Related Commercial Resources

CHAPTER 47

VALVES

1. FUNDAMENTALS

VALVES are the manual or automatic fluid-controlling elements in a piping system. They are constructed to withstand a specific range of temperature, pressure, corrosion, and mechanical stress. The designer selects and specifies the proper valve for the application to give the best service for the economic requirements.

Valves have some of the following primary functions:

- Starting, stopping, and directing flow
- Regulating, controlling, or throttling flow
- Preventing backflow
- Relieving or regulating pressure

The following service conditions should be considered before specifying or selecting a valve:

1. Type of liquid, vapor, or gas
   - Is it a true fluid or does it contain solids?
   - Does it remain a liquid throughout its flow or does it vaporize?
   - Is it corrosive or erosive?
2. Pressure and temperature
   - Will these vary in the system?
   - Should worst case (maximum or minimum values) be considered in selecting correct valve materials?
3. Flow considerations
   - Is pressure drop critical?
   - Does the valve conform to the required pressure ratings?
   - Is the valve to be used for simple shutoff or for throttling flow?
   - Is the valve needed to prevent backflow?
   - Is the valve to be used for directing (mixing or diverting) flow?
4. Frequency and speed of operation
   - Will the valve be operated frequently?
   - Will the valve need to reposition itself quickly?
   - Should it move slowly?
   - Does the valve have a required default position if there is no power (e.g., fail to normal position or fail in place)?
   - Will valve normally be open with infrequent operation?
   - Will operation be manual or automatic?

Nomenclature for basic valve components may vary from manufacturer to manufacturer and according to the application.

Body Ratings

The rating of valves defines the pressure-temperature relationship within which the valve may be operated. The valve manufacturer is responsible for determining the valve rating. ASME *Standard* B16.34 should be consulted, and a valve pressure class should be identified. Inlet pressure ratings are generally expressed in terms of the ANSI/ASME class ratings (ranging from ANSI Class 125 to 2500) or based on the body vessel pressure rating, depending on the style, size, and materials of construction, including seat materials. Tables in ANSI/ASME *Standard* B16.34 and in various books show pressure ratings at various operating temperatures.

Materials

ASME *Standard* B16.34 addresses requirements for valves made from forgings, castings, plate, bar stock and shapes, and tubular products. This standard identifies acceptable materials from which valves can be constructed. In selecting proper valve materials, the valve body-bonnet material should be selected first and then the valve plug and seat trim.

Other factors that govern the basic materials selection include

- Pressure-temperature ratings
- Corrosion-resistance requirements
- Thermal shock
- Piping stress
- Fire hazard

Types of materials typically available include

- Carbon steel
- Ductile iron
- Cast iron
- Stainless steels
- Brass
- Bronze
- Polyvinyl chloride (PVC) plastic

Bodies. Body materials for small valves are usually brass, bronze, or forged steel and for larger valves, cast iron, cast ductile iron, or cast steel as required for the pressure and service. Listings of typical materials are given in Lyons (1982) and Ulanski (1991).

Seats. Valve seats can be machined integrally of the body material, press-fitted, or threaded (removable). Seats of different materials can be selected to suit difficult application requirements. The valve seat and the valve plug or disk are sometimes referred to as the valve trim and are usually constructed of the same material selected to meet the service requirements. The trim, however, is usually of a different material than the valve body. Replaceable composition disks are used in conjunction with the plug in some designs in order to provide adequate close-off.

Maximum permissible leakage ratings for control valve seats are defined in standards such as Fluid Controls Institute (FCI) *Standard* 70-2 or European (CEN) *Standard* EN 12266-1.

Stems. Valve stem material should be selected to meet service conditions. Stainless steel, bronze, and brass are commonly used stem materials.

Stem Packings and Gaskets. Valve stem packings undergo constant wear because of the movement of the valve stem, and both the packings and body gaskets are exposed to pressure and pressure variations of the control fluid. Manufacturers can supply

The preparation of this chapter is assigned to TC 6.1, Hydronic and Steam Equipment and Systems.

recommendations regarding materials and lubricants for specific fluid temperatures and pressures.

Flow Coefficient and Pressure Drop

Flow through any device results in some loss of pressure. Some of the factors affecting pressure loss in valves include changes in the cross section and shape of the flow path, obstructions in the flow path, and changes in direction of the flow path. For most applications, the pressure drop varies as the square of the flow when operating in the turbulent flow range. For check valves, this relationship is true only if the flow holds the valve in the full-open position.

For convenience in selecting valves, particularly control valves, manufacturers express valve capacity as a function of a flow coefficient. Flow coefficient C_v is the volume (in U.S. gallons) of water at 60°F that will flow per minute through a fully open valve with a pressure drop of 1 psi. Manufacturers may also furnish valve coefficients at other pressure drops.

Figure 1 shows a typical test arrangement to determine the C_v rating with the test valve wide open. Globe valve HV-1 allows adjusting the supply gage reading (e.g., to 10 psig); HV-2 is then adjusted (e.g., to 9 psig return) to allow a test run at a pressure drop of 1 psig. A gravity storage tank may be used to minimize supply pressure fluctuations. The bypass valve allows fine adjustment of the supply pressure. A series of test runs is made with the weighing tank and a stopwatch to determine the flow rate. Further capacity test detail may be found in International Society for Measurement and Control (ISA) *Standard* S75.02.

Cavitation

Cavitation occurs when the pressure of a flowing fluid drops below the vapor pressure of that fluid (Figure 2). In this two-step process, the pressure first drops to the critical point, causing cavities of vapor to form. These are carried with the flow stream until they reach an area of higher pressure. The bubbles of vapor then suddenly collapse or implode. This reduction in pressure occurs when the velocity increases as the fluid passes through a valve. After the fluid passes through the valve, the velocity decreases and the pressure increases. In many cases, cavitation manifests itself as noise. However, if the vapor bubbles are in contact with a solid surface when they collapse, the liquid rushing into the voids causes high localized pressure that can erode the surface. Premature failure of the valve and adjacent piping may occur. The noise and vibration caused by cavitation have been described as similar to those of gravel flowing through the system.

Water Hammer

Water hammer is a series of pressure pulsations of varying magnitude above and below the normal pressure of water in the pipe. The amplitude and period of the pulsation depend on the velocity of the water as well as the size, length, and material of the pipe.

Shock loading from these pulsations occurs when any moving liquid is stopped in a short time. In general, it is important to avoid quickly closing valves in an HVAC system to minimize the occurrence of water hammer.

When flow stops, the pressure increase is independent of the working pressure of the system. For example, if water is flowing at 5 fps and a valve is instantly closed, the pressure increase is the same whether the normal pressure is 100 psig or 1000 psig.

Water hammer is often accompanied by a sound resembling a pipe being struck by a hammer (hence the name). The intensity of the sound is no measure of the magnitude of the pressure. Tests indicate that even if 15% of the shock pressure is removed by absorbers or arresters, adequate relief is not necessarily obtained.

Noise

Chapter 22 of the 2013 *ASHRAE Handbook—Fundamentals* points out that limitations are imposed on pipe size to control the level of pipe and valve noise, erosion, and water hammer pressure. Some data are available for predicting hydrodynamic noise generated by control valves. ISA *Standard* 75.01 compiled prediction correlations in an effort to develop control valves for reduced noise levels.

Body Styles

Valve bodies are available in many configurations depending on the desired service. Usual functions include stopping flow, allowing full flow, modulating flow between extremes, and directing flow. The operation of a valve can be automatic or manual.

The shape of bodies for automatic and manual valves is dictated by the intended application. For example, angle valves are commonly provided for radiator control. The principle of flow is the same for angle and straight-through valve configurations; the manufacturer provides a choice in some cases as a convenience to the installer.

The type or design of body connections is dictated primarily by the proposed conduit or piping material. Depending on material type, valves can be attached to piping in one of the following ways:

- Bolted to the pipe with companion flange.
- Screwed to the pipe, where the pipe itself has matching threads (male) and the body of the valve has threads machined into it (female).
- Welded, soldered, or sweated.
- Flared, compression, and/or various mechanical connections to the pipe where there are no threads on the pipe or the body.
- Valves of various plastic materials are fastened to the pipe if the valve body and the pipe are of compatible plastics.

2. MANUAL VALVES

Selection

Each valve style has advantages and disadvantages for the application. The questions listed in the section on Fundamentals must be evaluated carefully.

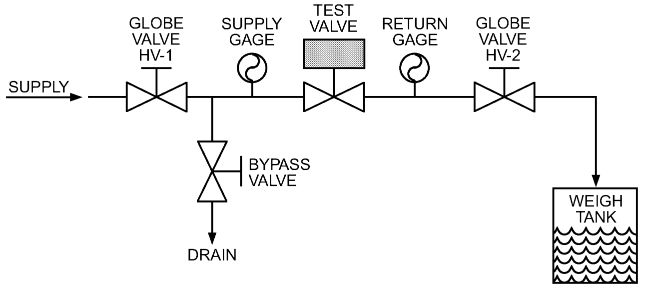

Fig. 1 Flow Coefficient Test Arrangement

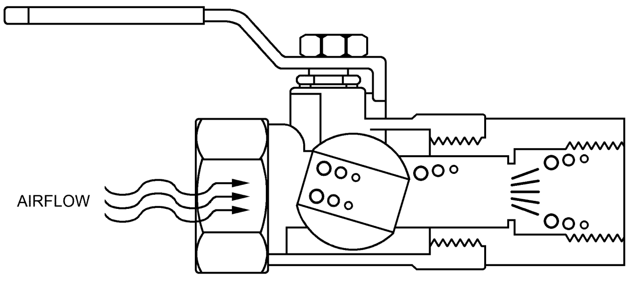

Fig. 2 Valve Cavitation at Sharp Curves

Globe Valves

In a globe valve, flow is controlled by a circular disk forced against or withdrawn from an annular ring, or **seat**, that surrounds an opening through which flow occurs (Figure 3). The direction of movement of the disk is parallel to the direction of the flow through the valve opening (or seat) and normal to the axis of the pipe in which the valve is installed.

Globe valves are most frequently used in smaller diameter pipes but are available in sizes up to 12 in. They are used for throttling duty where positive shutoff is required. Globe valves for controlling service should be selected by class, and whether they are of the straight-through or angle type, composition disk, union or gasketed bonnet, threaded, and solder or grooved ends. Manually operated flow control valves are also available with fully guided V-port throttling plugs or needle point stems for precise adjustment. Globe valves have a relatively high pressure drop when full open and therefore should be used for throttling (flow control) rather than shutoff (stop flow) applications.

Gate Valves

A gate valve controls flow by means of a wedge disk fitting against machined seating faces (Figure 4). The straight-through opening of the valve is as large as the full bore of the pipe, and the gate movement is perpendicular to the flow path.

Gate valves are intended to be fully open or completely closed. They are designed to allow or stop flow, and should not be used to regulate or control flow. Various wedges for gate valves are available for specific applications. Valves in inaccessible locations may be provided with a chain wheel or with a hammer-blow operator.

Plug Valves

A plug valve is a manual fluid flow control device (Figure 5). It operates from fully open to completely shut off within a 90° turn.

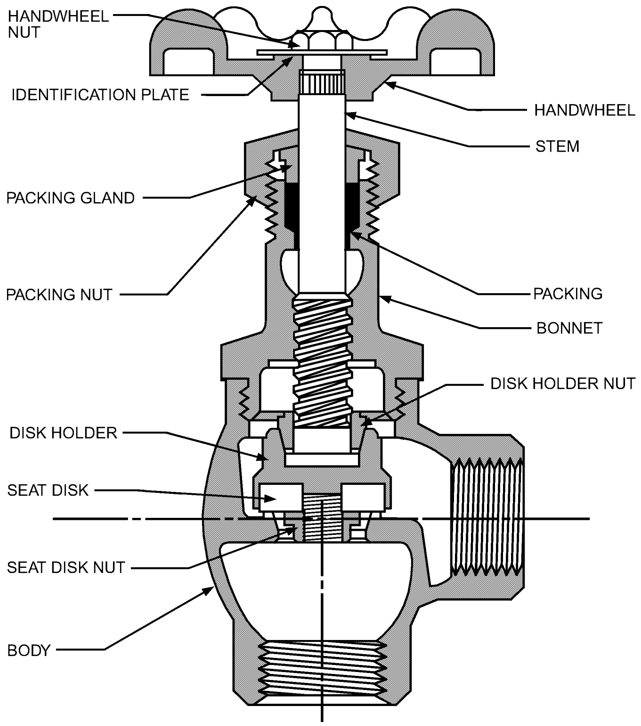

Fig. 3 Globe Valve
(Courtesy Anvil International)

The capacity of the valve depends on the ratio of the area of the orifice to the area of the pipe in which the valve is installed.

The cutaway view of a plug valve shows a valve with an orifice that is considerably smaller than the full size of the pipe. Lubricated plug valves are usually furnished in gas applications. The effectiveness of this valve as a flow control device is reduced if the orifice of the valve is fully ported (i.e., the same area as the pipe size).

Ball Valves

A ball valve contains a precision ball held between two circular seals or seats. Ball valves have various port sizes. A 90° turn of the handle changes operation from fully open to fully closed. Ball valves for shutoff service may be fully ported. Ball valves for throttling or controlling and/or balancing service should have a reduced port with a plated ball and valve handle memory stop. Ball valves may be of one-, two-, or three-piece body design (Figure 6).

Butterfly Valves

A butterfly valve typically consists of a cylindrical, flanged-end body with an internal, rotatable disk serving as the fluid flow-regulating device (Figure 7). Butterfly valve bodies may be **wafer style**, which is clamped between two companion flanges whose bolts

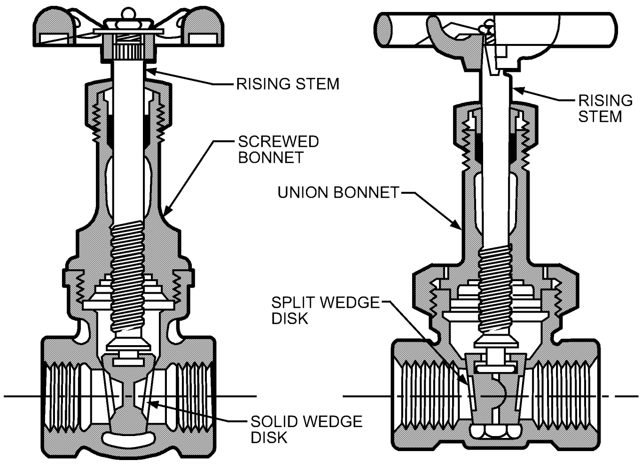

Fig. 4 Two Variations of Gate Valve

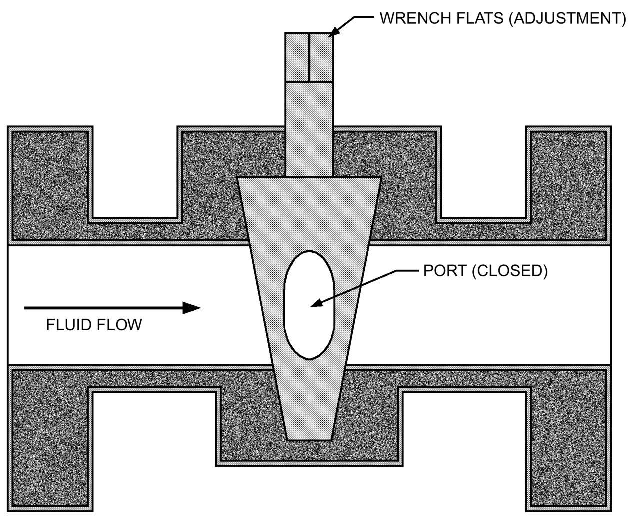

Fig. 5 Plug Valve

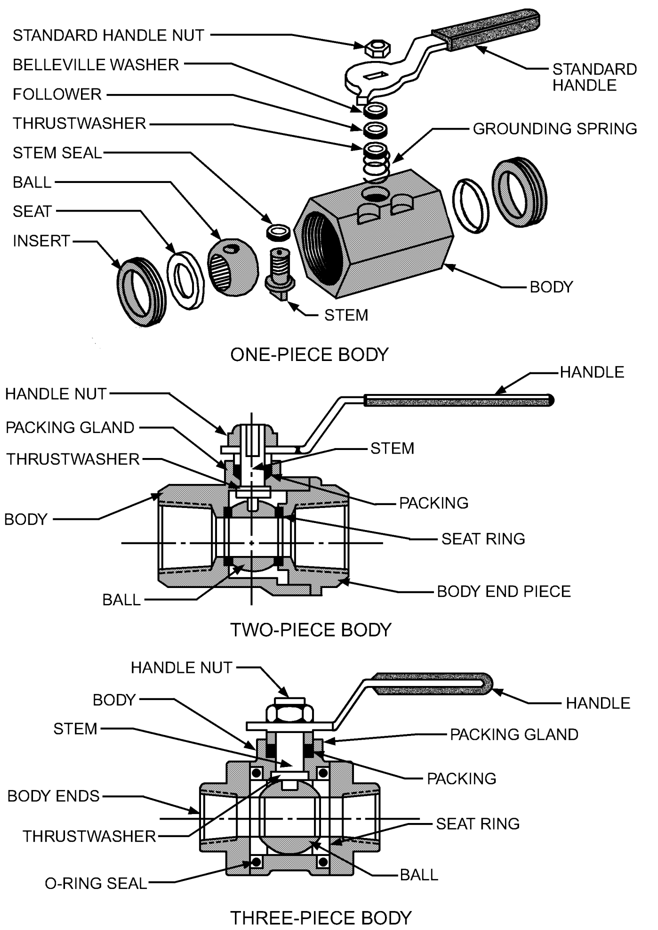

Fig. 6 Ball Valve

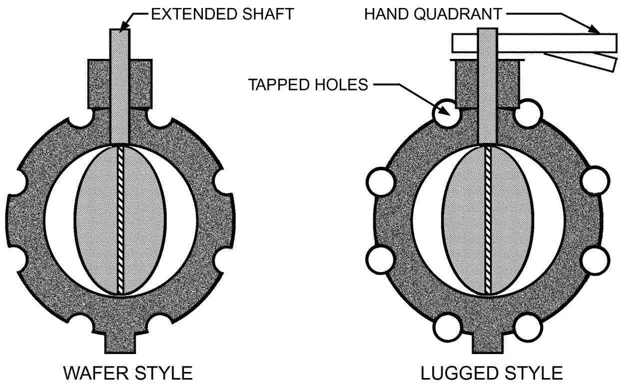

Fig. 7 Butterfly Valve

carry the pipeline tensile stress and place the wafer body in compression, or **lugged style**, with tapped holes in the wafer body, which may serve as a future point of disconnection. The disk's axis of rotation is the valve stem; it is perpendicular to the flow path at the center of the valve body. Only a 90° turn of the valve disk is required to change from the full-open to the closed position. Butterfly valves may be manually operated with **hand quadrants** (levers) or gear wheel operators, which are commonly used on larger valves. Valves may be provided with an extended shaft for automatic operation by an actuator. Special attention should be paid to manufacturers' recommendations for sizing an actuator to handle the torque requirements.

Simple and compact design, a low corresponding pressure drop, and fast operation characterize all butterfly valves. Quick operation makes them suitable for automated control, whereas the low pressure drop is suitable for high flow. Butterfly valve sizing for on/off applications should be limited to pipe sizing velocities given in Chapter 22 of the 2013 *ASHRAE Handbook—Fundamentals*; on the other hand, for throttling control applications, the valve coefficient sizing presented in the section on Automatic Valves must be followed.

3. AUTOMATIC VALVES

Automatic valves are commonly considered as control valves that operate in conjunction with an automatic controller or device to control the fluid flow. The "control valve" as used here actually consists of a valve body and an actuator. The valve body and actuator may be designed so that the actuator is removable and/or replaceable, or the actuator may be an integral part of the valve body. This section covers the most common types of valve actuators and control valves with the following classifications:

- Two-way globe bodies (single- and double-seated)
- Three-way globe bodies (mixing and diverting)
- Ball valves (two- and three-way)
- Butterfly arrangements (two- and three-way)

Actuators

The valve actuator converts the controller's output, such as an electric or pneumatic signal, into the rotary or linear action required by the valve (stem), which changes the control variable (flow). Actuators cover a wide range of sizes, types, output capabilities, and control modes.

Sizes. Actuators range in torque output from small solenoid or wax thermal actuators, to large pneumatic and electronic actuators. Selection of the actuator takes into account the design requirement for the control signal, fail-safe operation, ambient conditions, and required close-off pressure rating of the valve assembly.

Types. The most common types of actuators used on automatic valve applications are solenoid, thermostatic radiator, pneumatic, electric gear train motor, electronic, and electrohydraulic.

Pneumatic Actuators

Pneumatic or diaphragm valve actuators consist of a flexible diaphragm clamped between an upper and a lower housing. On direct-acting actuators, the upper housing and diaphragm create a sealed chamber (Figure 8). A spring opposing the diaphragm force is positioned between the diaphragm and the lower housing. Increasing air pressure on the diaphragm pushes the valve stem down and overcomes the force of the load spring to close a direct-acting valve. Springs are designated by the air pressure change required to open or close the valve. For example, a pneumatic actuator on a direct-acting control valve with an 8 to 13 psi spring range will have the control valve closed at pressures of 8 psi and below. For pressures between 8 and 13 psi, the valve will modulate proportionally based on the input control pressure. At 13 psi and above, the control valve will be fully open. Springs for commercial control valves usually have ±10% tolerance. Two valves may be sequenced simply with different actuator spring ranges using a single control signal.

Reverse-acting valves may use a direct-acting actuator if they have reverse-acting valve bodies; otherwise, the actuator must be reverse-acting and constructed with a sealed chamber between the lower housing and the diaphragm.

The manufacturer's close-off rating tables need to be consulted to determine if the actuator is of an adequate size or if a larger actuator or a pneumatic positive positioner relay is required.

A **pneumatic positive positioner relay** may be added to the actuator to provide additional force to close or open an automatic control valve (Figure 8). Sometimes called **pilot positioners**, these are basically high-capacity relays that add air pressure to or exhaust air pressure from the actuator in relation to the stroke position of the actuator. Their application is limited by the supply air pressure available and by the actuator's spring.

Electric Actuators

Electric (Gear Train) Actuators. Electric actuators usually consist of a double-wound electric motor coupled to a gear train and an output shaft connected to the valve stem with a cam or rack-and-pinion gear linkage (Figure 9). For valve actuation, the motor shaft typically drives through 160° of rotation. The use of damper actuators with 90° full stroke rotation is rapidly increasing in valve control applications. Gear trains are coupled internally to the electric actuators to provide a timed movement of valve stroke to increase operating torque and to reduce overshooting of valve movement. Gear trains can be fitted with limit switches, auxiliary potentiometers, etc., to provide position indication and feedback for additional system control functions.

In many instances, a linkage is required to convert rotary motion to the linear motion required to operate a control valve. Electric valve actuators operate with two-position, floating, and proportional control. Actuators usually operate with a 24/120/240 V (ac) power supply. Actuator time to rotate (or drive full stroke) ranges from 60 to 150 s.

Electric valve actuators may have a spring return, which returns the valve to a normal position in case of power failure, or it may be powered with an electric relay and auxiliary power source. Because the motor must constantly drive in one direction against the return spring, spring return electric valve actuators generally have less torque output than nonspring return electric gear train actuators.

Electronic (Direct-Coupled) Actuators. These actuators consist of a dc motor coupled to an internal gear box with an external clamp assembly. The actuator may be connected to the valve body by a linkage assembly that converts the rotary motion of the actuator to the linear motion required by some valves. The actuator can also be directly coupled to the valve body (e.g., of a ball or butterfly valve), providing the quarter-turn opening required by the valve. Internal/external auxiliary switches and potentiometers can be added to provide position indication and feedback for additional control functions.

Electronic direct-coupled actuators operate with two-position, floating, and proportional control. Some can be programmed for unique control signals or to allow sequencing of two separate valves off of a single control signal (similar to different spring ranges in two pneumatic actuators). Actuators are available with 24/120/240 V (ac) power supply. Typical rotation times (full closed to full open) are 90 to 150 s, but some models provide for programmable rotation times well outside of this range, from as fast as 5 s to as slow as 5 min.

Electronic actuators may be fail-safe, using either a mechanical spring or an electronic (capacitor) fail-safe. The mechanical spring is internal to the actuator and provides enough torque to drive the valve to its fail position (either open or closed) as selected upon loss of power to the actuator. With an electronic fail-safe, on-board capacitors are charged when the actuator powers on. On a loss of power to the actuator, the voltage discharge of the capacitors allows the actuator to be powered sufficiently to drive the valve to a preselected fail position (full open, full closed, or some point in between). In both cases (mechanical or electrical fail-safe), the drive to fail position will only occur once. Mechanical spring fail-safe actuators typically have less torque than their comparable nonspring return models. Electronic fail-safe actuators, in many cases, have a torque rating equal to or higher than their comparable electric nonspring return models.

Electronic Hydraulic Actuators

Electronic hydraulic actuators combine characteristics of electric and pneumatic actuators. A sealed housing contains the hydraulic fluid, pump, and some type of metering or control apparatus to provide pressure control across a piston or piston/diaphragm. A coil controlled by a low- to medium-level dc voltage activates the pressure control apparatus. The resulting output is a linear piston-type movement. This type of actuator is easily adapted to valves that require a linear motion, such as the stem movement of a globe valve. Electronic hydraulic actuators can be supplied with internal auxiliary switches for additional control functions. Actuators are available with 24/120/240 V (ac) power supply. Typical time to drive full stroke is 60 s. Electronic hydraulic actuators may be fail-safe, which returns the valve to its fail position upon a loss of power.

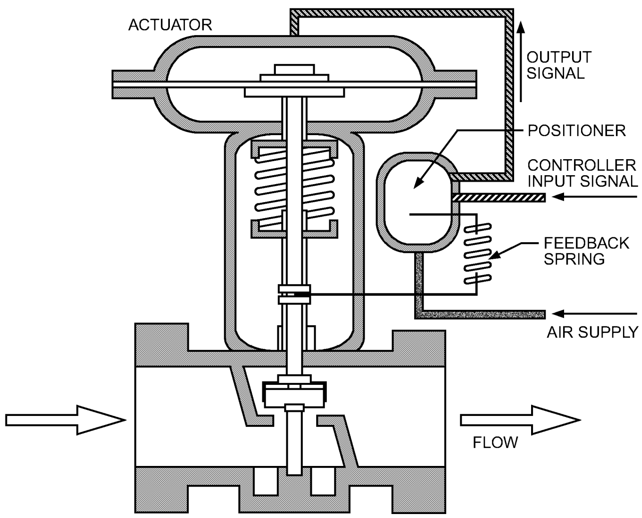

Fig. 8 Two-Way, Direct-Acting Control Valve with Pneumatic Actuator and Positioner

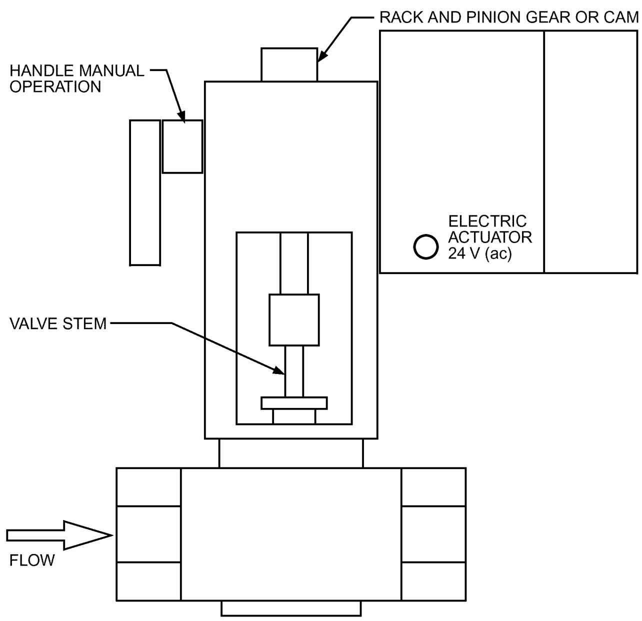

Fig. 9 Two-Way Control Valve with Electric Actuator

Solenoids

A solenoid valve is an electromechanical control element that opens or closes a valve on the energization of a solenoid coil. Solenoid valves are used to control the flow of hot or chilled water and steam and range in size from 1/8 to 2 in. pipe size. Solenoid actuators themselves are two-position control devices and are available for operation in a wide range of alternating current voltages (both 50 and 60 Hz) as well as direct current. Operation of a simple two-way, direct-acting solenoid valve in a deenergized state is illustrated in Figure 10.

Thermostatic Radiator Valves

Thermostatic radiator valves are self powered and do not require an external energy source. They control space temperature by modulating the flow of hot water or steam through free-standing radiators, convectors, or baseboard heating units. Thermostatic radiator valves are available for a variety of installation requirements with remote-mounted sensors or integral-mounted sensor and remote or integral set point adjustment (Figure 11).

Control of Automatic Valves

Computer-based control (direct digital control) of automatic control valves has replaced older technologies and provides many benefits, including speed, accuracy, and data communication. However, care must be used in selecting the value of control loop parameters such as loop speed and dead band (allowable set-point deviation). High loop speed coupled with very low dead band can cause the valve actuator to seek a new control position with each control loop cycle. For example, a 1 s control loop with zero dead band could result in more than 30,000,000 repositions (corrections) in 1 year of service. This **dithering** effect can decrease the effective life of the actuator.

This is not to say computer-based control systems will shorten the life of all automatic control valves. Computer-based control systems should be tuned to provide the minimum acceptable level of response and accuracy required for the application to achieve maximum valve and actuator service life. If valve attributes include high levels of accuracy and response speed, a high-performance actuator is required.

Two-Way Valves

In a two-way automatic valve, the fluid enters the inlet port and exits the outlet port either at full or reduced volume, depending on the position of the stem and the disk in the valve. Two-way globe valves may be single- or double-seated.

In the single-seated globe valve, one seat and one plug-disk close against the stream. The style of the plug-disk varies depending on the requirements of the designer and the application. For body comparison, see Figure 9 in Chapter 7 of the 2013 *ASHRAE Handbook—Fundamentals*.

The double-seated valve is a special application of the two-way valve with two seats, plugs, and disks. It is generally applied to cases where the close-off pressure is too high for the single-seated valve.

Three-Way Valves

Three-way valves either mix or divert streams of fluid. Figure 12 shows some common applications for three-way valves. Figure 8 in Chapter 7 of the 2013 *ASHRAE Handbook—Fundamentals* shows typical cross sections of three-way mixing and diverting globe valves.

A **three-way mixing valve** blends two streams into one common stream based on the position of the valve plug in relation to the upper and lower seats of the valve.

A **three-way diverting** or **bypass valve** takes one stream of fluid and splits it into two streams for temperature control. In some limited applications, such as a cooling tower control, a diverting or bypass valve must be used in place of a mixing valve. In most cases, a mixing valve can perform the same function as a diverting or bypass valve if the companion actuator has a very high spring rate. Otherwise, water hammer or noise may occur when operating near the seat.

Special-Purpose Valves

Special-purpose valve bodies may be used on occasion. One type of four-way valve is used to allow separate circulation in the boiler loop and a heated zone. Another type of four-way valve body is used as a changeover refrigeration valve in heat pump systems to reverse the evaporator to a condenser function.

Float valves are used to supply water to a tank or reservoir or serve as a boiler feed valve to maintain an operating water level at the float level location (Figure 13).

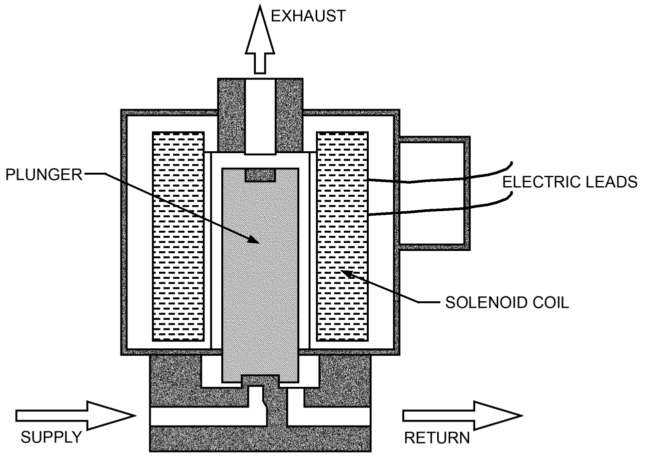

Fig. 10 Electric Solenoid Valve

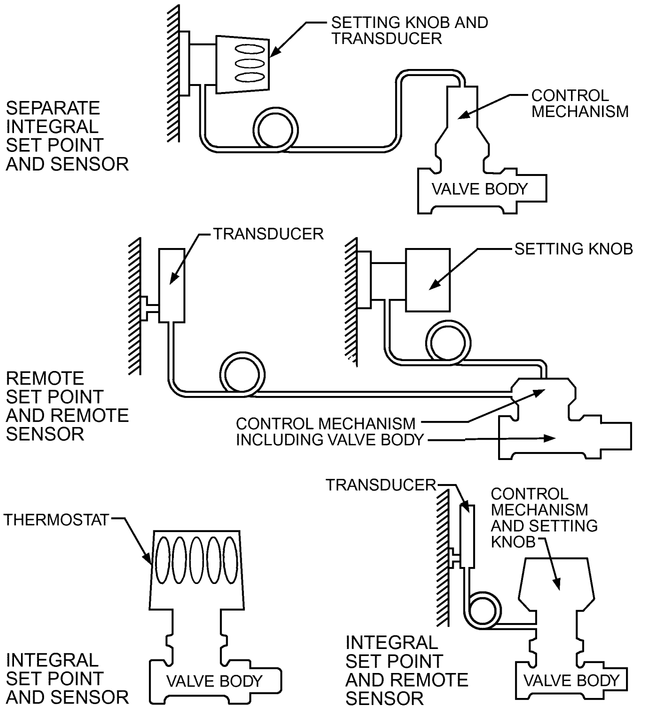

Fig. 11 Thermostatic Valves

Ball Valves

Ball valves coupled with electronic direct-coupled actuators are commonly used in HVAC control applications because it is easy to match the movement of the 90° actuator travel to the quarter-turn movement of the ball valve. For modulating flow applications, a reduced port or characterizing disc should be used on the ball valve to reduce the overall flow capacity of the valve and modify the flow characteristic (e.g., equal percentage) to prevent overflow or uneven flow. The packing system of a ball valve is designed to accommodate the modulating control action inherent in HVAC.

Butterfly Valves

Butterfly valves are used in two-position and modulating applications. Advantages of butterfly valves are their ability to provide a bubbletight close off against higher pressures, their lighter weight, and compact size.

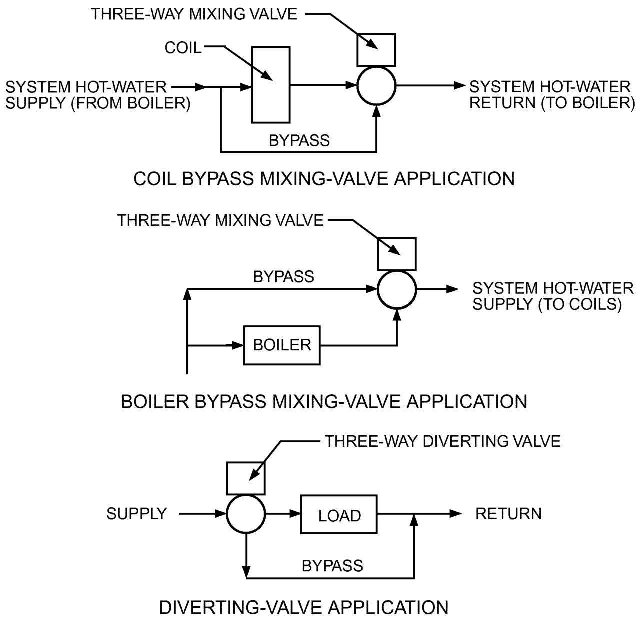

Fig. 12 Typical Three-Way Control Applications

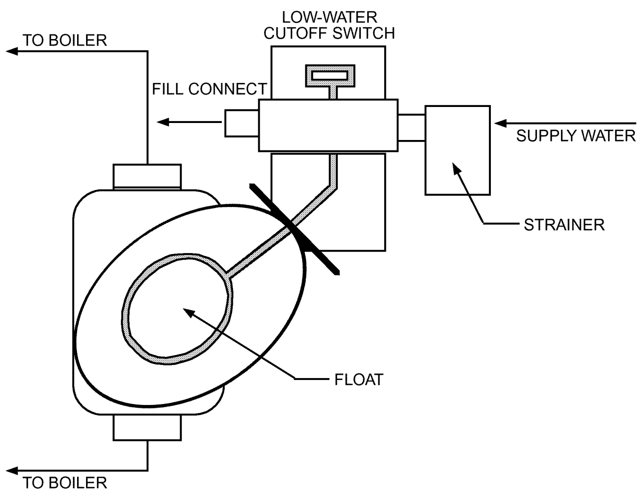

Fig. 13 Float Valve and Cutoff Steam Boiler Application

Butterfly valves are manufactured as two-way valves. In some applications where there is a need for a three-way valve application, two butterfly valves are mounted on a piping tee and cross-linked to operate as either three-way mixing or three-way bypass valves (Figure 14).

Butterfly valves have different flow characteristics from standard seat and disk-type globe valves, so they may be used only where their flow characteristics suffice. When sizing a butterfly valve for a modulating application, use the C_v rating at 60° or 70° rotation; for two-position (on/off) applications, use the 90° C_v rating. It is also important to follow the manufacturer's guideline for the butterfly valve rating for maximum fluid velocity, because exceeding this figure can shorten the valve's life expectancy.

Pressure-Independent Control Valves

Pressure-independent control valves (PICVs; Figure 15) are control valves coupled with an internal method of differential pressure regulation to eliminate variances of flow caused by differential pressure fluctuations across the valve assembly. This can be accomplished by using a dynamic pressure regulator or integrated software to monitor the flow in relation to the designed output of the valve. In practical application, a PICV replaces both a control valve and a balancing device.

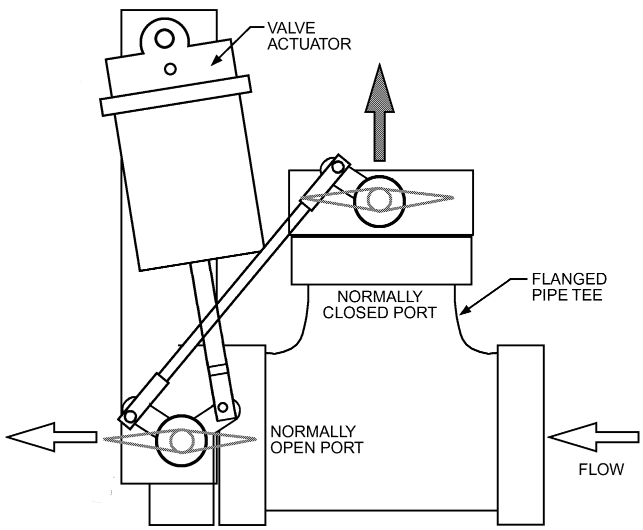

Fig. 14 Butterfly Valves, Diverting Tee Application

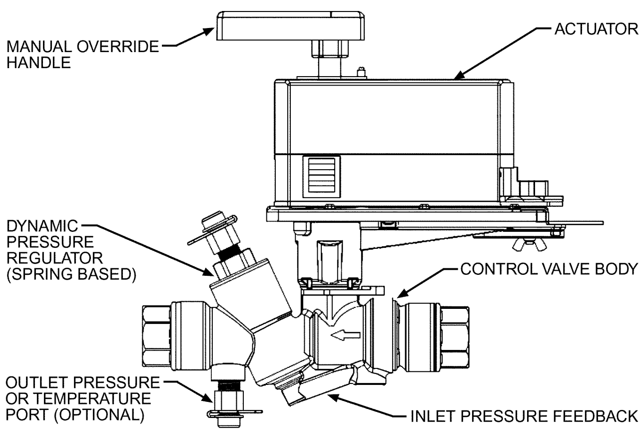

Fig. 15 Pressure-Independent Control Valve

The flow of standard pressure-dependent control valves (globe valves, ball valves, etc.) depends on the pressure differential across the valve. As this pressure rises across a standard valve with a fixed stem position, the flow increases. Likewise, as differential pressure across the valve drops, the flow decreases. This change in pressure is caused by factors such as the modulation of other control valves in the hydronic loop. Additionally, low differential pressure across a control valve results in over- and underflow caused by rapid changes in flow with small changes in valve positioning (see the section on Control Valve Flow Characteristics).

Advantages of PICVs include stable flow when the stem position is fixed, regardless of pressure fluctuations, and the elimination of a hydronic balancing device (e.g. balancing valve, flow-limiting device) where the PICV is mounted. Also, sizing a PICV is easier because it is no longer necessary to calculate a C_v for the valve. PICV selection is based on the full-open valve flow required.

PICVs are rated for a differential pressure range (e.g., 5 to 50 psi) where the PICV is pressure independent. If the pressure falls outside this range, the PICV will become a pressure-dependent valve, susceptible to flow variations from pressure changes. This differential pressure range is an operating range unrelated to the close-off pressure of the valve itself.

PICVs can be field adjustable for their maximum flow set point by either adjusting actuator end stops or programming, thereby eliminating the need to remove and replace components. The only limitation to adjusting the flow is the capacity of the valve body itself.

Flow-Limiting Valves

Flow-limiting valves (FLVs) are control valves coupled with an integrated flow-limiting device that prevents the flow from exceeding a predetermined limit. Flow is limited by an internal cartridge assembly. The FLV will not allow the flow to exceed the flow limit when operating within the predefined differential pressure operating range (e.g., 1 to 14 psi, 2 to 32 psi). However, unlike a pressure-independent control valve that eliminates flow variations (i.e., the over- and underflow caused by pressure across the entire opening range of the control valve), FLVs are only designed to cap the maximum flow allowed through the control valve. Thus, if the flow rises higher than expected because of pressure fluctuations at any position of the valve (except at full open), this excess flow will be allowed through the control valve. FLVs are for two-position (on/off) applications where the design calls for full flow or no flow, with no modulation in between.

The flow limit of FLVs can be field adjusted by (1) replacing their internal cartridge or (2) external adjustment, with the only limitation being the flow capacity of the valve body.

Control Valve Flow Characteristics

Based on the characteristics of the valve, three distinct flow conditions are possible (Figure 16):

- **Quick Opening.** When started from the closed position, a quick-opening valve allows a considerable amount of flow through a small opening of the valve. As the valve moves toward the full open position, the rate at which the flow is increased is reduced in a nonlinear fashion. This characteristic is used in two-position or on/off applications, because it is very difficult to position the stem accurately enough for low and medium flows in modulating applications.
- **Linear.** Linear valves produce equal flow increments per equal increments of the valve moving towards the full open position. This characteristic is used on steam coil terminals, bypass applications, and sometimes in the bypass port of three-way valves.
- **Equal Percentage.** This type of valve produces an exponential flow increase as the valve moves from the closed to the open position. The term equal percentage means that for equal increments of the valve opening, the flow increases by an equal percentage. For example, in Figure 16, if the valve is moved from 50 to 70% of full stroke, the percentage of full flow changes from 10 to 25%, an increase of 150%. Then, if the valve is moved from 80 to 100% of full stroke, the percentage of full flow changes from 40 to 100%, again, an increase of 150%. This characteristic is recommended for control on hot- and chilled-water coils to linearize the output of the coil-valve combination, which makes control tuning easier and typically results in more stable systems.

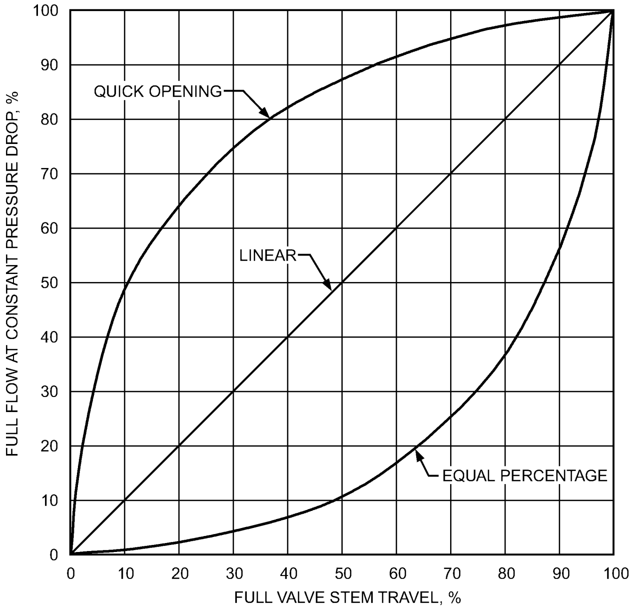

Fig. 16 Control Valve Flow Characteristics

The designer combines the valve flow characteristic with the coil performance curve (heating or cooling) to ensure the proper heat transfer characteristic. (Figure 17). For a typical hydronic heating or cooling coil, the coil output (Figure 17A) increases rapidly and begins to slow as it nears the design point. Mating this coil output with its mirror image in flow percentage (i.e., the equal percentage flow characteristic) as shown in Figure 17B results in a linear coil output (Figure 17C).

The three flow patterns are obtained by imposing a constant pressure drop across the modulating valve, but in actual conditions, the pressure drop across the valve varies between a maximum (when it is controlling) and a minimum (when the valve is near full open). The ratio of these two pressure drops is known as authority. Figures 18 and 19 show how linear and equal-percentage valve flow characteristic are distorted as the control valve authority is reduced because of a reduction in valve pressure drop. The quick-opening characteristic, not shown, is distorted to the point that it approaches two-position or on/off control. The selection of the control valve pressure drop directly affects the valve authority and should be at least 25 to 50% of the branch pressure drop (i.e., the pressure drop from the branch connection from the supply main to return main, including the piping, fittings, coil, balancing device, and control valve). The location of the control valve in the system results in unique pressure drop selections for each control valve. A higher valve pressure drop allows a smaller valve size and better control, but also higher friction energy losses.

Authority ranges between 0.0 and 1.0. A low authority can cause the coil output to be quick opening instead of providing the desired

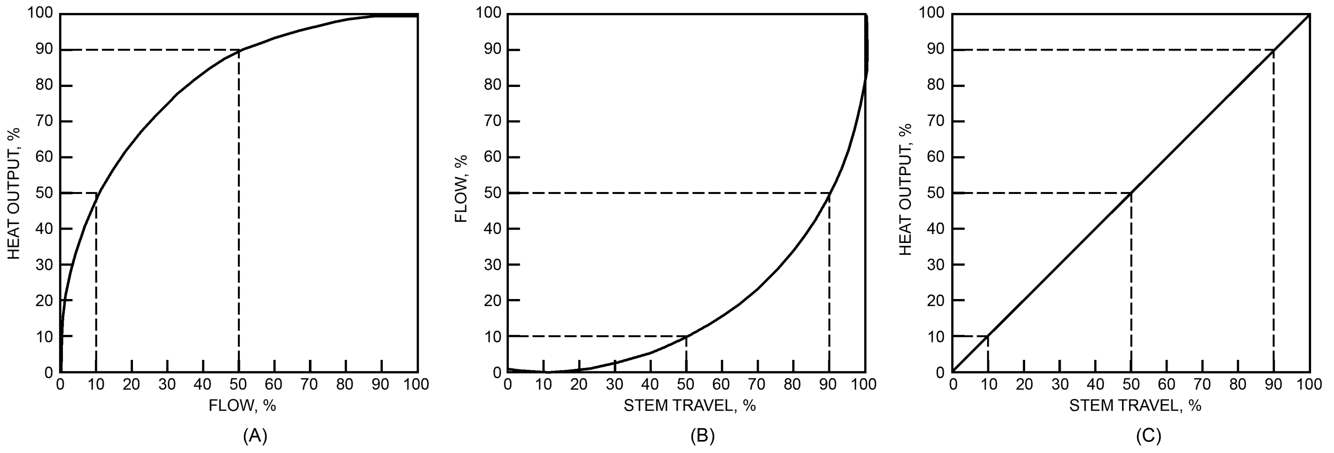

Fig. 17 Heat Output, Flow, and Stem Travel Characteristics of Equal-Percentage Valve

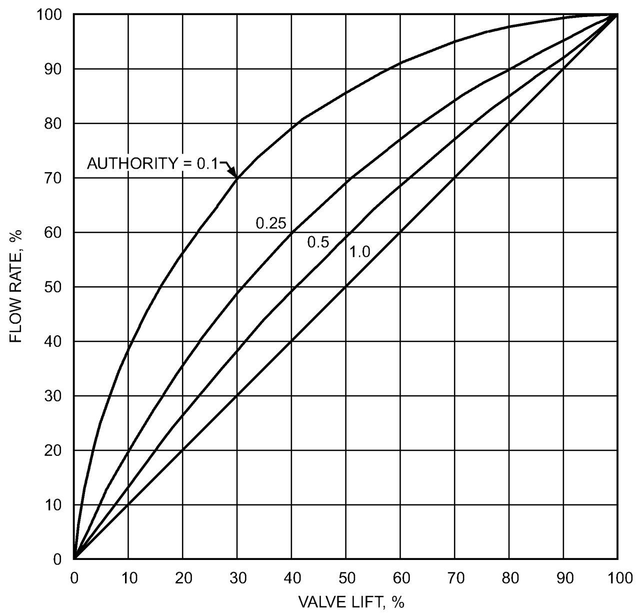

Fig. 18 Authority Distortion of Linear Flow Characteristics

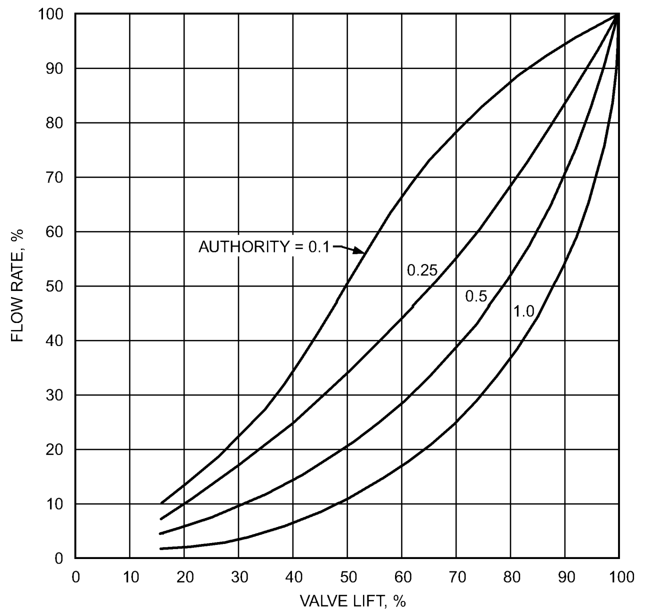

Fig. 19 Authority Distortion of Equal-Percentage Flow Characteristic

linear coil output, causing the flow, temperature, and pressure oscillations discussed previously. An authority of 1.0 will cause the valve to operate along its theoretical curve. A high authority value results in high pressure losses, even when the valve is full open. In modulating applications, an authority between 0.25 and 0.5 usually provides the right balance between controllability and energy performance.

Authority = Differential pressure of valve/
(Differential pressure of valve + Differential pressure of branch)

Control Valve Sizing

Liquids. Two-position valves are generally selected to be the same size as the pipe. The flow characteristic (e.g., linear, equal percentage) does not matter in this application, so any type can be used. Ball valves should be selected without a characterizing disc and for the largest port size (largest C_v).

Sizing modulating pressure-dependent valves is based on the following equation for flow coefficient C_v:

$$C_v = Q(\text{SG}/\Delta p)^{0.5} \tag{1}$$

where

C_v = flow coefficient
Q = flow, gpm
SG = specific gravity of fluid = 1 (for water), dimensionless
Δp = pressure drop, psi

Note that C_v (used with I-P units) and the SI equivalent K_v are not numerically equal. Therefore, before selecting valves from a catalog expressed in the other unit system, convert the calculated value as follows: $C_v = 1.16K_v$; $K_v = 0.862C_v$.

To determine the flow coefficient C_v of a control valve, the flow rate and the pressure drop desired across the control valve must be known.

The flow rate should be obtained from the design, shop drawings, the equipment itself, or other available data. The desired pressure drop is required to provide reasonable authority as discussed in the previous section.

Pressure drop and, ultimately, the valve sizing itself are based on the valve in a fully open state, because the valve capacity must be large enough to handle the design flow conditions. To estimate the desired pressure drop, first determine whether the valve is a two-position (on/off) or modulating (floating/proportional) type of control.

Two-position (on/off control) valves are sized with a 1 psi (2.31 ft head) pressure drop. Thus, if flow is 10 gpm, the desired C_v for the two-position control valve is

$$C_v = Q(\text{SG}/\Delta p)^{0.5} = Q(1/\Delta p)^{0.5} = Q/(\Delta p)^{0.5} = 10/(1)^{0.5} = 10/1 = 10 \quad (2)$$

The selected control valve should have a C_v as close as possible to that calculated using this equation, without going below this value.

Caution: in a two-position application, the "rule of thumb" historically has been to select a line-sized control valve. However, with many more selections of C_v values now available across the range of control valves, specifying a 1/2 in. control valve for a 1/2 in. line without specifying the C_v could result in the installation of a valve with a C_v below 1.

Often, designers will specify a pressure drop higher than 1 psi for a two-position control valve. For example, with a maximum flow required of 10 gpm, but using a 4 psi pressure drop across the control valve instead of 1 psi,

$$C_v = 10/(4)^{0.5} = 10/2 = 5 \quad (3)$$

This result indicates that the valve will have only half the capacity at 4 psi pressure differential as it would at the 1 psi differential used in the previous calculation.

Modulating valves are sized using the same flow coefficient equation. However, because the control valve is modulating the pressure across the valve, the pressure differential will be higher than that of a two-position control valve. As stated previously, the pressure drop across the control valve should be 25 to 50% of the branch pressure. Many factors affect the branch pressure, and it varies as other valves in the system open and close. To avoid the complexity of hydraulic circuit analysis, a rule of thumb for desired control valve pressure drop is 4 to 5 psi.

For example, the C_v for a modulating control valve in a reheat coil application with a flow rate of 3 gpm and 5 psi, pressure drop is

$$C_v = 3/(5)^{0.5} = 3/2.24 = 1.3 \quad (4)$$

Note that installed flow coefficients may vary from catalog values because of pipe geometry factors, particularly with low-pressure drop valves such as full-port ball valves and butterfly valves. The greater the difference in valve and piping line size, the larger the impact on installed (corrected) flow coefficient. Where multiple flow coefficients are available for a given valve line size, such as with ball valves, the valve should be selected to match the pipe line size where available. Where the valve must be smaller than the line size, consult the manufacturer for flow coefficient adjustments. Typically, if the valve is no more than one size smaller than the pipe line size, the impact will be negligible for globe and characterized ball valves.

Steam. For steam flow, the inlet and outlet pressures of the steam, and the type of control (modulating or two-position) must be taken into account:

$$Q = 2.1C_v/K[\Delta p(P_1 + P_2)]^{0.5} \quad (5)$$

where

Q = steam mass flow, lb/h
K = 1 + 0.0007 × (°F superheat). Typically, this value is 1 for nonsuperheated steam.
C_v = flow coefficient
P_1 = differential pressure (inlet pressure – outlet pressure), psi
P_2 = outlet steam pressure (absolute), psia

There are two cases for selecting the differential pressure across the steam control valve:

1. Inlet steam pressure ≤ 15 psig.
   a. Two-position (on/off) control: differential pressure = 10% of inlet steam gage pressure.
   b. Proportional control: differential pressure = 80% of inlet steam gage pressure
2. Inlet steam pressure > 15 psig.
   a. Two-position (on/off) control: differential pressure = 10% of inlet steam absolute pressure.
   b. Proportional control: differential pressure = 25% of inlet steam absolute pressure.

Whenever possible, avoid selecting the differential pressure higher than 42% (saturated steam), because this takes the steam in the valve into critical or sonic velocity operation. In this case, the flow and C_v do not follow Equation (5), instead conforming to the following equation:

$$w_s = 1.6C_vP_1 \quad (6)$$

where

w_s = steam flow, lb/h
C_v = flow coefficient
P_1 = entering steam absolute pressure, psi

4. BALANCING VALVES

Balancing valves are placed in the distribution system to adjust water flow to a terminal, branch, zone, riser, or main. The valve should be located on the leaving side of the hydronic branch.

Two approaches are available for balancing hydronic systems: (1) a manual valve with integral pressure taps and a calibrated port, which allows field proportional balancing to the design flow conditions; (2) or an automatic flow-limiting valve selected to limit the circuit's maximum flow to the design flow.

Manual Balancing Valves

Manual balancing valves can be provided with the following features:

- Manually adjustable stems for valve port opening or a combination of a venturi or orifice and an adjustable valve
- Stem indicator and/or scale to indicate the relative amount of valve opening
- Pressure taps to provide a readout of the pressure difference across the valve port or the venturi/orifice
- Ability to be used as a shutoff for service of the heat transfer terminal
- Locking device for field setting the maximum opening of a valve
- Body tapped for attaching drain hose

Manual balancing valves may have rotary, rising, or nonrising stems for port adjustment (Figure 20).

Meters with various scale ranges, a field carrying case, attachment hoses, and fittings for connecting to the manual balancing valve should be used to determine its flow by reading the differential pressure. Some meters use analog measuring elements with direct-reading mechanical dual-element Bourdon tubes. Other meters are electronic differential pressure transducers with a digital data display.

Many manufacturers of balancing valves produce circular slide rules to calculate circuit flow based on pressure difference readout across the balancing valve, its stem position, and/or the valve's flow coefficient. This calculator can also be used for selecting the size and setting of the valve when the terminal design flow conditions are known.

Automatic Flow-Limiting Valves

A **differential pressure-actuated flow control valve**, also called an automatic flow-limiting valve (Figure 21), regulates the flow of fluid to a preset value when the differential pressure across it is varied. This regulation prevents an overflow condition in the circuit where it is installed, even when other system components are changing (modulating valves, pump staging, etc.).

Typically, the valve body contains a moving element containing an orifice, which adjusts itself based on pressure forces so that the flow passage area varies.

The area of an orifice can be changed by either (1) a piston or cup moving across a shear plate or (2) increased pressure drop to squeeze the rubber orifice in rubber grommet valves.

A typical performance curve for the valve is shown in Figure 22. The flow rate for the valve is set. The flow curve is divided into three ranges of differential pressure: the start-up range, the control range, and the above-control range.

Balancing Valve Selection

Balancing valves should be selected with 0.45 to 1 psi pressure drop at the branch design flow when full open. Too-small pressure drops affect the accuracy of the flow measurements, causing inadequate balancing. Too-high pressure drops reduce the control valve's authority, affecting the controlled variable (e.g., room temperature) stability, and produce unnecessary friction losses. Refer to Chapter 38 of the 2015 *ASHRAE Handbook—HVAC Applications* for balancing details.

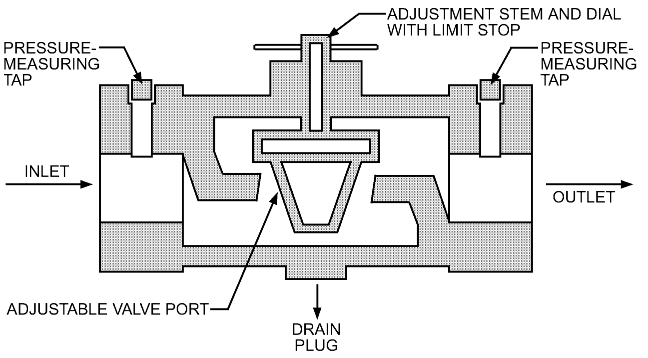

Fig. 20 Manual Balancing Valve

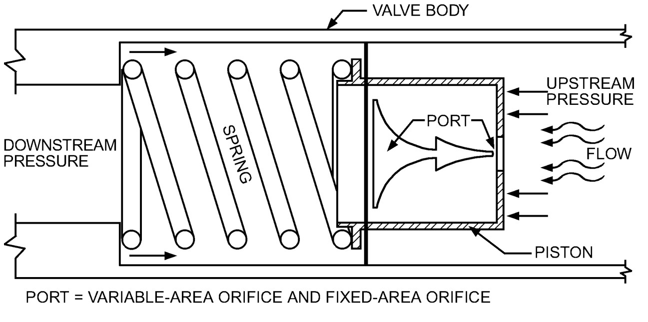

Fig. 21 Automatic Flow-Limiting Valve

5. MULTIPLE-PURPOSE VALVES

Multiple-purpose valves are made in straight pattern or angle pattern. The valves can provide shutoff for servicing or can be partially closed for balancing. Pressure gage connections to read the pressure drop across the valve can be used with the manufacturer's calibration chart or meter to estimate the flow. Means are provided to return the valve to its as-balanced position after shutoff for servicing. The valve also acts as a check valve to prevent backflow when parallel pumps are used and one of the pumps is cycled off.

Figure 23 shows a straight pattern multiple-purpose valve designed to be installed 5 to 10 pipe diameters from the pump discharge of a hydronic system.

Figure 24 shows an angle pattern multiple-purpose valve installed 5 to 10 pipe diameters downstream of the pump discharge with a common gage and a push button trumpet valve manifold to measure the differential pressure across the strainer, pump, or multiple-purpose valve. From this, the flow can be estimated. The differential pressure across the pump suction strainer can also be estimated to determine whether the strainer needs servicing.

6. SAFETY DEVICES

The terms safety valve, relief valve, and safety relief valve are sometimes used interchangeably, and although the devices generally provide a similar function (safety), they have important differences

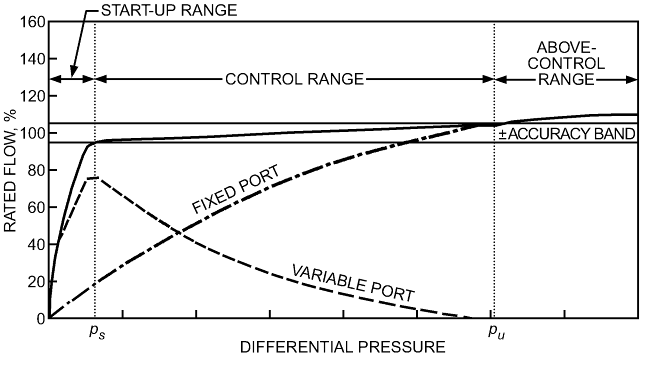

Fig. 22 Automatic Flow-Limiting Valve Curve

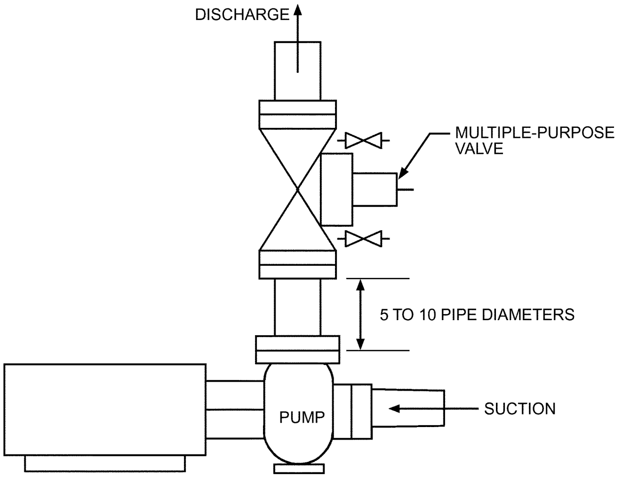

Fig. 23 Typical Multiple-Purpose Valve (Straight Pattern) on Discharge of Pump

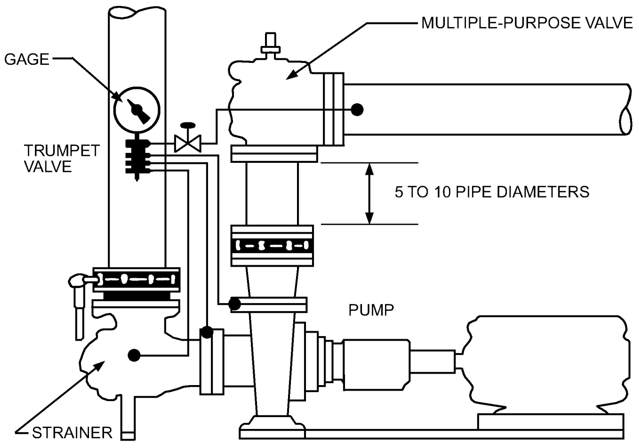

Fig. 24 Typical Multiple-Purpose Valve (Angle Pattern) on Discharge of Pump

in their modes of operation and application in HVAC systems (Jordan 1998).

Safety valves open rapidly (pop-action). They are used for gases and vapors (e.g., compressed air and steam).

Relief valves open or close gradually in proportion to excessive pressure. They are used for liquids (e.g., unheated water).

Safety relief valves perform a dual function: they open rapidly (pop-action) for gases and vapors and gradually for liquids. Typical HVAC application is for heating water.

Temperature-actuated pressure relief valves (or temperature and pressure safety relief valves) are activated by excessive temperature or pressure. They are commonly used for potable hot water.

Application of these safety devices must comply with building codes and the ASME *Boiler and Pressure Vessel Code*. For the remainder of this discussion, the term “safety valve” is used generically to include any or all of the four types described.

Safety valve construction, capacities, limitations, operation, and repair are covered by the ASME *Boiler and Pressure Vessel Code*. For pressures above 15 psig, refer to Section I. Section IV covers steam boilers for pressures less than 15 psig. Unfired pressure vessels (such as heat exchange process equipment or pressure-reducing valves) are covered by Section VIII.

The capacity of a safety valve is affected by the equipment on which it is installed and the applicable code. Valves are chosen based on accumulation, which is the pressure increase above the maximum allowable working pressure of the vessel during valve discharge. Section I valves are based on 3% accumulation. Accumulation may be as high as 33.3% for Section IV valves and 10% for Section VIII. To properly size a safety valve, the required capacity and set pressure must be known. On a pressure-reducing valve station, the safety valve must have sufficient capacity to prevent an unsafe pressure rise if the reducing valve fails in the open position.

The safety valve set pressure should be high enough to allow the valve to remain closed during normal operation, yet allow it to open and reseat tightly when cycling. A minimum differential of 5 psi or 10% of inlet pressure (whichever is greater) is recommended.

When installing a safety valve, consider the following:

- Install the valve vertically with the drain holes open or piped to drain.
- The seat can be distorted if the valve is overtight or the weight of the discharge piping is carried by the valve body. A drip-pan elbow on the discharge of the safety valve prevents the weight of the discharge piping from resting on the valve (Figure 25).
- Use a moderate amount of pipe thread lubricant (first 2 to 3 threads) on male threads only.

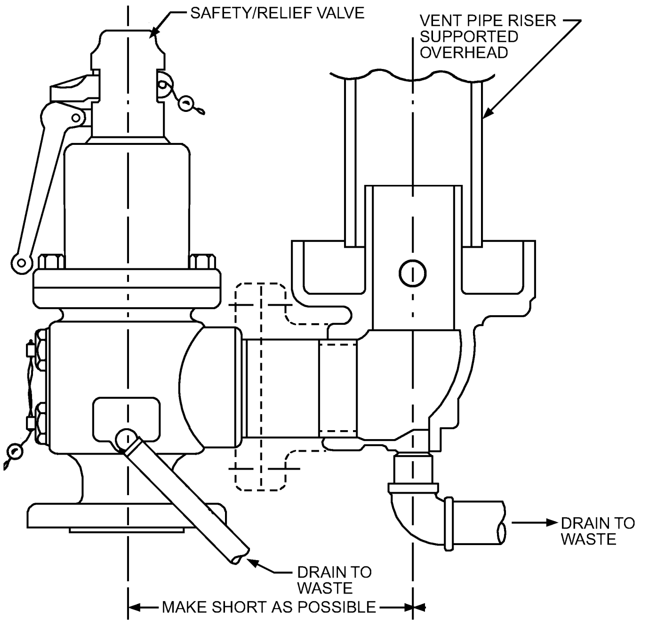

Fig. 25 Safety/Relief Valve with Drip-Pan Elbow

- Install clean flange connections with new gaskets, properly aligned and parallel, and bolted with even torque to prevent distortion.
- Wire cable or chain pulls attached to the test levers should allow for a vertical pull, and their weight should not be carried by the valve.

Testing of safety valves varies between facilities depending on operating conditions. Under normal conditions, safety valves with a working pressure under 400 psig should be tested manually once per month and pressure-tested once each year. For higher pressures, the test frequency should be based on operating experience.

When steam safety valves require repair, adjustment, or set pressure change, the manufacturer or approved stations holding the ASME V, UV, and/or VR stamps must perform the work. Only the manufacturer is allowed to repair Section IV valves.

7. SELF-CONTAINED TEMPERATURE CONTROL VALVES

Self-contained or self-operated temperature control valves do not require an outside energy source such as compressed air or electricity (Figure 26). They depend on a temperature-sensing bulb and capillary tube filled with either an oil or a volatile liquid. In an **oil-filled** system, the oil expands as the sensing bulb is heated. This expansion is transmitted through the capillary tube to an actuator bellows in the valve top, which causes the valve to close. The valve opens as the sensing bulb cools and the oil contracts; a spring provides a return force on the valve stem.

A volatile-liquid control system is known as a **vapor pressure** or **vapor tension** system. When the sensing bulb is warmed, some of the volatile liquid vaporizes, causing an increase in the sealed system pressure. The pressure rise is transmitted through the capillary tube to expand the bellows, which then moves the valve stem and closes the valve. Thermal systems actuate the control valve either directly or through a pilot valve.

In a **direct-actuated** design, the control directly moves the valve stem and plug to close or open the valve. These valves must compensate for the steam pressure force acting on the valve seat by generating a greater force in the bellows to close the valve. An adjustable spring adjusts the temperature set point and provides the return force to move the valve stem upward as the temperature decreases.

A **pilot-operated valve** (Figure 27) uses a much smaller intermediate pilot valve that controls the flow of steam to a large diaphragm that then acts on the valve stem. This allows the control system to work against high steam pressures caused by the smaller area of the pilot valve.

For self-contained temperature valves to operate as proportional controls, the bulb must sense a change in the temperature of the process fluid. The difference in temperature from no-load to maximum controllable load is known as the **proportional band**. Because the size of this proportional band can be varied depending on valve size, the accuracy is variable. Depending on the application, proportional bands of 2 to 18°F may be selected, as shown in the following table:

Application	Proportional Band, °F
Domestic hot-water heat exchanger	6 to 14
Central hot water	4 to 7
Space heating	2 to 5
Bulk storage	4 to 18

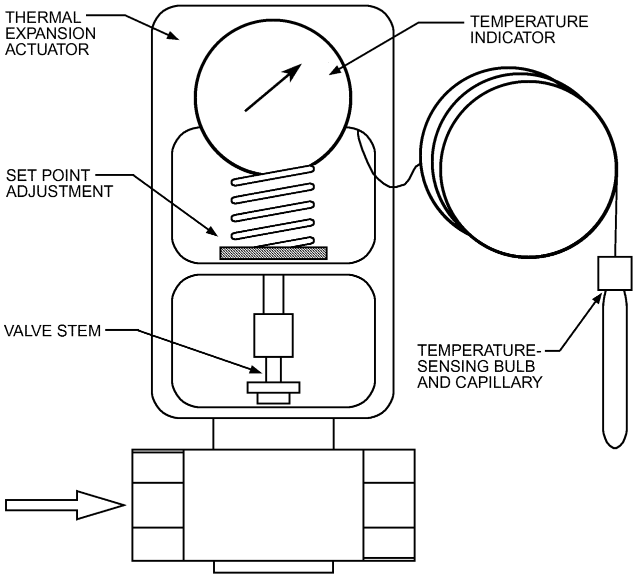

Fig. 26 Self-Operated Temperature Control Valve

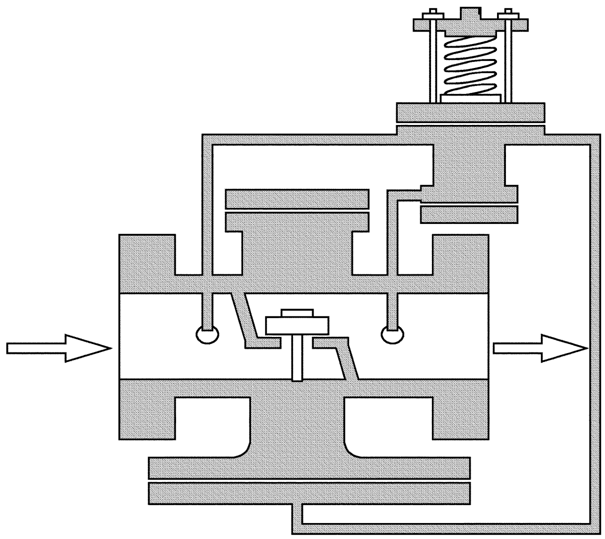

Fig. 27 Pilot-Operated Steam Valve

Although their response time, accuracy, and ease of adjustment may not be as good as those of electrically or pneumatically actuated valves, self-contained steam temperature controls are widely accepted for many applications.

8. PRESSURE-REDUCING VALVES

Should steam pressure be too high for a specific process, a self-contained pressure-reducing valve (PRV) may be used to reduce this pressure, which will also increase the available latent heat. These valves may be direct acting or pilot operated (see Figure 27), much like temperature control valves. To maintain set pressure, the downstream pressure must be sensed either through an internal port or an external line.

The amount of pressure drop below the set pressure that causes the valve to react to a load change is called **droop**. As a general rule, pilot-operated valves have less droop than direct-acting types. To properly size these valves, only the mass flow of steam, the inlet pressure, and the required outlet pressure must be known. Valve line size can be determined by consulting manufacturers' capacity charts.

Because of their construction, simplicity, accuracy, and ease of installation and maintenance, these valves have been specified for most steam-reducing stations.

Makeup Water Valves

A pressure-reducing valve is normally provided on a hydronic heating or cooling system to automatically fill the system with domestic or city water to maintain a minimum system pressure. This valve may be referred to as a fill valve, PRV fill valve, or automatic PRV makeup water valve, and is usually located at or near the system expansion tank. Local plumbing codes may require a backflow prevention device where the city water connects to the building hydronic system (see the section on Backflow Prevention Devices).

9. CHECK VALVES

Check valves prevent reversal of flow, controlling the direction of flow rather than stopping or starting flow. Some basic types include swing check, ball check, wafer check, silent check, and stop-check valves. Most check valves are available in screwed and flanged body styles.

Swing check valves have hinge-mounted disks that open and close with flow (Figure 28). The seats are generally made of metal, whereas the disks may be of metallic or nonmetallic composition materials. Nonmetallic disks are recommended for fluids containing dirt particles or where tighter shutoff is required. The Y-pattern check valve has an access opening to allow cleaning and regrinding in place. Pressure drop through swing check valves is lower than that through lift check valves because of the straight-through design. Weight- or spring-loaded lever arm check valves are available to limit objectionable slamming or chattering when pulsating flows are encountered.

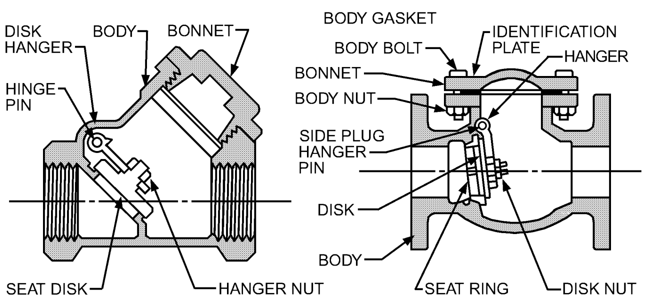

Fig. 28 Swing Check Valves
(Courtesy Anvil International)

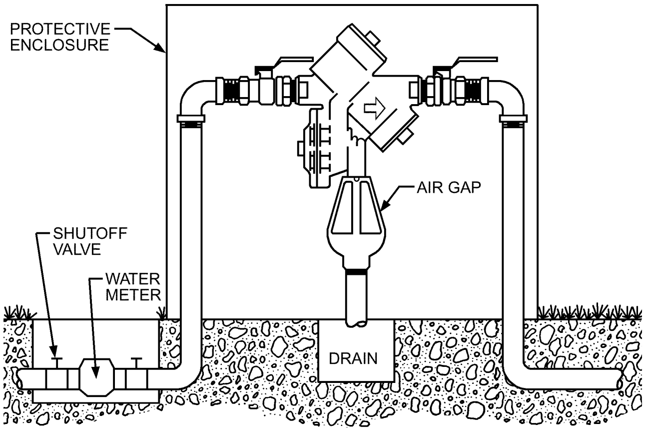

Fig. 29 Backflow Prevention Device

Lift check valves have a body similar in design to a globe or angle valve body with a similar disk seating. The guided valve disk is forced open by the flow and closes when flow reverses. Because of the body design, the pressure drop is higher than that of a swing check valve. Lift check valves are recommended for gas or compressed air or in fluid systems not having critical pressure drops.

Ball check valves are similar to lift checks, except that they use a ball rather than a disk to accomplish closure. Some ball checks are specifically designed for horizontal flow or vertical upflow installation.

Wafer check valves are designed to fit between pipe flanges similar to butterfly valves and are used in larger piping (4 in. diameter and larger). Wafer check valves have two basic designs: (1) dual spring-loaded flapper, which operates on a hinged center post, and (2) single flapper, which is similar to the swing check valve.

In **silent or spring-loaded check valves**, a spring positively and rapidly closes a guided, floating disk. This valve greatly reduces water hammer, which may occur with slow-closing check valves like the swing check. Silent check valves are recommended for use in pump discharge lines.

10. STOP-CHECK VALVES

Stop-check valves can operate as both a check valve and a stop valve. The valve stem does not connect to the guided seat plug, allowing the plug to operate as a conventional lift check valve when the stem is in the raised position. Screwing the stem down can limit the valve opening or close the valve. Stop-check valves are used for shutoff service on multiple steam boiler installations, in accordance with the ASME *Boiler and Pressure Vessel Code*, to prevent backflow of steam or condensate from an operating boiler to a shutdown boiler. They are mandatory in some jurisdictions. Local codes should be consulted.

11. BACKFLOW PREVENTION DEVICES

Backflow prevention devices prevent reverse flow of the supply in a water system. A **vacuum breaker** prevents back siphonage in a nonpressure system, while a **backflow preventer** prevents backflow in a pressurized system (Figure 29).

Selection

Vacuum breakers and backflow preventers should be selected on the basis of the local plumbing codes, the water supply impurities involved, and the type of cross-connection.

Impurities are classified as (1) contaminants (substances that could create a health hazard if introduced into potable water) and (2) pollutants (substances that could create objectionable conditions but not a health hazard).

Cross-connections are classified as nonpressure or pressure connections. In a nonpressure cross-connection, a potable-water pipe connects or extends below the overflow or rim of a receptacle at atmospheric pressure. When this type of connection is not protected by a minimum air gap, it should be protected by an appropriate vacuum breaker or an appropriate backflow preventer.

In a pressure cross-connection, a potable-water pipe is connected to a closed vessel or a piping system that is above atmospheric pressure and contains a nonpotable fluid. This connection should be protected by an appropriate backflow preventer only. Note that a pressure vacuum breaker should not be used alone with a pressure cross-connection.

Vacuum breakers should be corrosion-resistant. Backflow preventers, including accessories, components, and fittings that are 2 in. and smaller, should be made of bronze with threaded connections. Those larger than 2 in. should be made of bronze, galvanized iron, or fused epoxy-coated iron inside and out, with flanged connections. All backflow prevention devices should meet applicable standards of the American National Standards Institute, the Canadian Standards Association, or the required local authorities.

Installation

Vacuum breakers and backflow preventers equipped with atmospheric vents, or with relief openings, should be installed and located to prevent any vent or relief opening from being submerged. They should be installed in the position recommended by the manufacturer.

Backflow preventers may be double check valve (DCV) or reduced pressure zone (RPZ) types. Refer to manufacturers' information for specific application recommendations and code compliance.

12. STEAM TRAPS

For a description and diagram of these traps, see Chapter 11.

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