTIONS

Control valve end connections may be classified as threaded, butt-welded, socket-welded, flanged, or flangeless.

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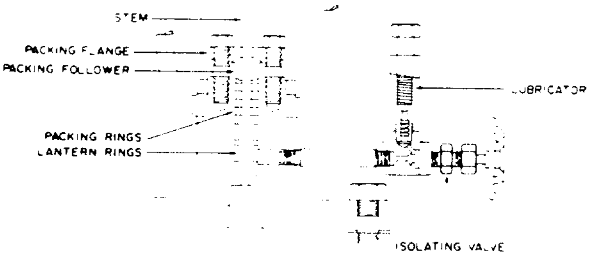
[1] For example, Monel.
[2] For example, Stellite.
[3] For example, Hastelloy B or C.



NOTE: Many packing box assemblies available today do not require lubrication. In such cases the lubricator and isolating valve shown in this figure are not required.

Figure 6-2—Packing Box Assembly (Bolted) With Lubricator and Isolating Valve

Female National Pipe Thread connections are common in valve sizes 1 inch and smaller and are sometimes used for control valves up to 2 inches.

Welded ends may be used where high pressure, high temperature, or highly toxic fluids are encountered. Care should be taken that the valve body material specified is compatible with the adjoining pipe material.

Flanged-end globe bodies generally conform to the standardized face-to-face dimensions listed in the Instrument Society of America (ISA) standard S75.03-1984, *Face-to-Face Dimensions for Flanged Globe-Style Control Valve Bodies*, with the exception of Saunders types, angle bodies, and rotary valves. The flange rating is determined by the type of service, required material, maximum pressure, and maximum fluid temperature.

Flangeless valves have no flange connections as part of the valve body and are simply bolted or clamped between the adjoining line flanges. Flangeless valve face-to-face dimensions generally conform to ISA S75.04-1984. Note that butterfly valves are not covered by a standard.

6.3.5 PACKING

The packing box assembly, Figure 6-2, provides a means for preventing the leakage of process fluid past along the surface of the valve stem. Packing boxes should be easily accessible for periodic adjustment and should permit the addition of at least one more split packing ring without disassembly. The packing material should (1) be elastic and easily deformable, (2) be as chemically inert as possible, (3) be able to withstand applicable process conditions, (4) provide a degree of fire resistance, and (5) minimize friction.

Polytetrafluoroethylene[4], because of its excellent inertness and its good lubricating properties, is one of the most popular valve packing materials. It may be used in solid molded, braided, or turned form (chevron rings) or as a lubricant for asbestos packing. Its temperature limit with standard packing box construction is 450 F (232 C).

Another popular packing type is braided asbestos with nickel-chromium-iron alloy[5] wire employing additives such as mica or graphite for lubrication. This packing may be used in high-temperature steam and petroleum service, approaching 1000 F (538 C). Manufacturers should be consulted to ensure proper valve construction.

A recent addition is an all-graphite[6] product that is essentially chemically inert except when strong oxidizers are handled. This type of packing can be used for temperature applications approaching 2000 F (1093 C). Manufacturers should be consulted to ensure proper valve construction.

6.3.6 SEAT LEAKAGE

The control valve plug is the moving component of the valve that throttles flow by positioning itself within the seat orifice and shuts off flow by contacting the seat.

The degree of sealing (shutoff) accomplished is dependent upon the valve construction, the materials and condition of the seating surfaces, and the actuator power available. Double-seated globe valves, due to machining tolerances, do not seat tightly. Manufacturers therefore publish a leakage rate of 0.5 percent of the rated valve capacity coefficient (C_V). Single-seated valves with metal-to-metal seating surfaces provide less leakage, and the normal published leakage rate is 0.01 percent of rated C_V.

Most control valve manufacturers follow the voluntary test and leakage standards established by ANSI B16.104-1976.

With additional considerations, such as careful lapping of the seating surfaces and increased actuator power, single-seated globe valves with metal-to-metal seating surfaces can meet even more stringent seat tightness requirements.

For specialized applications, control valves can be provided with a resilient composition insert (soft-seat construction) in either the plug or seat ring that will allow the valve to obtain bubble-tight sealing with relatively small actuator force. Common insert materials are nitrile rubber[7] or polytetrafluoroethylene.[8] However, before an insert material is selected, it should be determined that the insert is compatible with the process.

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[4] For example, Teflon.

[5] For example, Inconel.

[6] For example, Grafoil.

[7] For example, Buna N.

[8] For example, Teflon.

6.3.7 CONTROL VALVE CHARACTERISTICS

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. These are shown in Figure 6-3. A modified percentage characteristic generally falling between the linear and equal percentage characteristics is also available.

The three inherent characteristics can be described as follows:

1. *Quick Opening*. As the name implies, this characteristic provides a large opening as the plug is first lifted from the seat, with lesser flow increase as the plug opens further. This type is most commonly used where the valve will be either open or closed with no throttling of flow required.
2. *Linear*. Linear trim provides equal increases in C_V for equal increases in stem travel. Thus the C_V increase is linear with plug position throughout its travel.
3. *Equal Percentage*. Equal percentage trim provides equal percentage increases in C_V for equal increments of stem travel. This is accomplished by providing a very small opening for plug travel near the seat and very large increases toward the more open position. As a result, a wide rangeability of C_V is achieved.

The pressure difference across the valve often varies with flow. This results in an "installed characteristic," which will differ from the inherent characteristic.

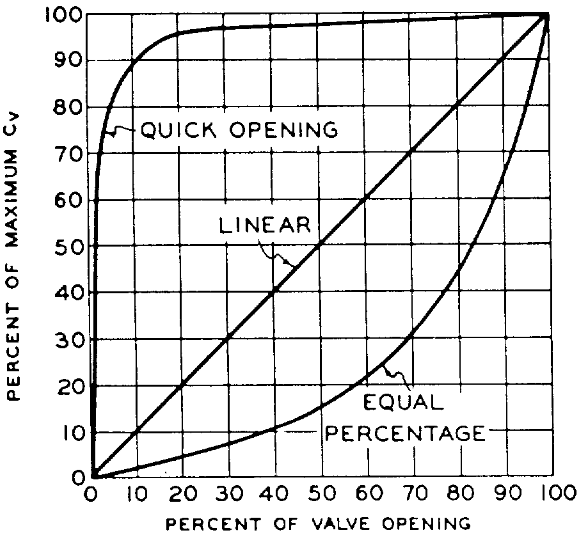

Figure 6-3—Representative Inherent Flow Characteristic Curves

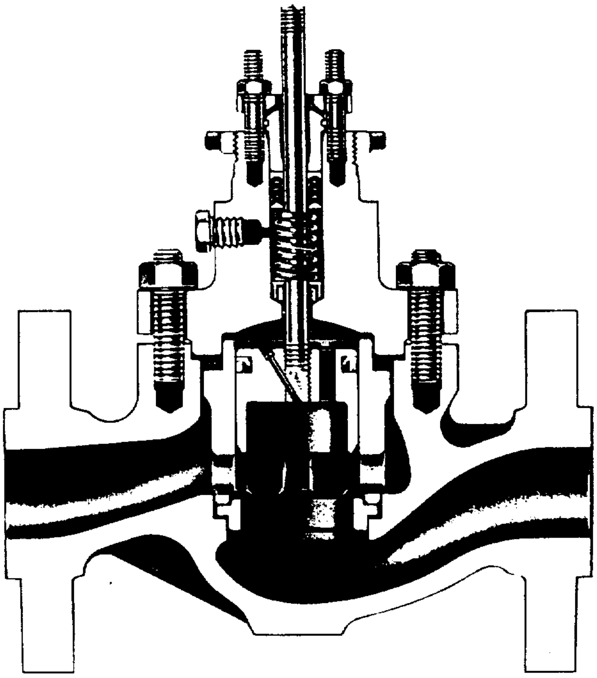

Figure 6-4—Globe Body Valve, Cage Guided

6.4 Control Valve Types

6.4.1 GENERAL

Today's control valves operate by one of two primary motions: reciprocating (sliding stem) motion, or rotary motion. The selection of a valve for a particular application is primarily a function of the process requirements, and no attempt will be made here to cover this subject. Some of the more common types of control valve bodies are discussed in 6.4.2 through 6.4.8.

6.4.2 GLOBE BODY VALVE

The globe valve design illustrated in Figure 6-4 is known as cage guided. This design uses a piston or plug moving inside a cylindrical guide (cage) having characterized ports. In this design two options are available:

1. A single-seat construction for minimum leakage in the closed position.
2. A balanced construction requiring less actuator force, but possibly allowing more leakage in the closed position. The

valve trim may be replaced without removing the valve body from the line.

The globe valve design illustrated in Figure 6-5 is known as top guided. In this design the plug guiding is accomplished within the lower portion of the valve bonnet. This design is a single-seat type and provides minimum leakage in the closed position. Because of the unbalanced construction, it requires considerable actuator power, particularly in larger sizes.

The globe valve design illustrated in Figure 6-6 is known as top and bottom guided. In this design the plug guiding is accomplished in the valve bonnet and the valve bottom flange. It is a double-seat type and has a higher leakage rate in the closed position than a single-seat type. The plug design does provide a balancing feature, which reduces required actuator forces.

A similar design, but with single-seat construction, is also available from some manufacturers.

Another variation is the split body valve shown in Figure 6-7, which is available both in globe- and angle-type patterns. In this valve, the seat ring is clamped between the two body sections, which makes it easily removable for replacement. This design is a single-seat type and minimizes leakage in the closed position. However, because of the unbalanced construction, it requires considerable actuator power, particularly in the larger sizes. Guiding is accomplished in the upper portion of the valve body and is known as stem guiding. The split body valve is used extensively in chemical processes because of (1) its availability in alloy materials and (2) its use of separable flanges, which can be manufactured from less expensive materials.

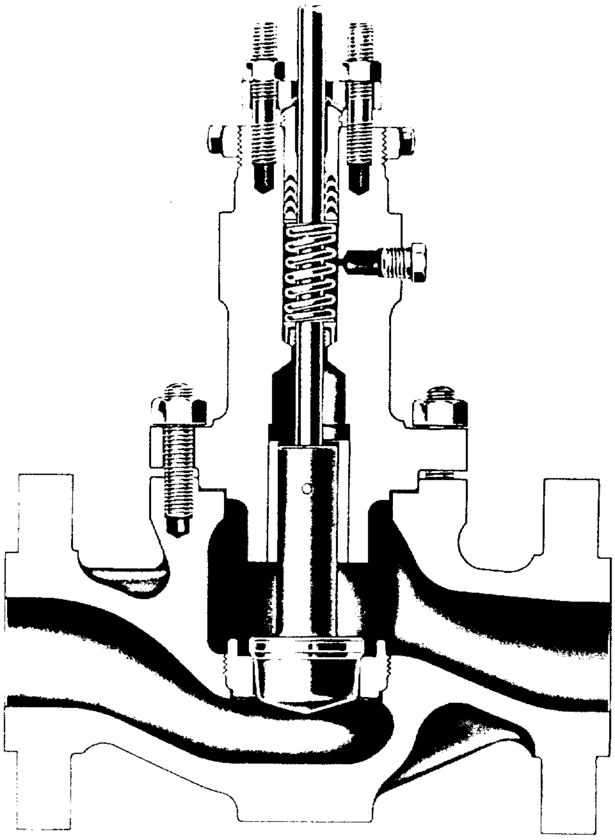

Figure 6-5—Globe Body Valve, Top Guided

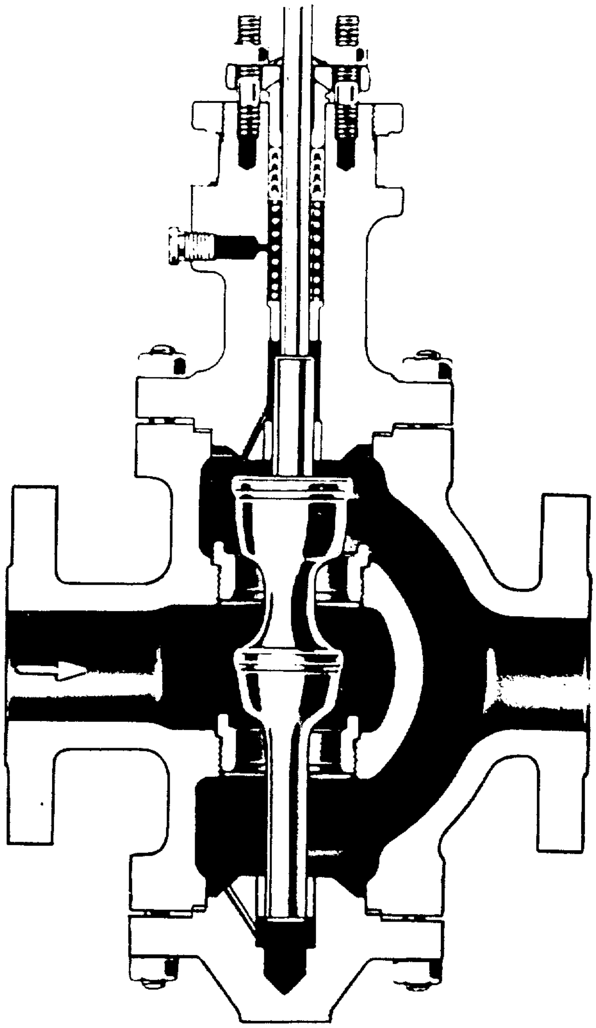

Figure 6-6—Globe Body Valve, Top and Bottom Guided

6.4.3 BUTTERFLY VALVE

The butterfly valve shown in Figure 6-8 is a rotating-vane valve characterized by high pressure-recovery (see 6.5.4) and used in applications where high capacity and low pressure

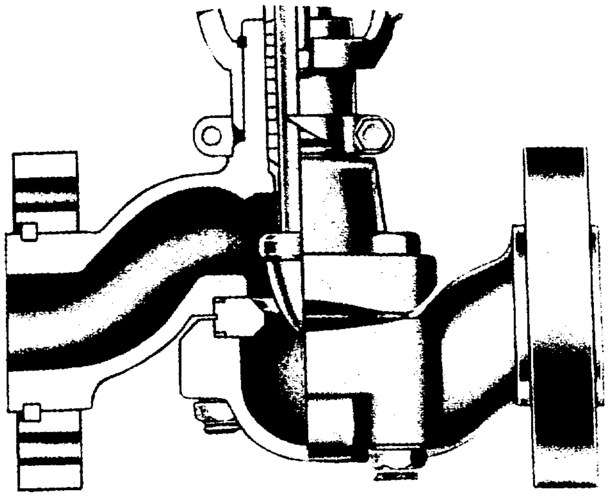

Figure 6-7—Split Body Valve, Stem Guided

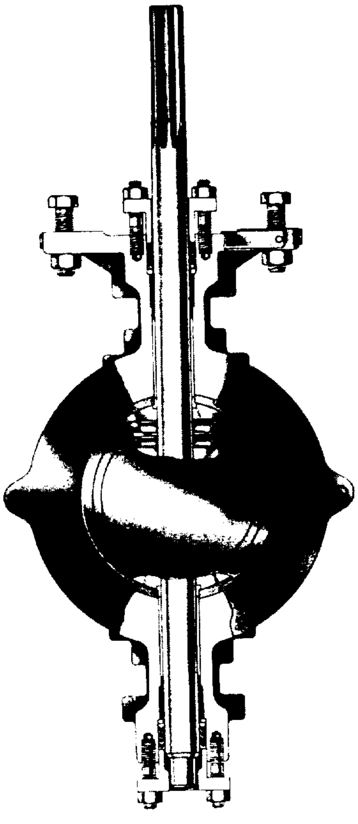

Figure 6-8—Butterfly Valve

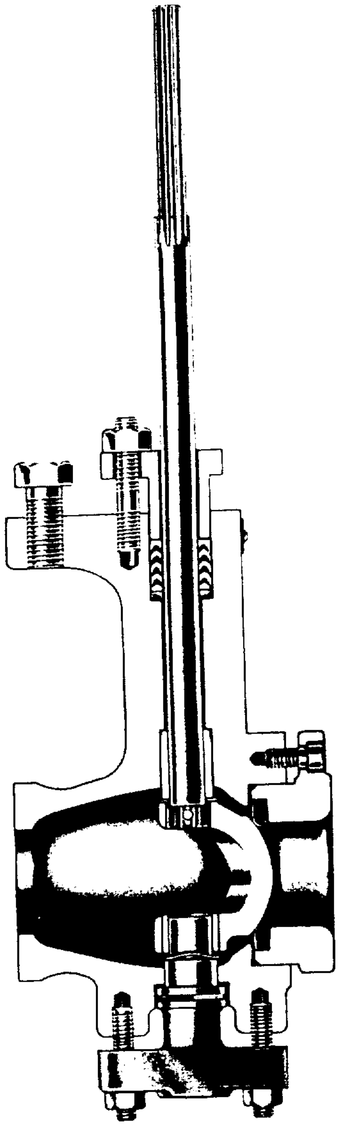

Figure 6-9—Ball Valve

drop are required. Although not normally used in minimum leakage applications, it is available with piston ring, pressurized seat, or various types of elastomer seating surfaces if minimum leakage is required.

6.4.4 BALL VALVE

The ball control valve shown in Figure 6-9 is a rotating-stem, high pressure-recovery type of valve in which the flow of fluid is restricted by using a full- or partial-type ball in the valve body. This valve has a high flow coefficient and

Figure 6-10—Eccentric Plug Valve

may be used to control many types of fluids. However, it is especially useful in handling fibrous materials and slurries and in applications where very high rangeability is required. It can provide minimum leakage in most cases.

6.4.5 ECCENTRIC SPHERICAL PLUG VALVE

The rotating-stem valve shown in Figure 6-10 has a plug in the form of a spherical segment mounted off-center to the stem. The eccentric cam-like plug motion prevents physical contact between plug and seat ring until the instant of seating. It has a flow coefficient and rangeability capability between those of a globe valve and a ball valve. The single-seat design provides minimum leakage in the closed position.

6.4.6 THREE-WAY VALVE

The three-way valve shown in Figure 6-11 is a special type of valve primarily used for splitting (diverting) or mixing (combining) service. It is most commonly used for the controlled mixing of two streams or for diverting streams through or around exchangers to control the heat transferred. It should be noted that there are various three-way valve constructions available. It is best to consult the manufacturer for the proper application.

6.4.7 SAUNDERS VALVE

In this valve design, shown in Figure 6-12, the flow is directed over a transverse weir, and closure is obtained by compressing a dome-shaped diaphragm upon the weir. The design intent is minimum-leakage shutoff, corrosion resistance, and a high ratio of internal area to pipe size. The streamline design produces a self-cleaning action so that the valve is often used on sludges and viscous liquids. The body can be fully lined with materials such as glass, plastics, and synthetic or natural rubber to improve corrosion resistance. Closure diaphragms may also be made of a variety of materials, such as rubber, polytetrafluoroethylene[9], and monochlorofluoroethylene polymer.[10]

6.4.8 MISCELLANEOUS VALVE BODY TYPES

There are many other types of valves available for control service. Among these, gate valves, plug valves, and slide and rubber pinch valves should be noted.

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[9] For example, Teflon.

[10] For example, Kel F.

Special-purpose valves are available, such as those designed to reduce noise, cavitation, and erosion (see 6.5.5 and 6.6) through the use of tortuous internal paths or multiple orifices. Typical designs are illustrated in Figures 6-13 and 6-14. In most cases these valves use the same types of actuators as the control valves previously mentioned.

6.4.9 SELF-ACTUATED REGULATORS

The self-actuated regulator is a variation of the diaphragm actuator and normally uses the process fluid as the operating medium. For pressure applications, some self-actuated regulators use bellows instead of diaphragms for the actuator. For temperature applications, bellows with a filled system and bulb are used instead of diaphragms. Piping arrangements are shown in Figure 6-15.

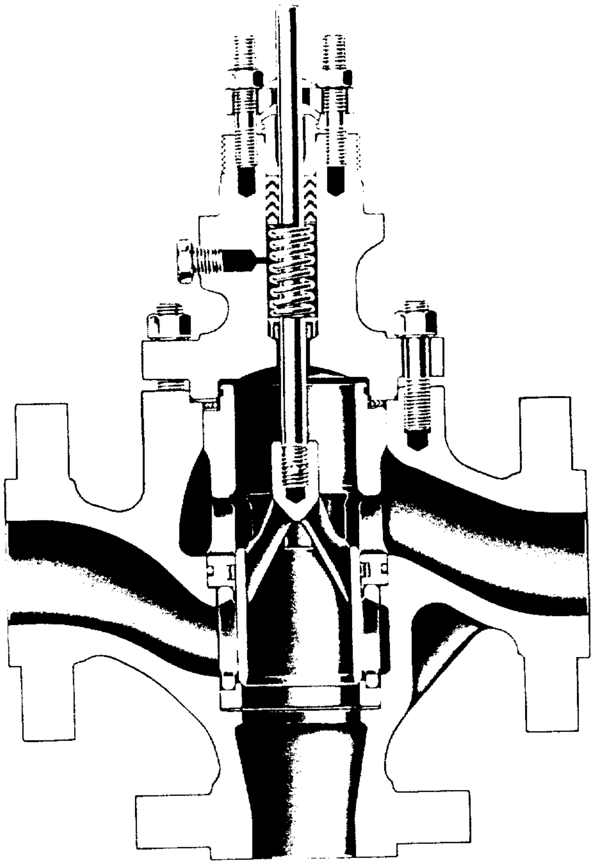


Figure 6-11—Three-Way Valve

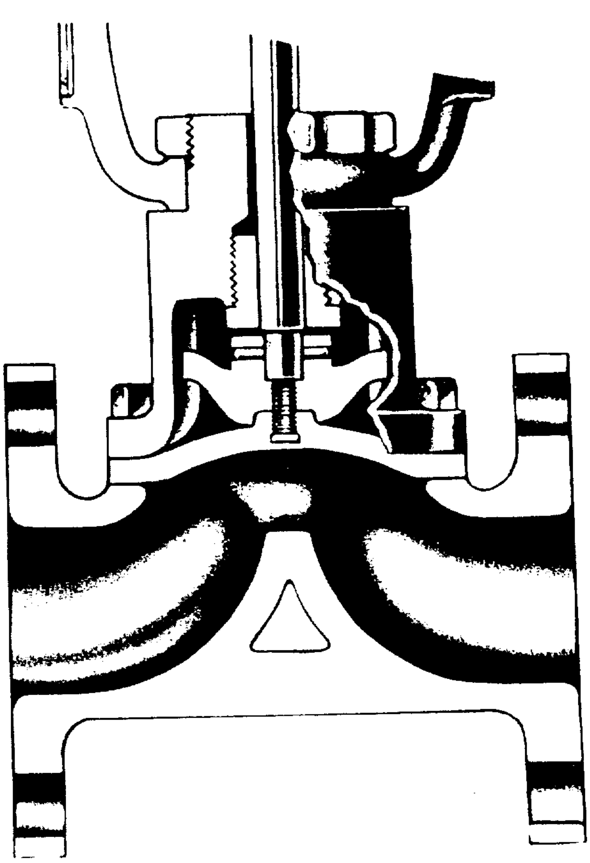


Figure 6-12—Saunders Valve

6.5 Factors Affecting Control Valve Sizing

6.5.1 DEFINITION OF TERMS

The definitions in 6.5.1.1 through 6.5.1.3 have been simplified for clarity.

6.5.1.1 Choked Flow

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

6.5.1.2 Vena Contracta

Vena contracta is that point downstream of the flow restriction where the flow stream reaches its minimum cross-sectional area and thus its maximum velocity and minimum pressure.

6.5.1.3 Critical Pressure Ratio

The critical pressure ratio is the minimum pressure attainable at the vena contracta of a restriction divided by the inlet pressure.

6.5.2 GENERAL

Correct sizing of control valves is necessary to optimize operation, provide sufficient rangeability, and minimize cost. The key to correct control valve sizing is the proper determination of the required valve capacity coefficient (C_V).

By definition, C_V is the number of gallons per minute of water at 60 F (15 C) that will pass through a given flow restriction with a pressure drop of 1 pound per square inch (7 kilopascals). For example, a control valve that has a maximum flow coefficient (C_V) of 12 has an effective port area in the full open position such that it passes 12 gallons per minute of water with a pressure drop of 1 pound per square inch (7 kilopascals).

Determination of the required C_V for a given application may be accomplished through formula or slide rule methods. For detailed information regarding control valve sizing equations refer to ISA S75.01-1977, *Control Valve Sizing Equations*. In addition, most valve manufacturers publish information on this subject. In using these methods, full knowledge of actual flowing conditions is essential. The primary factors that should be known for accurate sizing are (1) the upstream and downstream pressures at the flow rates being considered, (2) the generic identity of the process fluid, (3) the temperature of the fluid, (4) the fluid phase (gas-liquid, slurry, and so forth), (5) the density of the fluid (specific gravity, specific weight, molecular weight, and so forth), (6) the viscosity (liquids), and (7) the vapor pressure (liquids).

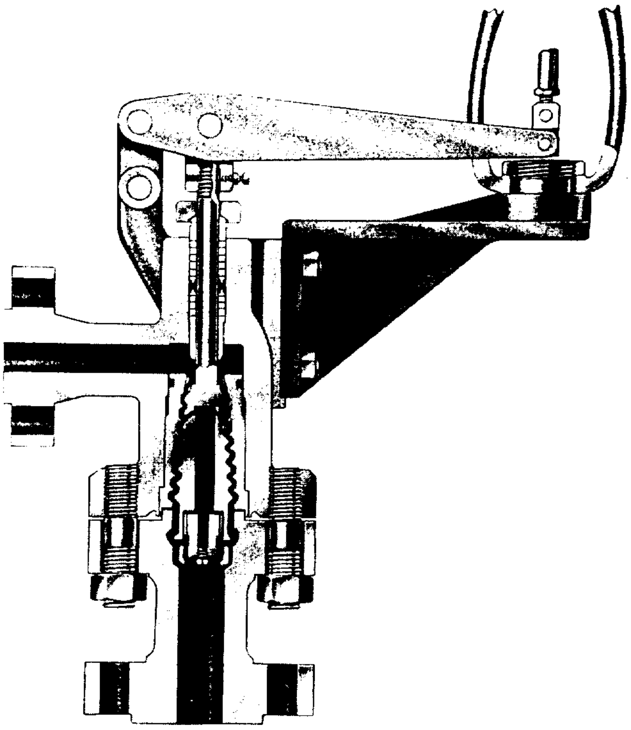


Figure 6-13—Angle Body Valve, Low Noise Trim

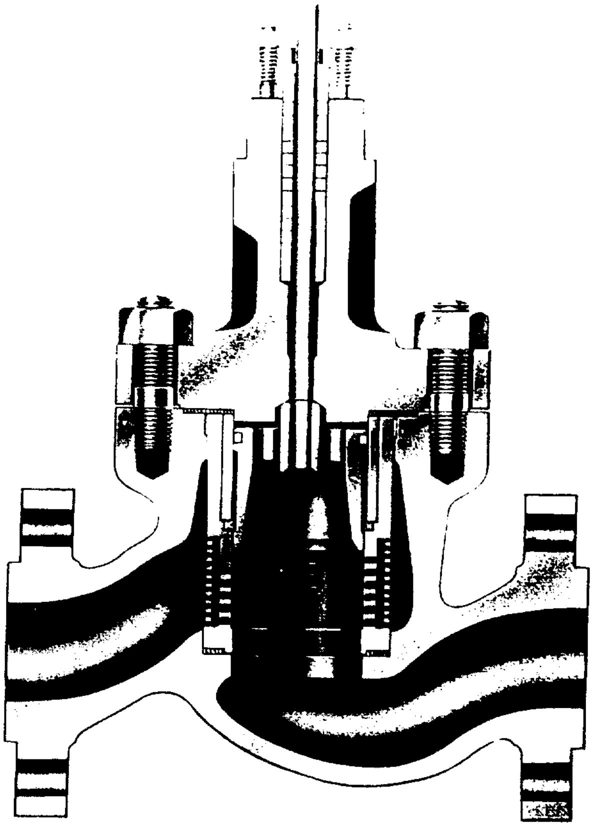


Figure 6-14—Globe Body Valve, Low Noise Trim

As part of valve selection, the overall system in which the valve is to be installed must be considered. A typical system (in addition to the control valves) includes a pump or compressor, which provides energy, and other types of refinery equipment, such as piping, exchangers, furnaces, and hand valves, which offer resistance to flow. Figure 6-16 describes the hydraulics of such a system. 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 were used, the flow would always be at the rate indicated by the intersection of the two curves.

Other factors that directly relate to sizing and selection follow in 6.5.3 through 6.5.8.

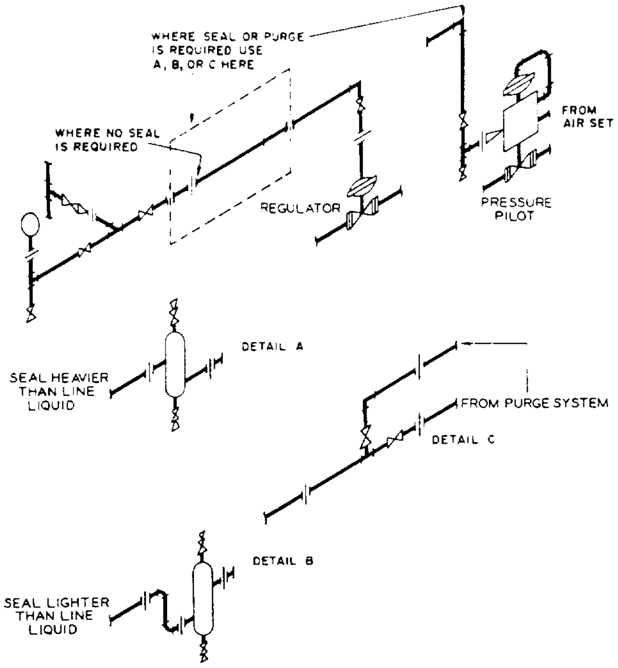


Figure 6-15—Piping at Regulator Valve or Pressure Pilots

6.5.3 PIPING INFLUENCE

The presence of reducers upstream and downstream of the valve will usually result in a reduction in capacity because of the creation of an additional pressure drop in the system by these enlargements or contractions in series with the valve. Capacity correction factors that can be simply applied to calculated C_V values are readily available from most manufacturers for the various styles of valves.

6.5.4 PRESSURE RECOVERY

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. 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. Pressure recovery in liquid flow results in a vena contracta pressure lower than the downstream pressure and can cause cavitation (see 6.5.5).

Pressure recovery in gas or vapor flow has the effect of achieving choked flow at a pressure drop that is less than would be predicted by the critical pressure ratio.

Because the capacity coefficient C_V is measured with pressure recovery (using water at low pressure drop), the flow rate at choked conditions for liquid or gas will be incorrectly predicted unless a pressure recovery coefficient is included in the valve sizing formula. Pressure recovery coefficients have been established by valve manufacturers for the various valve body configurations.

As a general comment, globe-style valves have lower pressure recovery than ball or butterfly styles.

6.5.5 CAVITATION

Cavitation is a two-stage phenomenon, the first stage of which is the formation of vapor bubbles within the liquid system. The second stage is the collapse or implosion of these bubbles back into the all-liquid state. This phenomenon will affect valve sizing procedures and may limit the life expectancy of the valve components and immediate downstream piping.

Control valves with inherent high pressure-recovery characteristics can cause cavitation when fluid pressure and temperature conditions would indicate otherwise.

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 to stage the pressure reduction through the use of two or more valves. Manufacturers should be consulted for recommendations.

6.5.6 FLASHING

If the cavitation process stops before the completion of the second stage, so that vapor persists downstream of the region where bubble collapse normally occurs, the process is known as flashing. Flashing, like cavitation, can cause physical damage and decreased valve capacity. Manufacturers should be consulted for recommendations.

6.5.7 RANGEABILITY

The rangeability required for the control valve should be considered during valve selection. Although many control valves are available with published ranges of 50 to 1 and even greater, remember that these are at constant pressure drop, a condition that rarely exists in actual practice. The requirement for rangeability is that the valve must handle the maximum flow at the minimum pressure drop available down to the minimum flow at maximum pressure drop.

Sizing calculations should be checked at both extremes to assure controllability over the entire range of flow rates and pressure drops.

6.5.8 GUIDELINES

Unfortunately, precise data (as shown in Figure 6-16) often are not available at the time the control valve must be sized.

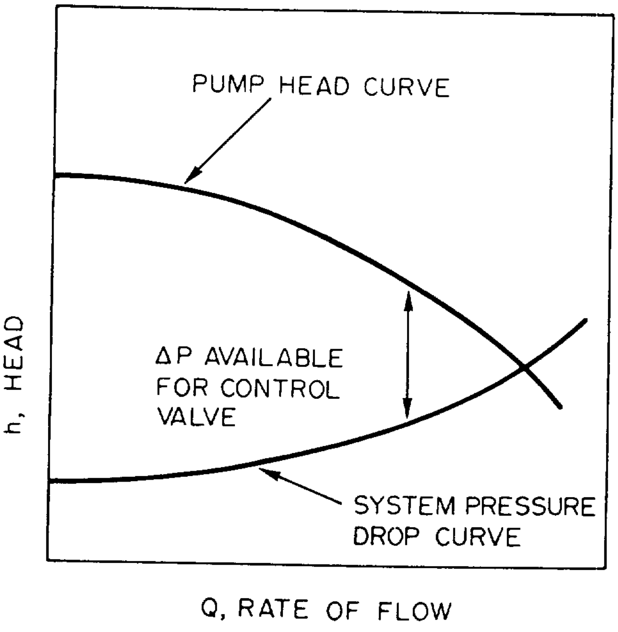


Figure 6-16—Typical Pump Head and System Pressure Drop Curves

Therefore, many users have developed guidelines to assist in this process. Obviously these do not fit all applications and must be used with sound engineering judgment. Some of the guidelines that are employed are the following:

1. The control valve pressure drop should equal 30 percent of the system dynamic pressure drop at the normal flow rate.
2. The calculated C_V should be multiplied by a factor of 1.2 to 2.
3. The control valve should be one size smaller than the line.

6.6 Control Valve Noise

6.6.1 GENERAL

Under certain conditions control valves can produce noise, which at a high enough level can be an annoyance, prevent speech communication, damage workers' hearing, and cause physical damage to equipment.

Present federal government regulations limit the noise level in industrial locations to 90 decibels absolute for an 8-hour exposure, or 115 decibels absolute for up to 15 minutes exposure.

NOTE: Because the noise level limits specified in the regulations are subject to change, periodic verification will be necessary.

Control valve noise can be reduced by piping design, acoustical insulation, or use of special control valves. Special-purpose control valves designed to reduce noise levels are available. Manufacturers are able to supply noise prediction methods. Further reference material on this subject is available in API Publication 931, *Manual on the Disposal of Refinery Wastes, Volume on Atmospheric Emissions,* Chapter 17—Noise.

Figures 6-13 and 6-14 illustrate typical control valve designs intended for this type of service. The three ways that a control valve can develop noise are described in 6.6.2 through 6.6.4.

6.6.2 MECHANICAL VIBRATION

Mechanical vibration is induced by the pulsation of a fluid (liquid or gas) passing through the valve, and can lead to resonance of the valve trim and fatigue failure of the valve stem, plug post, or other parts. Possible cures for this type of noise include reduction of guide clearances, larger stem size, change in plug mass, or sometimes reversal of flow direction.

6.6.3 CAVITATION

The phenomenon of cavitation has been described in 6.5.5. In addition to limiting the life expectancy of valve components and downstream piping, cavitation creates noise. Some methods for prediction of noise levels in liquids exist, but much work remains to be done.

6.6.4 AERODYNAMIC NOISE

Aerodynamic noise is the result of turbulent flow. The higher levels of aerodynamic noise occur at the higher velocities associated with gas flow. While the other forms of noise generation are more significant with respect to the valve damage they cause, aerodynamic noise propagates to the upstream and, to some degree, the downstream piping. As a result, this noise is accompanied by the damaging effects of vibration and the creation of annoying or potentially dangerous sound pressure levels in the surrounding atmosphere. The problem can be reduced by the use of one or a combination of the following:

1. Specially designed valves that have tortuous paths or multiple orifices to reduce velocities.
2. Several valves or valves and orifices in series.
3. In-line mufflers upstream and downstream.
4. Heavy-walled piping.
5. Acoustic insulation covering the affected piping.

While the last three items can effect ambient noise level reduction, it should be noted that the potential for damage to the piping will not be reduced and that the noise will still propagate in the piping beyond the insulation.

6.7 Control Valve Actuators

6.7.1 GENERAL

There are many types of actuators for stroking control valves. The selection of a particular actuator is a function of the following:

1. Operating media available (air, hydraulic fluid, or other).
2. Thrust requirements.
3. Length of stroke.
4. Speed of stroke.
5. Control valve body type.

In addition, control valve actuators should be selected so that on failure of the operating medium the valve will automatically take a position (open, closed, or locked) that will result in the safest configuration for the operating unit. Total failure of the operating medium, as well as failure at the specific valve only, should be considered during the selection of an actuator. Some of the more commonly used types of actuators are described in 6.7.2 through 6.7.4.

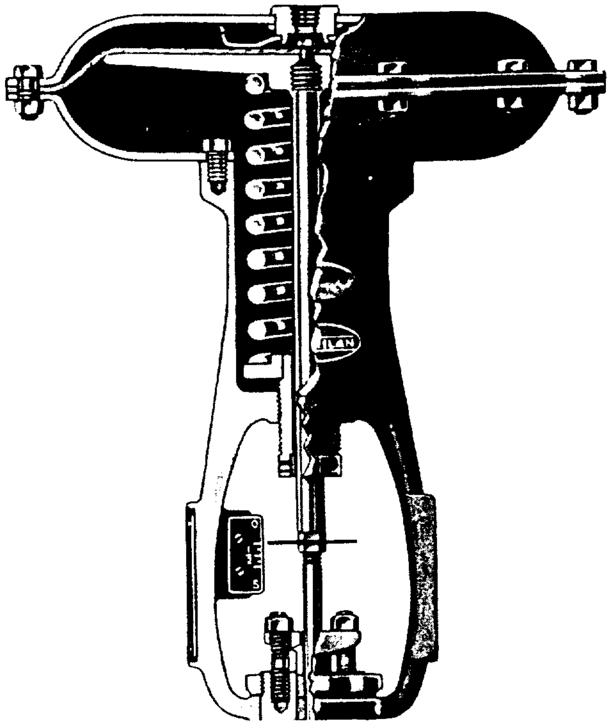


Figure 6-17—Spring Diaphragm Actuator

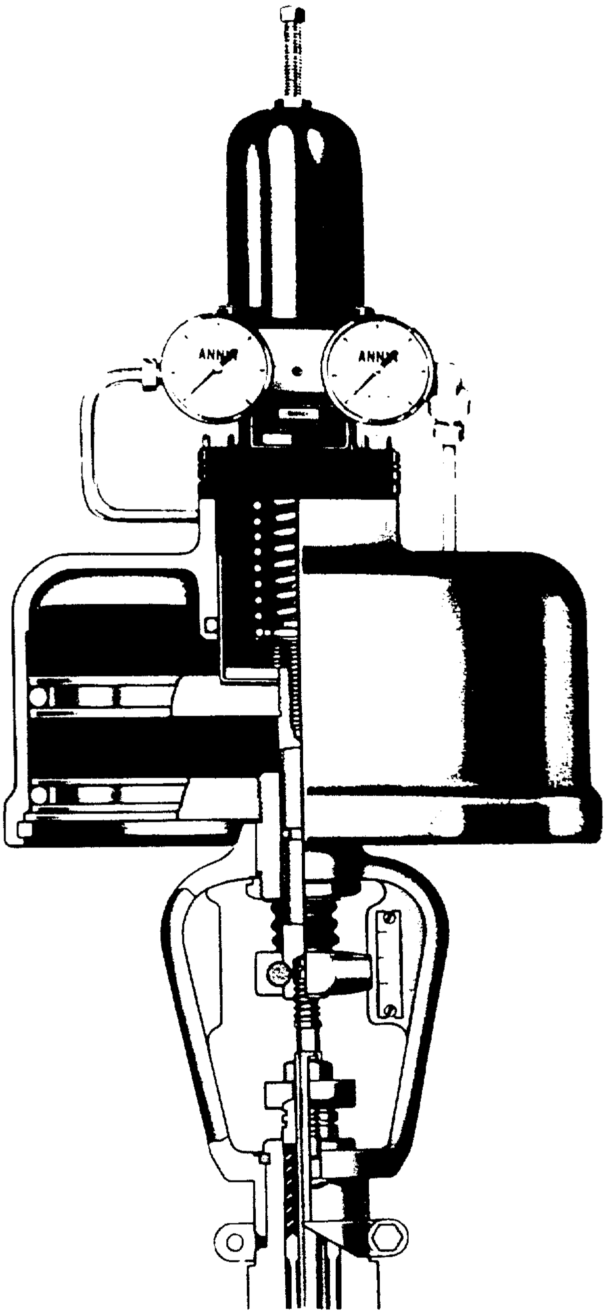


Figure 6-18—Piston Operator

6.7.2 SPRING DIAPHRAGM ACTUATORS

The spring diaphragm, with air as the operating medium, is the most commonly used type of control valve actuator. Construction of a typical spring diaphragm actuator is shown in Figure 6-17.

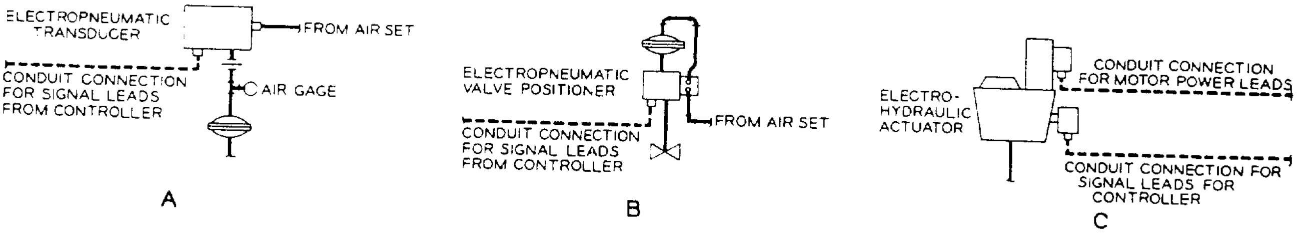


Figure 6-19—Electropneumatic and Electrohydraulic Actuators

Actuators are usually 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).

Selection of direct or reverse action is usually based upon failure requirements of the control valve, with reliance placed on the spring to drive the control valve to the desired position in the event of operating medium failure.

Commonly accepted operating spring ranges are nominally 3-15 pounds per square inch gage (20-100 kilopascals) and 6-30 pounds per square inch gage (40-200 kilopascals). Other spring ranges are utilized when necessary to provide thrust for specific applications. The air pressure required for stroking the valve (bench range) measured when the valve is not under operating conditions may vary from the operating spring range because the static and dynamic loads induced by the process fluids are not present. The maximum air pressure allowable on spring diaphragm actuators usually does not exceed 60 pounds per square inch (400 kilopascals). The amount of thrust a given spring diaphragm actuator will develop is based on a combination of case size (effective area), spring range, and available operating air pressure.

Most manufacturers publish tables that allow proper selection of actuator size based on valve size, flow direction, air action, and pressure drop. These tables will usually allow selection of larger actuators or varying spring ranges to handle pressure drops higher than those allowable with standard actuators.

It should be remembered that guidelines for actuator selection, unless they state otherwise, will be based upon the assumption that the control valve will be required to operate against the maximum differential pressure expected (usually taken to be the maximum upstream pressure) with the downstream pressure vented to the atmosphere. This condition for selection of the actuator ensures adequate power for maximum service conditions but can drastically affect operator size, particularly on larger valve sizes.

6.7.3 PISTON ACTUATORS

Piston or cylinder actuators are usually used where valve designs with long strokes or high forces are encountered. Construction of a typical piston operator is shown in Figure 6-18. The piston or cylinder can be operated hydraulically or with air or gas. Both single- and double-acting piston actuators are available. The choice depends on whether high torques and forces are required in both directions of valve movement. For failure (fail-safe) information see 6.8.8.

A variation of this type is the electrohydraulic operator, which uses a continuously running electric motor to drive a pump and supply hydraulic pressure for the piston (see Figure 6-19, Arrangement C).

6.7.4 MOTOR ACTUATORS

Motor actuators for control valves can be electrical, hydraulic, or air- or gas-powered. Air- or gas-driven motors usually use a vane or nutating disk.

Electric-motor-driven actuators should be mounted so that the motor is above the gear box. This arrangement prevents gear oil from saturating the motor windings.

Air motors of the air-turbine or nutating-disk type normally require an aspiration-type lubricator in the air supply line.

6.8 Control Valve Accessories

6.8.1 GENERAL

Control valves may be supplied with a variety of accessory equipment such as extension bonnets, positioners, electropneumatic positioners and transducers, booster relays, solenoids, and so forth.

In 6.8.2 through 6.8.7 the more common accessories are described. For other accessories (such as position transmitters, limit switches, travel stops, and so forth) the manufacturer should be consulted.

6.8.2 EXTENSION BONNETS

The standard control valve bonnet, with the packing area relatively near the bonnet flange connection, is usually limited to temperatures not exceeding 450 F (232 C). For higher temperatures an extension bonnet containing sufficient area to provide radiating heat loss may be used (see Figure 6-20). In no case should such a bonnet be covered with thermal insulating material.

A similar bonnet design is employed on low-temperature applications (-20 F [-29 C] and below). This extension bonnet places the packing far enough away from the cold area of the valve to prevent freeze-up of the packing.

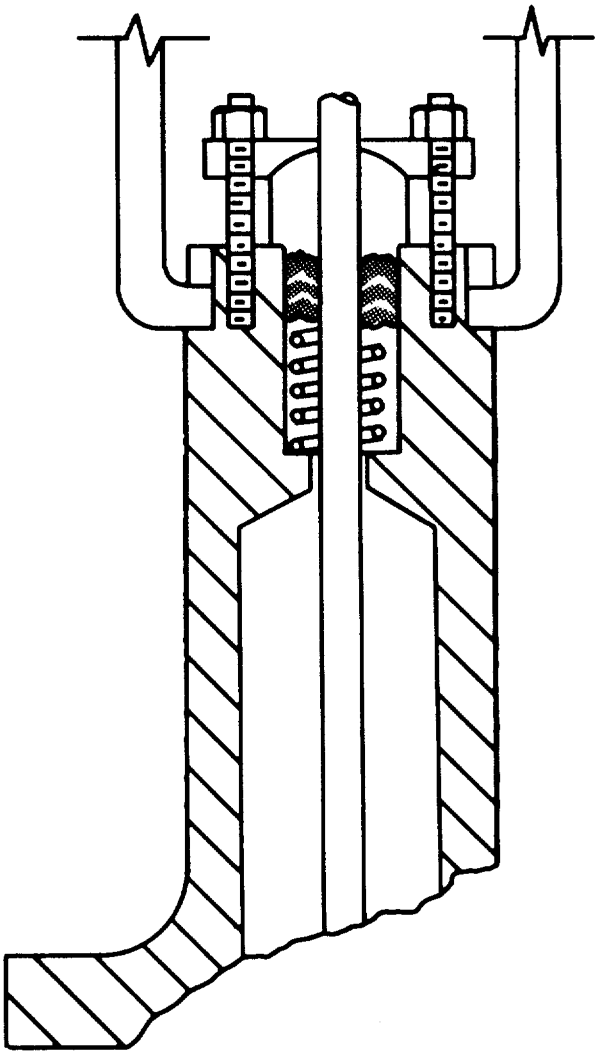


Figure 6-20—Extension Bonnet

6.8.3 POSITIONERS

Control valves have inherent operation characteristics that hinder precise positioning under varying operating conditions.

Factors such as a pressure differential across the valve seat, overtightening of packing, and viscous or fouling service can create additional forces preventing the valve from assuming the position called for by the controller.

The valve positioner compares the valve stem position with the demand generated by the controller. If the valve stem is incorrectly positioned, the positioner either increases or decreases the air in the actuator until the correct valve stem position is obtained.

The following is a list of six functions a positioner can accomplish:

1. Provide for split-range operation.
2. Improve transmission line speed of response to accommodate large actuator volumes at the end of signal transmission lines.
3. Reverse the valve action without changing the "fail-safe" action of the spring in the actuator. (Note that this may also be done with a reversing-type relay.)
4. Increase the thrust in spring diaphragm actuators for use in high pressure-drop applications, and allow the same linearity in the installed characteristic as in the "bench setting" characteristic.
5. Change the control valve flow characteristic (cam-type positioner).
6. Improve the resolution or sensitivity of the actuator where high-precision valve control is required. Precision is enhanced by the availability of positioners with various gains, and by the fact that modern packings generally have equal static and dynamic coefficients of friction which eliminate the stick/slip behavior.

In the past a positioner was thought to reduce control loop stability for fast acting loops. Modern positioners with volume or pressure boosters, where required, can be made faster than any actuator without a positioner.

6.8.4 HANDWHEELS

Handwheels can be supplied with most types of valves. They provide the operator with the means to override the control system and to operate the valve manually. Various designs are available, including those that can stroke the valve in either direction and those that stroke the valve in one direction, relying on the valve spring for the return stroke. Some handwheels are continuously connected. Others use a clutch, pin, or other means of engagement, and must be disengaged when not in use or damage may result. Some designs may also be used as limit stops. A typical handwheel is shown in Figure 6-21.

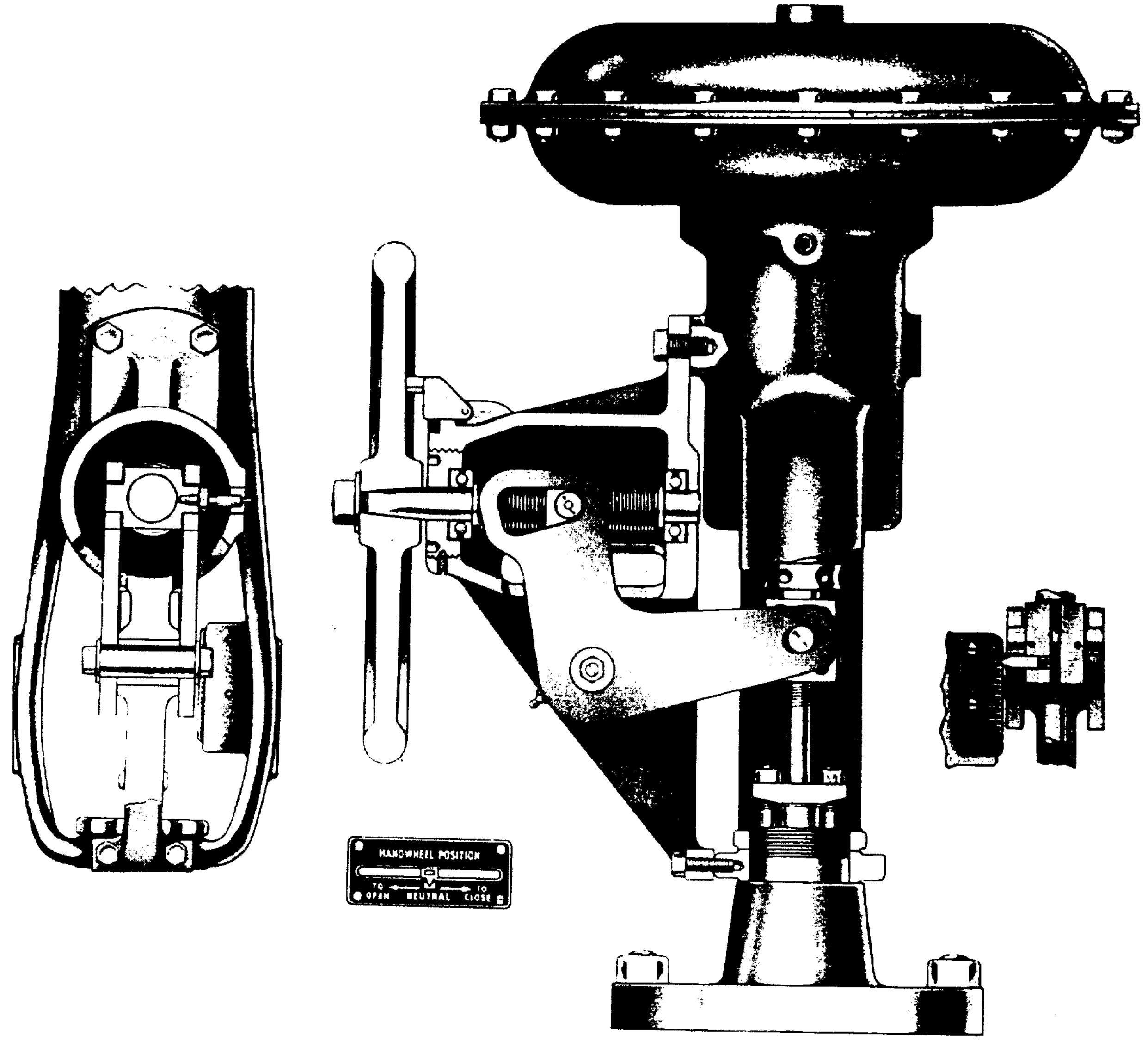


Figure 6-21—Side-Mounted Auxiliary Handwheel

6.8.5 ELECTROPNEUMATIC TRANSDUCERS

Electropneumatic transducers convert the electrical output signals from electronic controllers into pneumatic signals that may be used to operate diaphragm control valves. Mounting transducers on control valves is common practice. However, caution should be exercised since some transducers are susceptible to vibration.

6.8.6 BOOSTER RELAYS

Booster relays may be used to increase the speed of response of the control valve and are especially useful when the valve is remotely located from the controller.

The function of the pressure booster is to amplify the signal from the controller to above 20 pounds per square inch gage (138 kilopascals) in certain applications (see Figure 6-22).

Volume boosters are used to increase the speed of response of the control valve (see Figure 6-23). An application of a booster relay is included in 6.8.3.

6.8.7 SOLENOID VALVES

A common application of a solenoid valve to a diaphragm control valve is illustrated in Figure 6-24. In an emergency the solenoid valve can be switched, causing the control valve to go to the failure position.

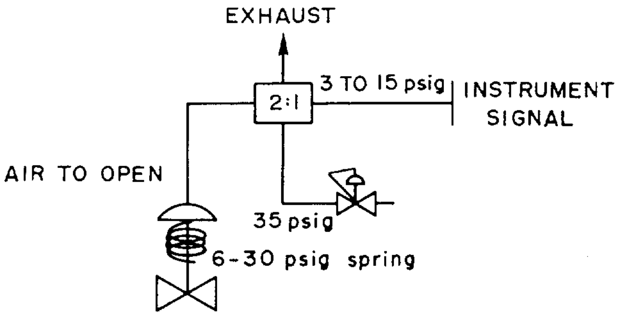


Figure 6-22—Pressure Booster in a Control Valve Loop

6.8.8 MISCELLANEOUS

Any of the pneumatically-powered actuators may be arranged in a variety of ways so that they hold their last position or drive to one extreme position in the event of air failure. These methods of arrangement are (1) trapping the air pressure in the diaphragm chamber by means of a soft-seated, tight shutoff valve (lockup valve), (2) providing a separate air volume tank as a reserve source of power, (3) mechanically locking the stem to prevent further travel, or (4) using a spring to drive the valve to an extreme position in the event of air failure.

NOTE: The first two methods are considered temporary only, since leakage of trapped air will occur over a period of time.

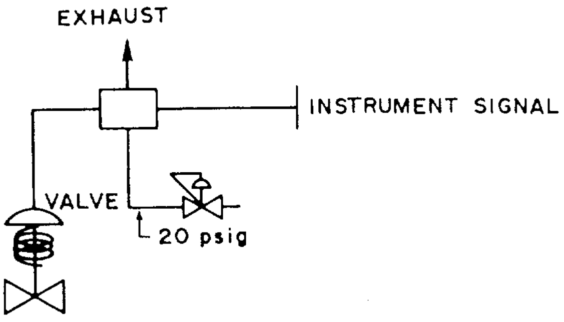


Figure 6-23—Volume Booster in a Control Valve Loop

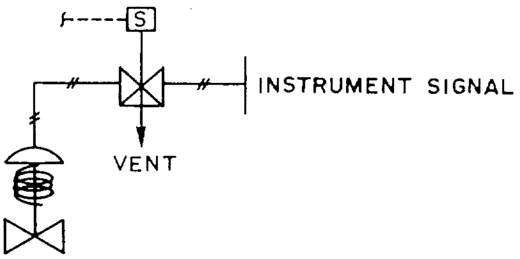


Figure 6-24—Three-Way Solenoid Valve in a Control Valve Loop

6.9 Control Valve Manifolds

6.9.1 GENERAL

The design of control valve manifolds varies widely because operating conditions and requirements for blocking and bypassing the control valve must be considered. In applications where a process shutdown for the servicing of control valves and the process can be safely operated manually, block and bypass valves should be provided. For details refer to Figure 6-25. Some users install blocks and bypasses only in smaller-size lines (up to 2 inches [50 millimeters] or some other arbitrary size) because experience may not economically justify their use in larger sizes.

When a high-recovery type of valve is to be used, the fact that the piping configuration can significantly reduce the capacity of the valve should be considered. In such a case it is advisable to obtain the valve manufacturer's recommendation.

For additional information on control valve manifolds reference may be made to ISA RP75.06-1981, *Control Valve Manifold Design*.

6.9.2 BLOCK AND BYPASS VALVES—FLEXIBLE DESIGN

Where the greatest flexibility is to be provided for future expansion, the block valves upstream and downstream of the control valve should be line size. In situations where the control valve is two or more sizes smaller than line size, the block valves may be one size smaller than line size.

It is often necessary, for purposes other than manual control, that bypass valves be full line size or not more than one size smaller. For example, this might be necessary in order to provide the capacity for filling and emptying the unit in a reasonable length of time, especially under gravity flow conditions. In addition, where a small control valve is installed in a large line, the larger bypass valve gives added mechanical strength to the manifold.

Caution should be exercised to prevent bypass valves from becoming so large that extremely poor bypass control results and larger relief systems are required. It is not unusual to make bypass valves smaller in such cases.

In selecting and sizing block and bypass valves the installed cost should be considered. In some cases the installed cost of the line-size valves is less than the cost of valves one size smaller plus the swages, welding, and labor required for installation. A further consideration is that when process conditions change, the control valve size can then be increased without changing the manifold.

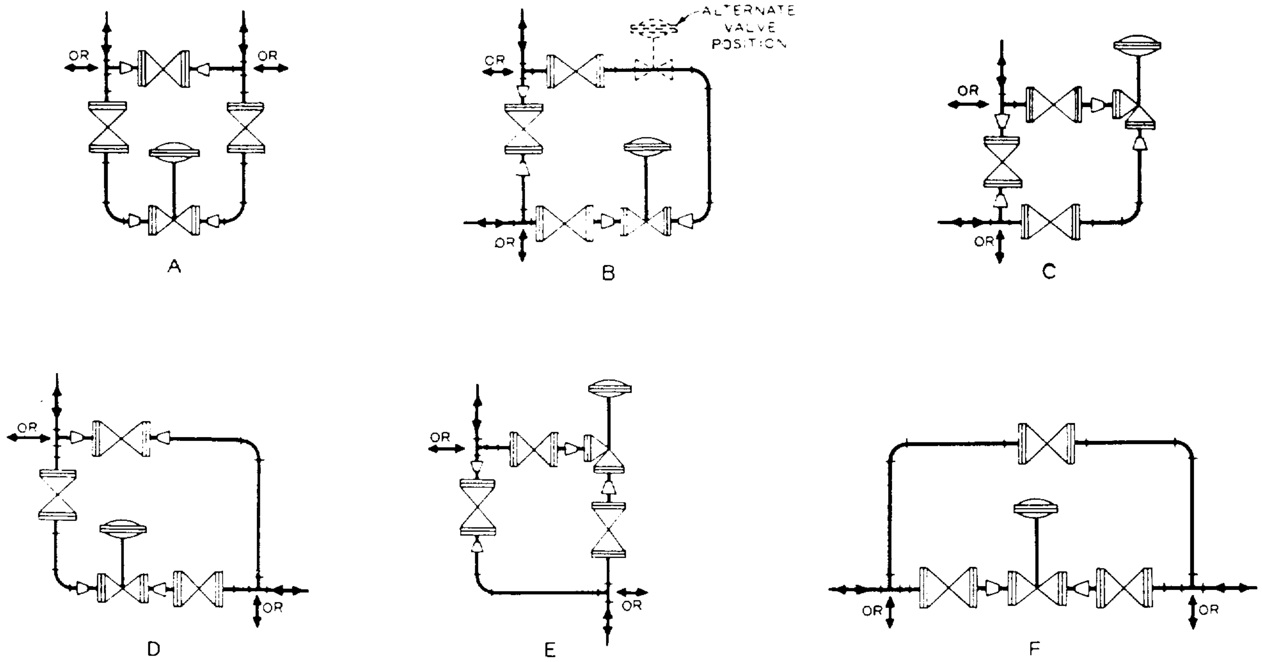
Bypass valves in sizes of 4 inches (100 millimeters) or less are usually globe valves that allow throttling. For larger sizes, because of cost, gate valves are normally used. Recommended minimum sizes for block and bypass valves are given in Table 6-1.

6.9.3 BLOCK AND BYPASS VALVES—MINIMUM DESIGN

Where significant future expansion is not anticipated, a less flexible but more economical approach that gives a minimum acceptable design is to make the block valves one size larger than the control valve (but no larger than line size). The bypass line and valve should normally have a capacity at least equal to the calculated or required C_V of the control valve, but not greater than twice the selected C_V of the control valve.

6.9.4 SWAGES AT CONTROL VALVES

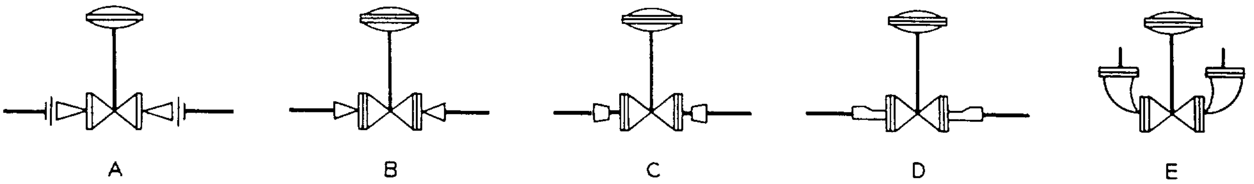
Where a screwed control valve smaller than line size is used, the union connections are placed at the large end of



NOTES:

1. Arrangement A (ISA RP75.06, Type 1) is preferred because the manifold is compact, the control valve is readily accessible for maintenance, and the assembly is easily drained.
2. Arrangement B is preferred because the control valve is more readily accessible.
3. Arrangement C is often used with angle valves. The control valve is self-draining and the valve is inaccessible.
4. Arrangement D (ISA RP75.06, Type 3) is preferred because the control valve is readily accessible. The bypass is self-draining.
5. Arrangement E results in a compact manifold, but the control valve may not be readily accessible.
6. Arrangement F is preferred because the bypass is self-draining; however, it requires greater space.
7. Block and bypass valves should be installed close to tees, as shown, to minimize pockets. Drain and vents on either side of the control valve are not shown, nor are the supports. Many manifolds can be rotated into any plane, keeping the control valve vertical.

Figure 6-25—Control Valve Manifold Arrangements



NOTES:

1. Arrangement A uses swages screwed into the control valve, with unions at the large ends of the swages.
2. Arrangement B uses flanges to match the control valve; a welding tee or ell is used at the large end of the swage.
3. Arrangement C uses extra pipe nipple between the swage and the flange to permit easy removal of bolts.
4. Arrangement D has eccentric swages, which are often used to permit complete drainage of the line and prevent buildup of deposits that may occur in concentric swages.
5. Arrangement E has reducing ells, which may be used in place of welding ells and swages where space is limited.

Figure 6-26—Swages at Control Valves

the swage with the smaller end screwed directly into the control valve. Schedule 80 (minimum) swages should be used to provide adequate support with minimum restriction to the flow. However, even heavier swages may be required to meet line specifications. Where a flanged or flangeless control valve smaller than line size is used, swages are placed adjacent to the control valve except where additional pipe nipples are required to permit removal of tie-rod through bolts.

Eccentric swages are often used in place of concentric swages to allow ready draining of the line and to prevent buildup of deposits in the pockets formed by the concentric swages. The use of swages at control valves is illustrated in Figure 6-26.

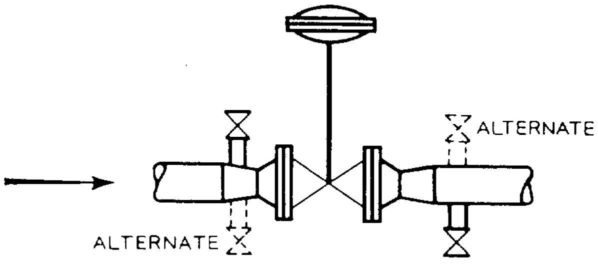
6.9.5 PIPING WITHOUT BLOCK AND BYPASS VALVES

A block and bypass valve system may not be necessary where the process can be shut down to repair the control valve without significant economic loss, or where the process cannot be feasibly operated on the bypass. However, the consequences of shutting down a process unit to perform a simple task (such as replacing control valve packing) should always be considered.

Some instances where these valves are not always necessary are the following:

1. With control valves in steam lines to pump drives that are sparing motor drives.
2. In instances where it is desirable to reduce the sources of leakage of hazardous fluids, such as hydrogen, phenol, or hydrofluoric acid.
3. In clean services where the operating conditions are mild, especially when 3-inch or larger valves are used and omission of the manifold will not jeopardize the safety or operability of the unit.
4. In interruptable operations.

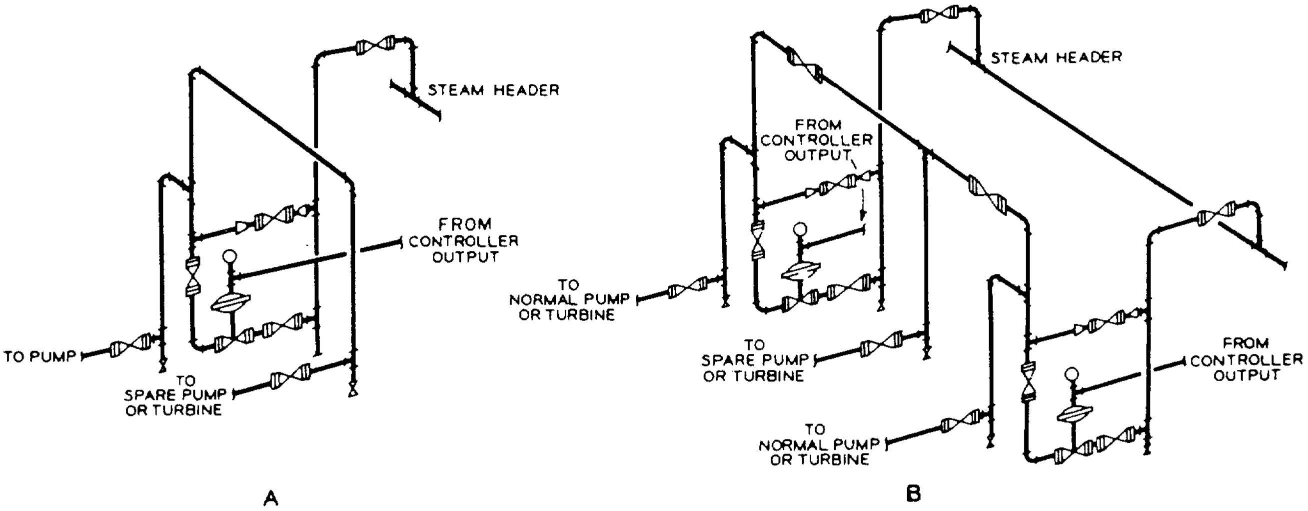
In cases where the block and bypass valves are not used, some users require that the control valve be equipped with a handwheel or other operating device.



NOTES:

1. Vent or drain connections may be placed in the line or in the swage as shown.
2. Nipples and valves are sometimes replaced by plugs or caps.
3. Various combinations of vents and drains are used successfully depending upon the requirements of the service.

Figure 6-27—Locations of Vent and Drain Valves



NOTE: See Figure 6-29 for piping notes.

Figure 6-28—Steam Piping to Spare Pump or Turbine

6.9.6 MANIFOLD PIPING ARRANGEMENTS

The manifold piping should be arranged to provide flexibility for removing control valves, particularly where ring-type joints are used. Flexibility of piping is also necessary to keep excessive stresses from being induced in the body of the control valve. Arrangements for vent and drain valves are shown in Figure 6-27. Nipples for such connections are usually a minimum of ¾-1 inch (20-25 millimeters), Schedule 80 or heavier as required to meet line specifications. Such connections may be used for (1) drains; (2) telltale indicators to determine absence of pressure when removing control valves; (3) vents; (4) bleeds; (5) flushing; (6) extra pressure taps; and (7) sample connections. The piping around control valves should be self-supporting or should be permanently supported so that when the control valve or block valve is removed, the lines will remain in place without the necessity of providing temporary supports.

Control valve manifold piping arrangements are shown in Figure 6-25. Details of steam piping to pumps or turbines are shown in Figures 6-28 and 6-29.

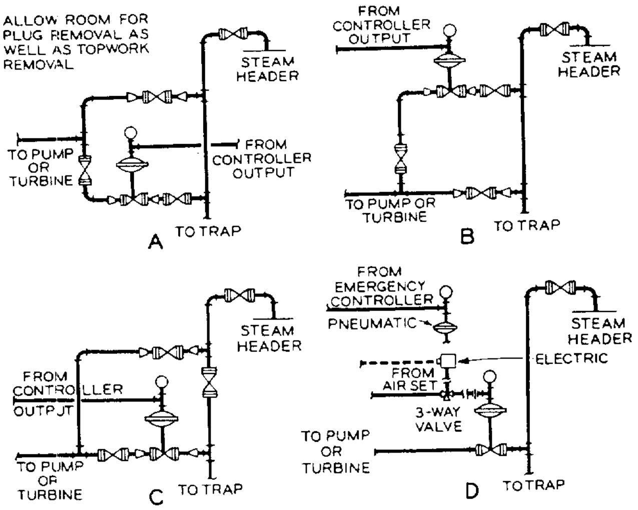
6.10 Piping and Wiring to Control Valve Actuators

6.10.1 GENERAL

This discussion covers the installation of piping and wiring for control valves and associated equipment.

The following codes and standards, as well as references to other separate sections of this manual, should be followed as they apply to the installation of equipment:

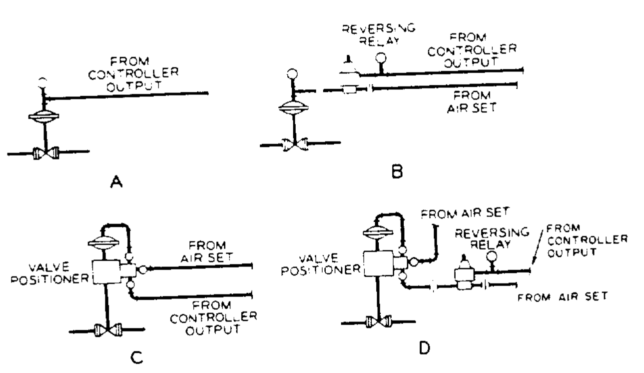
1. NFPA 70, *National Electrical Code*.



NOTES:

1. Arrangement A makes the control valve readily accessible; the piping is self-draining. The steam inlet may be above the minimum distance required for plug removal.
2. Arrangement B may be used where the bypass can be installed at the turbine or pump inlet. The control valve may be too high for easy access; the piping is self-draining.
3. Arrangement C is often used to make the control valve more accessible because the control valve can be located at the same elevation as the turbine or pump steam inlet.
4. Arrangement D is often used for emergency start or stop of the pump or turbine.
5. The bypass and bypass valve should not be so located as to form a pocket; they should be self-draining.
6. The location of separators, strainers, and traps is not shown because company standards differ on use and placement. The control valve should be located as low as possible for easy access.

Figure 6-29—Control Valve Arrangements for Steam to Pump or Turbine



NOTES:
1. Arrangement A shows nominal control valve piping with a gage for reading diaphragm pressure.
2. Arrangement B shows the control valve with a reversing relay. The reversing relay is used to reverse controller output to the valve when two valves with different actions are connected to one controller. The reversing relay is also used to provide the same action when on automatic or manual control.
3. Arrangement C shows the control valve with a positioner.
4. Arrangement D shows the control valve with a positioner and reversing relay. The reversing relay is the same as used in Arrangement B with the standard control valve. In addition, the reversing relay allows the positioner to be bypassed. A reverse acting positioner may be used, but it may not be bypassed.

Figure 6-30—Piping at Control Valves

2. API RP 500A, *Recommended Practice for Classification of Areas for Electrical Installations in Petroleum Refineries.*
3. ANSI/ISA S75.01-1977, *Standard Control Valve Sizing Equations.*

6.10.2 POWER SUPPLY

The actuator power supply may be instrument air, gas, hydraulic fluid, or electricity. It must be at a suitable level and of adequate capacity for the actuator to assure operation of the control valve under the most severe conditions. Capacity should be based on the most stringent requirements of the actuator.

6.10.3 DIAPHRAGM ACTUATORS

Diaphragm actuators may be operated directly by the controlled air signal or through positioners or booster relays.

Pneumatic piping to diaphragm-actuated control valves is shown in Figure 6-30. Piping arrangements for solenoids and booster relays are illustrated in Figures 6-22, 6-23, and 6-24.

6.10.4 PISTON OR CYLINDER ACTUATORS

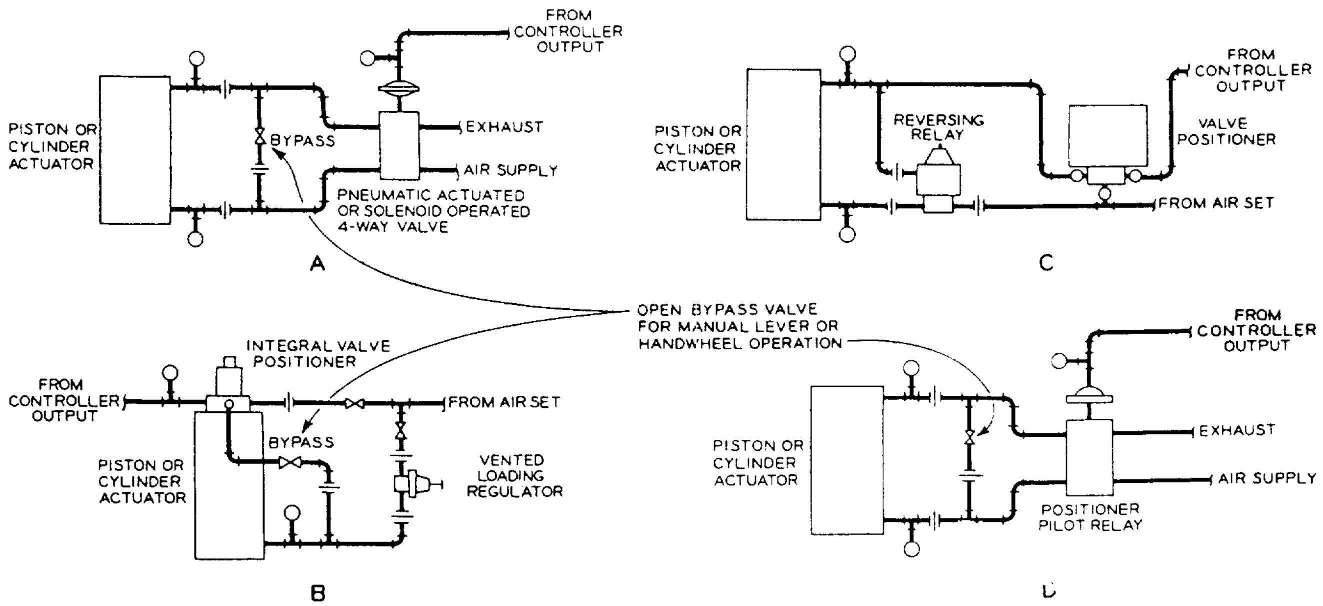
On cylinder actuators, manually operated four-way valves may be provided for local control of the operation of the valve.

Table 6-1—Recommended Minimum Block and Bypass Valve Sizing (Flexible Design)

Control Valve Size (inches)	Type of Valve to be Sized	Line Size (inches)										
		½	¾	1	1½	2	3	4	6	8	10	12
½	Block	½	¾	1	1½	-	-	-	-	-	-	-
	Bypass	½	¾	1	1½	-	-	-	-	-	-	-
¾	Block	-	¾	1	1½	2	-	-	-	-	-	-
	Bypass	-	¾	1	1½	2	-	-	-	-	-	-
1	Block	-	-	1	1½	2	2	-	-	-	-	-
	Bypass	-	-	1	1½	2	2	-	-	-	-	-
1½	Block	-	-	--	1½	2	2	3	-	-	-	-
	Bypass	-	-	--	1½	2	2	3	-	-	-	-
2	Block	-	-	-	-	2	3	3	4	-	-	-
	Bypass	-	-	-	-	2	2	3	4	-	-	-
3	Block	-	-	-	-	-	3	4	4	6	-	-
	Bypass	-	-	-	-	-	3	3	4	6	-	-
4	Block	-	-	-	-	-	-	4	6	6	8	-
	Bypass	-	-	-	-	-	-	4	4	6	8	-
6	Block	-	-	-	-	-	-	-	6	8	8	10
	Bypass	-	-	-	-	-	-	-	6	6	8	10
8	Block	-	-	-	-	-	-	-	-	8	10	10
	Bypass	-	-	-	-	-	-	-	-	8	8	10
10	Block	-	-	-	-	-	-	-	-	-	10	12
	Bypass	-	-	-	-	-	-	-	-	-	10	10
12	Block	-	-	-	-	-	-	-	-	-	-	12
	Bypass	-	-	-	-	-	-	-	-	-	-	12

NOTE: SI equivalents for the sizes listed are as follows:

inches:	½	¾	1	1½	2	3	4	6	8	10	12
millimeters:	15	20	25	40	50	80	100	150	200	250	300



NOTES:
1. Arrangement A shows the actuator used with a four-way valve in two-position service.
2. Arrangement B shows the actuator with constant pressure loading on one side.
3. Arrangement C shows the actuator with a reversing relay.
4. Arrangement D shows the actuator with a pilot relay for throttling service.

Figure 6-31—Air Cylinder or Piston Actuators

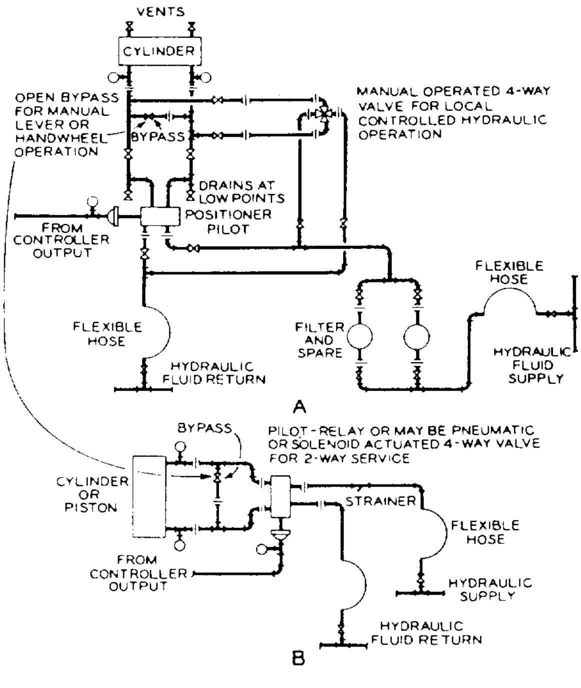
A bypass valve also should be provided between the two ends of the cylinder actuator to equalize the cylinder pressure should manual operation of the valve be required (see Figure 6-31).

For hydraulic cylinders, the following points should be considered:

1. If the hydraulic manifold is rigidly piped, it should be connected to the hydraulic fluid supply and return headers by flexible metallic hose.
2. To assure a continuous supply of hydraulic fluid to actuators, it is advisable to provide both an oil filter or strainer and a spare suitably valved and piped so that either unit may be removed and cleaned without shutting off the supply.
3. Vent valves should be provided at high points in the hydraulic fluid system.
4. Depending upon whether the valve served by the actuator will move if the hydraulic oil pressure is lost, it may be necessary to use automatic fluid-trapping valves that lock the hydraulic fluid in the cylinders upon failure of the hydraulic system.

Piping arrangements for hydraulic actuators are shown in Figure 6-32.

Some electrohydraulic actuators have self-contained reservoirs, pumps, and power cylinders. Such units must be mounted in an upright position to permit proper functioning



NOTES:
1. Arrangement A shows the cylinder actuator with provision for local manual hydraulic operation.
2. Arrangement B shows the cylinder or piston actuator without local hydraulic operation.

Figure 6-32—Hydraulic Cylinder or Piston Acutator of the hydraulic system. Because the pump motors are operating continuously, these units should have adequate ventilation to prevent overheating. Typical piping arrangements for electropneumatic and electrohydraulic actuators are illustrated in Figure 6-19.

6.11 Bibliography

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