Heating, Ventilation, and Air Conditioning Solutions

Valve Applications Guide

BELIMO®

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Introduction

Motorized valves are the controlled devices that adjust the flow of water in a hydronic heating and cooling system. The information in this guide relates to sizing and selection of traditional control valves, which are pressure dependent. Flow through these valves is dependent on the pressure across the valve orifice. Typical pressure dependent valves include globe valves, standard ball valves, and the Belimo Characterized Control Valve (CCV). Pressure Independent Valves (PIV) are discussed as a superior solution to traditional control valves because pressure independent valves regulate and maintain a constant flow to the coil regardless of pressure fluctuation within the system.

Valve sizing cannot be accurate without firm understanding of the hydronic system. While valves are the final control element, the balancing, coil sizing, coil response curve, and the piping losses all play a role in accurate sizing. A control valve cannot be properly sized without full analysis of the system. If the designer of the system requires high accuracy, then a rigorous analysis is required and the designer may have to size the valves.

Everything interacts in a hydronic system, so the valves cannot be treated as a simple subject by themselves. Instead, the whole hydronic system has to be taken into account. There is a good deal of data necessary for careful sizing and selection of valves, but when all of it is not available, the accuracy will suffer.

There are times when the specification does not take as built conditions fully into account. Valves may be missized by adherence to the specification and the design engineer should be consulted.

Every process, every coil has a unique response. It is most difficult to fully study each and design a special characterized valve to control the process. But we can do some things to improve control.

1. Select a valve with an overall characteristic which most matches the process. If we cannot do full hydraulic analysis of the system, we can choose linear or equal percentage depending on which is closest to the response needed.
2. Select a valve with the proper capacity.
3. Balance the system.
4. Eliminate excessive pump head.
5. Select an actuator which is capable of good control and we tune the control loop.
6. Select pressure independent valves to maintain the controllers flow setpoint.

The approach detailed for pressure dependent valves is common in HVAC and process control.

It must be considered an error for the control engineer to unquestioningly accept project specifications and select valves in a stereotyped manner from a limited range of possibilities. A thorough analysis is needed.

Under any circumstance, this booklet should give a general knowledge of how the control valves and the hydronic system interacts. Hopefully, this will lead to good system design.

Types of Valves

Two, Three, Four and Six-Way Valves

Two-way valves have two ports and control flow in variable flow systems. Refer to Figure 1.

Three-way valves have three ports, one common to the other two that can be piped for mixing or diverting service. Mixing means the flow can enter two ports and exit through the common port. Diverting means the flow enters the common port and exits through the other two ports. Damage can result if piped opposite to the intended function of the valve. Three-way valves are used in constant flow systems. Refer to Figure 2.

Four-way valves have four ports equally spaced and are known as slide type valves. It can serve two constant flow loops, each with its own pump. Two ports connected to the first loop (boiler) and two ports connected to the second loop (peripheral system). These valves are common in Europe.

Six-way valves have the functionality of four 2-way control valves with two sequences providing different Cv capabilities (e.g. heating and cooling). One valve performs change over and modulating control for a single coil in a four-pipe system.

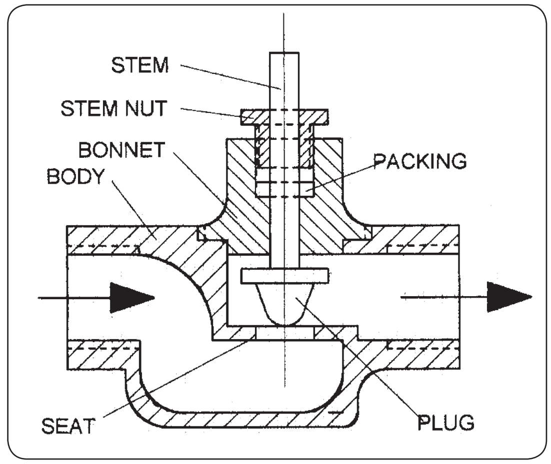


Figure 1 - 2-way Globe Valve

Globe Valves

Globe valves have a linear stem movement, which operates a plug against one seat for two-way valves and two seats (one upper and one lower) for three-way valves. The accuracy and rangeability of globe valves is covered in Section 5. Globe valves are used in pipe sizes from ½ " to 6".

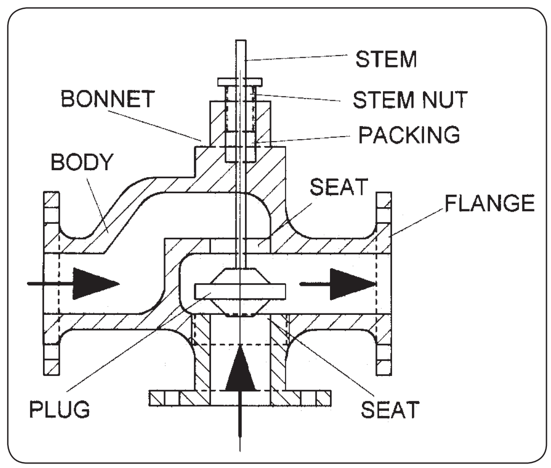


Figure 2 - 3-way Globe Valve

Standard Ball Valves

Ball valves are available in both two and three-way configurations which use an internal ball with a hole drilled through the center of the ports. The flow is controlled by turning the ball 0-90 degrees versus the flow path through the body. They offer high-pressure valve bodies with high close-off capabilities.

Three major variants are available: flat ball reduced port, round ball reduced port and standard full port. Many are adapted for use as modulating valves by drilling bolt holes in the bonnet to mount an actuator.

Flat ball reduced port valves have a flat surface on the ball. These valves provide poor flow response curve and are only used for 2-position control. When opening, flow is delayed until the hole in the center of the ball rotates beyond the restriction of the body. Flow increases rapidly as the hole clears the restriction of the body until full flow is achieved; additional opening travel has no effect with the flow. Flow goes from 0% to 100% over about 40° rotation; this is a quick opening valve. Refer to Figures 3a and b.

Round ball reduced port valves are somewhat less quick opening than flat ball reduced port valves but they have more delay to achieve initial flow. With the ball set up for a 90° rotation, there is a delayed opening until approximately 20° rotation, and full flow is achieved at about 50° open. To avoid the delayed response, install the actuator with the ball rotated about 10° toward open. While this avoids the delay, the quick response remains, and the valve reaches full flow at 40% open. This is a delayed response, quick opening valve used for 2-position control, not modulation.

Standard full port ball valves are inexpensive and are used for shut off applications. Refer to Figure 4a. There is a delay in flow until the hole clears the body. The response curve is logarithmic (shallow equal percentage) along its middle portions, and the flow flattens and does not increase appreciably during the last 30° of rotation. Reduced ports vary in size from about 60% of the pipe size to very small. The response curve worsens as the Cv goes down with the small ports as shown in Figure 4b.

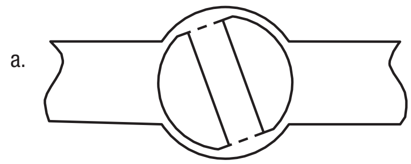
Additionally, the high flow capacity of the valve is suitable for isolation or on/off control but causes problems when applied to modulating applications. Because the valve Cv is much larger than the coil requires, design flow to the coil occurs when the valve is about half open. The flow characteristic of the valve is not suited for modulating service because valve rangeability and actuator resolution are not optimal. Absent a balancing valve; the control signal should be set to approximately 2.5V-6V to achieve minimum to maximum flow instead of a typical 2-10V operating voltage range.

Types of Valves

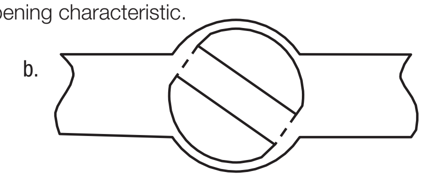
There are two other factors which distort the nominal flow curves. One is if the valve is smaller than pipe size then the characteristic curve is flattened. The full open flow is less while the partial open flow is unaffected, refer to Figure 4c. The second factor is the distortion in the flow curves is worse with poor valve authority. More information on these considerations is found in other sections of this guide.

In general, standard ball valves are only ideal for 2-position control in pipe sizes from ½ " to 3" in the HVAC industry.

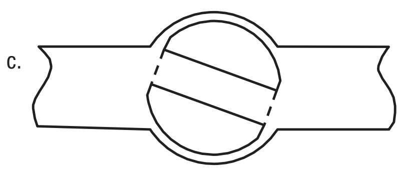
Flat end reduced port ball valves See response curves in Figure 3B. View from above.



Here the ball is rotated before the actuator is installed. This avoids a delay in flow, but the valve has a quick opening characteristic.

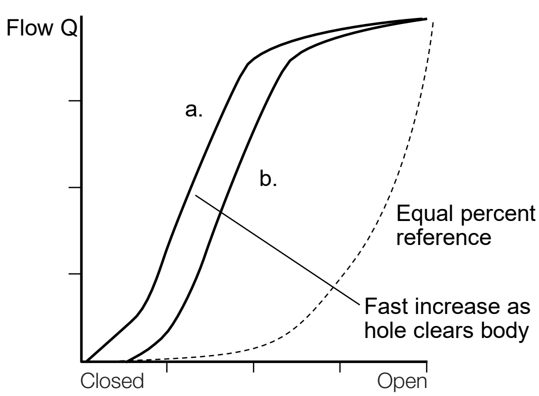


Here the ball is rotated to 25% open and the flow path is quite large. As soon as the opening clears, flow is near maximum.



The valve experiences maximum flow before full open rotation.

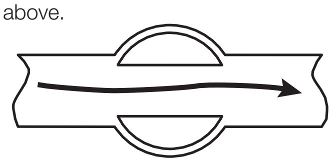
Figure 3a - Flat End Reduced Port Ball Valve



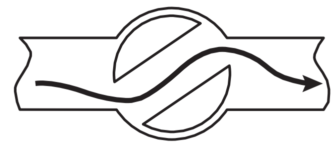
Note flow delay as hole clears the valve body

Figure 3b - Reduced Port Ball Valve Flow Characteristic

View from above.



Full ported ball has a hole about 80% of the ball body.



Here the ball has rotated about 50% and flow is greatly reduced.

Figure 4a - Full Ported Ball Valve

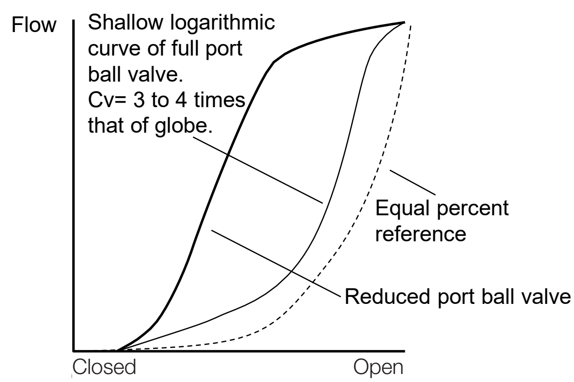


Figure 4b - Full Port Ball Valve Flow Characteristic

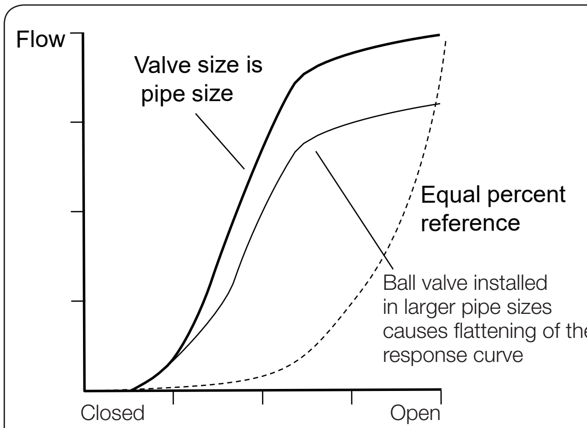


Figure 4c - Distortion Curve Due to Pipe Size

Belimo Characterized Control Valves

Belimo Characterized Control Valve (CCV) marks a true advancement in control valves. It combines the high close-off capabilities of a ball valve with a specialized disc that ensures an equal percentage flow characteristic. One side of the disc is concave and matches the surface of the ball. Flow is controlled by the opening in the ball and by a specially designed opening in the disc. This reduces the flow coefficient (Cv). The valve increases flow slowly, especially when it begins to open. Therefore, equal percentage flow characteristic is provided and the resulting heat output is linear. Figure 5a and 5b illustrate the CCV technology.

Better valve control prevents "hunting" of the control loop in which the system is constantly adjusting itself to maintain set point. When the operating conditions of the actuator are improved and the full operating range is used, system life span is increased, and energy consumption is reduced.

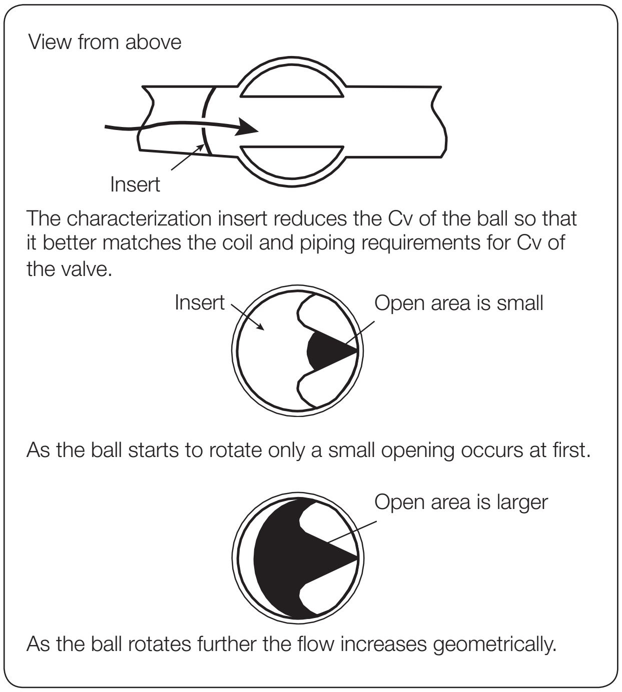


Figure 5a - Belimo Characterized Control Valve

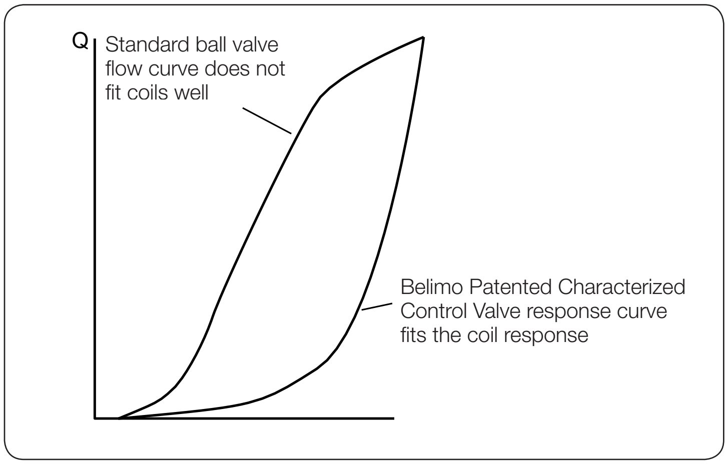


Figure 5b - Belimo Characterized Control Valve Flow Characteristic

Pressure Independent (PI) Control Valves

Belimo offers two types of PI valves; mechanical pressure independent and electronic pressure independent. The valve trim section may utilize globe or characterized control valve type construction. The regulator section of a PI valve will compensate for changes in differential pressure to keep the flow equal to the output of the control signal. PI valves interpret the control signal as a flow setting, whereas pressure dependent valves interpret the control signal as a position setting. Pressure Independent valves have the inherent advantage of not requiring an associated balancing valve because the function is built into the valve.

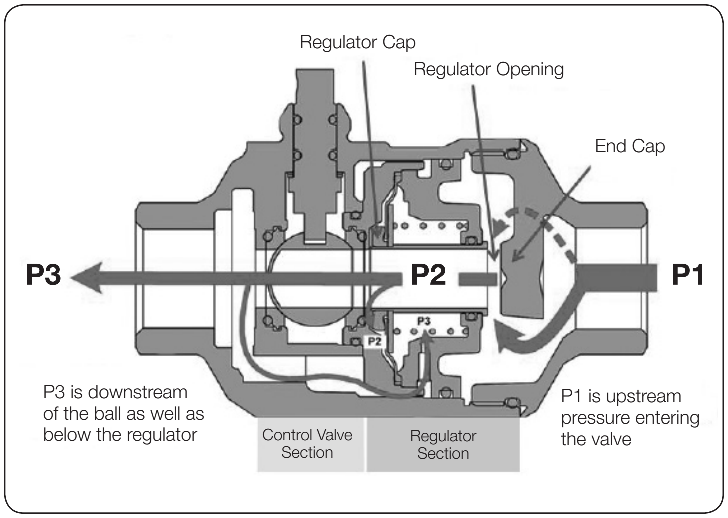


Figure 5c – Mechanical Pressure Independent Valve

Mechanical Pressure Independent Valves combine a differential pressure regulator with a 2-way control valve to supply a specific flow for each degree of ball opening regardless of system pressure fluctuations. The valve performs the function of a balancing valve and control valve in one unit.

Electronic Pressure Independent Valves (ePIV) utilize a furnished flow meter and control logic within the actuator to adjust the valves opening position in order to maintain the flow setting of the control signal. ePIV's have the ability to provide either position feedback, or flow rate feedback, to the control system. See Critical Zone Reset on page 23 for additional information.

Energy Valves build upon ePIV functionality with additional coil inlet and outlet temperature sensors and energy saving logic within the actuator to manage the coil differential temperature by limiting coil water flow - under defined conditions. Optional "Power Control" logic enables the valve to interpret the control signal to be the heat transfer setting of the coil, expressed in BTUH or KWH units.

Shoe Valves

Rotary shoe valves have a cylindrical inner surface, with openings in the circumference. A shoe, or slide, is operated by the turning motion of a stem, and covers or uncovers the openings, thereby controlling the flow. In process control, this type of valve is referred to as a "trunnion mounted characterized port ball valve."

Types of Valves

Butterfly Valves

Butterfly valves are two-way valves that use a disc to control the flow. The disc rotates 0-90 degrees inside a ring shaped body, which usually is sandwiched between two pipe flanges. When the disc is parallel with the pipe, the valve is fully open. When the disc is perpendicular to the pipe, the valve is closed. Refer to Figure 6.

Often, the body of a butterfly valve has an inner lining of resilient material that provides a tight seal against the disc when the valve is closed. When a butterfly valve is partially open, dynamic forces will act upon the disc and produce a torque that tends to open the valve. The forces peak between 60° and 85° and drop to near zero when full open. It is important that the actuator is powerful enough to produce a sufficient torque to operate the valve from closed to fully open. Valves with a resilient seat requires a quite high torque to operate the disc near the closed position. Undercut discs reduce close-off torque requirement and close-off pressure rating while keeping leakage low below the reduced pressure rating. This is standard practice in HVAC where high close-off pressures are not often required.

The butterfly valve has a flow characteristic similar to the full port ball valve or a modified parabolic. Refer to Figure 11.

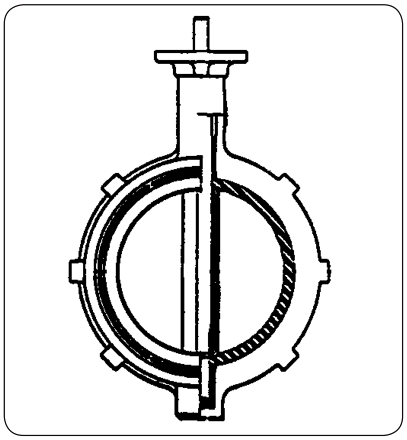


Figure 6 - Butterfly Valves

Two butterfly valves can be linked together so they operate as a three-way valve. They are mounted on a pipe-T and are linked so when one valve closes, the other valve opens. Ball valves, butterfly valves and rotary slide valves are operated by a 0 - 90 degree movement. It is therefore easy to operate these valves by rotary electric actuators.

Coil Characteristics

Heating Coils

The relationship between the heat output and the flow of hot water through a typical heating coil is not linear. Different types of coils have different characteristics, but the basic "convex" shape remains essentially the same - the only difference is how pronounced the curvature. The convex shape depends upon the type of heat exchanger, the waterside temperature drop, the airside temperature rise, the viscosity of water, and the relative humidity of the air. The "convex" shape of the curve means that when flow increases from zero, the heat output increases at a high rate in the beginning, but the increase in output is lower as the flow is increased. When the coil water flow is low, the water takes a long time to pass through the coil so the temperature drop of the water will be substantial. Refer to Figure 7.

Conversely, when the flow increases, the water spends less time inside the coil and the temperature drop of the water is less. A coil is selected for a specific airflow and heat output at full flow. The specified temperature drop of the water flow through the coil and the rise in air temperature is produced only at design conditions.

Different characteristics of water coils with a design temperature drop of 10°F, 20°F, and 60°F respectively are detailed in Figure 8.

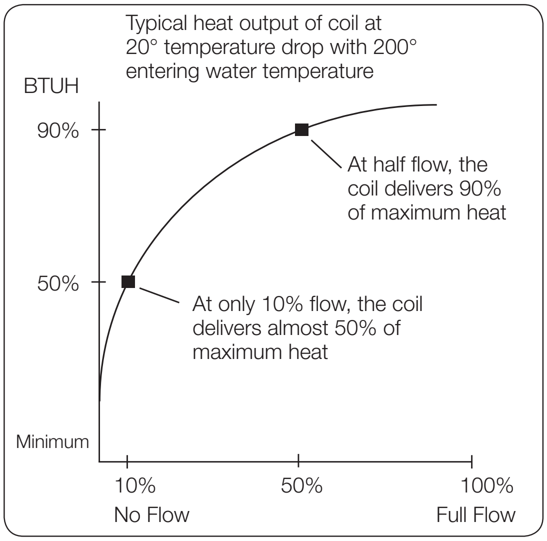


Figure 7 - Heat Output of Coil

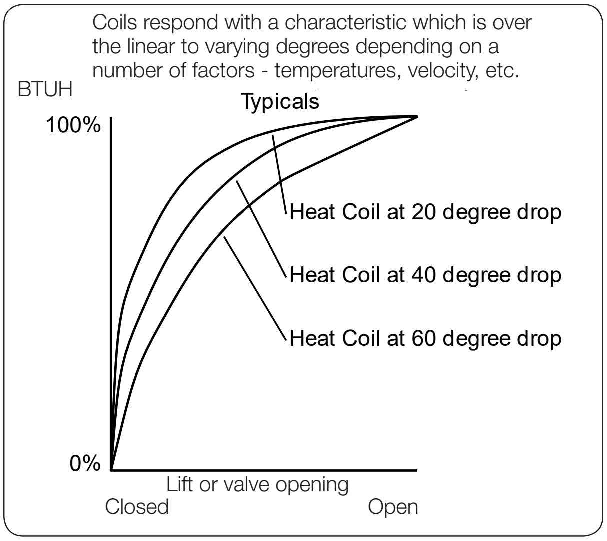


Figure 8 - Heat Output of Coil with Varying Temperatures

Cooling Coils

Figure 9 shows the characteristic response curve of a cooling coil. When studying the sensible heat emission versus the water flow, we find that the characteristic resembles a heating coil.

Total heat exchange also includes latent heat (moisture) removal. Dehumidification is an essential function, but concerning the stability aspects of temperature control, the sensible heat curve is the determining factor. The cooling curve is much closer to linear than the typical heating coil. The waterside drop is 10° instead of 20° for heating, the air side change is from 75° to 55° instead of from 70° to approximately 120° for heating.

For simplicity, the following text refers to heating coils. However, what is said also applies to cooling coils, except that heat is rejected and the temperature of the water passing through the coil increases. The curves however are different. Strictly speaking a typical cooling coil needs a different valve characteristic than a heating coil.

Notice that the cooling coil at a 10 degree rise is very similar to the heating coil at a 20 degree drop. The entering and leaving air temperatures are also factors.

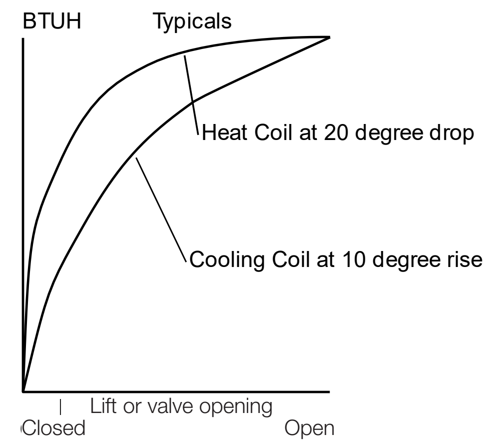


Figure 9 - Response Curve of Cooling Coil

Flow Coefficient

The correct sizing of the control valves is very important to the operation of the HVAC system. Without properly sizing the valves the system will never operate at an efficient level. The valve must be large enough to supply the maximum required flow when fully open. However, it is imperative when modulating control is used, that the valve is not oversized. When a valve is too large, the maximum required flow occurs when the valve is partially open; only a portion of the stem travel is used. Consequently, a small change of the stem travel results in a disproportionately large change in the heat output, especially when the valve begins to open. Stable control is hard to accomplish under these conditions.

The first step in selecting the proper size of a pressure dependent valve is to calculate the required flow coefficient. The flow coefficient is expressed as the Cv value, which is defined as the flow in GPM (Gallons per Minute) of 60°F water through a fully open valve with 1 psi differential pressure across the valve.

By definition, $Cv = GPM/\sqrt{(\Delta P/g)}$ or after rearranging, $GPM = Cv\,\sqrt{(\Delta P/g)}$

Where g is the specific gravity of the fluid, water = 1

$\sqrt{\Delta P}$ is in psi.

Kv is the metric counterpart to C_V. Kv of 100 = C_V of 116. Multiply the K_V value by 1.16 to obtain the C_V value. K_V is the m3/h of water flowing through the valve at 100 kPa pressure drop.

C_V Calculations

The C_V value is used for valves. It can be calculated for any component in a system. For example, a heat exchanger with a 4 psi pressure drop at 100 GPM has a $Cv = 100 / \sqrt{4} = 50$.

C_V is a flow quantity. When 2 valves are piped in parallel the Total Cv = Cv1 + Cv2.

Usually in piping we use K loss coefficient factors to express resistance. K x H_V, the velocity head pressure, is the total pressure loss of a fitting. But C_V could be used for series systems if desired.

For capacities in series, if C_V is used, C_V Total can be found using $\left(\frac{1}{Cv1}\right)^2 + \left(\frac{1}{Cv2}\right)^2 + \ldots\ldots\ldots\ldots \left(\frac{1}{Cv\ Total}\right)^2$

This is derived from $Cv = 1 / \sqrt{K \text{ and } K1 + K2 + \ldots}$ = K total for a series of pipe elements. Derivation can be found in ASHRAE S41.8 which uses R in place of K. K is more commonly found in fluid mechanics texts.

Therefore: $K = \left(\frac{1}{Cv}\right)^2$

Valve Characteristics

Control

The key assumption made while matching the coil and valve characteristic is that the control signal output and the actuator have a linear response. With a linear response, a 1V signal increase results in the same rotation or lift of a valve regardless of its location on the signal range. Typically, a 2 to 10V signal is used in HVAC. For example, the change from 2 to 3 V results in the same lift or rotation as the change from 8 to 9 V. In addition, the loop tuning constants, whether PID (Proportional Integral Derivative) or fuzzy logic generated, assume a mechanically linear process.

The output of a coil is non-linear. PID logic was developed with an approximate linear process in mind. Loop tuning can compensate for non-linearity, but the loop tuning time is excessive, and many controllers cannot have multiple gain values. Even self-tuning loops have difficulty as the response curve changes with other system variations.

The published Cv of a valve is the GPM that flows with a 1 psi pressure drop when the valve is full open. However, Cv is also used to define the flow when the valve is less than full open. The GPM flow at modulated positions is also measured at a 1 psi drop; a plot of these values is the response curve of the valve. Typical response curves are equal percentage or linear and will be listed accordingly in the valve specifications. The Cv at modulated positions may be important considerations when selecting a control valve, in particular for process control applications.

Characteristic Curves

For the HVAC industry, the valve characteristic is determined primarily by the shape of the ports, ball, disc, or plugs of the valve and is determined by laboratory conditions. In the laboratory, the pressure drop across the valve is held constant at 1 psi and its flow quantity is measured. (This could be water, air, or other fluid.) The valve is opened at 10° steps and a curve is graphed. The Instrument Society of America (ISA) requires three different pressures be used and the average of the values is published. Consequently, the published Cv of a valve is an approximation. The small variations due to pressures in lab testing are inconsequential compared to authority and valve type variations discussed below. Reference Figure 10.

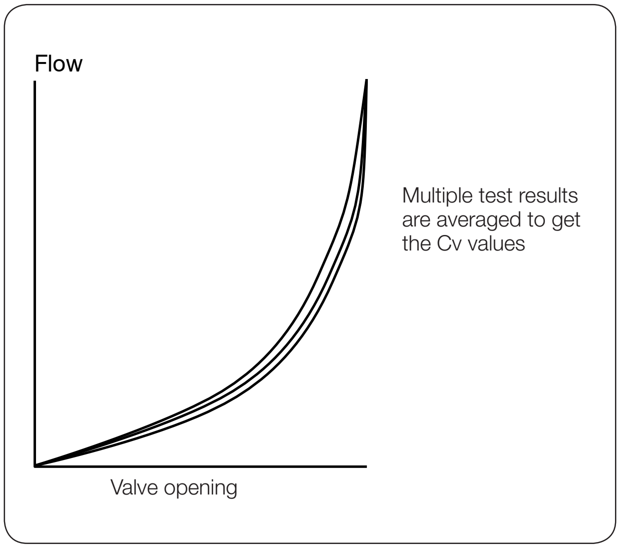


Figure 10 - Cv Value Curves

Quick Opening

Quick opening globe valves have a “plug” that is just a flat disc, which is operated against the seat. As soon as the disc lifts from the seat, the flow increases very quickly. This type of characteristics is suitable for on/off control. It gives a large flow capacity (Cv value) compared to the valve size. Refer to Figure 11. Flat end reduced port ball valves delay opening and then increase flow quickly. Globe valves can be manufactured with a quick opening characteristic.

Linear

Linear characteristic valves produce a flow proportional to the position of the valve stem found in some 2-way valves for pressure or steam control, and some 3-way valves. Reference Figure 11.

Modified Parabolic

Modified parabolic or shallow equal percentage curve falls between linear and the traditional equal percentage characteristic. Valves with this characteristic provide good modulating control as the valve first opens but yield more heat output per stem rotation as the valve continues to open. This curve is referred to as an equal percentage. Butterfly valves and standard and full-ported ball valves have characteristics close to the modified parabolic curve. Reference Figure 11.

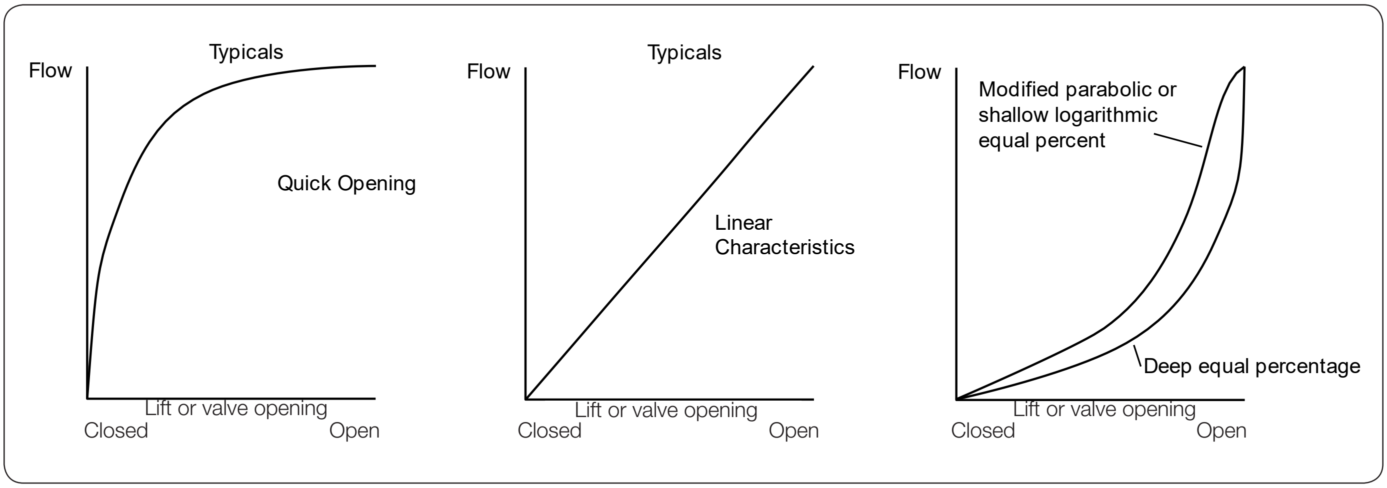


Figure 11 - Typical Response Curve Characteristics

Equal Percent

Valves with equal percent characteristic provide a logarithmic non-linear relationship between flow and the stem position. When the valve first begins to open, the flow increases at a small rate, as the valve is opens further, the rate gradually increases. The valve curve is always below linear and designed to complement the coil heat response curve, which is also logarithmic but above linear. The "concave" valve characteristic counteracts the "convex" nature of the coil. The intended net result is that the heat output becomes proportional to the stem position. The equal percent characteristic is suitable for modulating control of heating and cooling coils and other water-based heat exchangers. Reference Figure 11.

This characteristic is called "equal percent" because when the valve is opened in equal percent increments, the flow increases by an equal percentage number over the previous value. Conversely, the flow decreases by an equal percentage number, when the valve is closed in equal percent increments. In the following example, if the valve flow is 100 GPM when fully open, then flow is decreased 30% for each 10% increment decrease of the opening. This theoretical curve "aims" at 2.8 GPM for the 0% position. However, at the 0% position, the valve needs to be closed. Therefore, the real curve is slightly different near the closed position. The flow follows the equal percent curve down to 4 GPM then is modified to achieve close-off.

%Open	100	90	80	70	60	50	40	30	20	10	0
GPM	100	70	49	34	24	17	12	8	6	4	[2.8]

The percentages and flow quantities above are typical of the deep equal percentage curve of most globe valves, Belimo Characterized Control Valves (CCV), as well as opposed blade dampers. A shallower curve occurs with standard ball valves, butterfly valves, and parallel blade dampers.

There are many different logarithmic curves, which follow a formula that is referred to as equal percent. The curve can be more or less pronounced depending upon the percentage number used. Equal percent characteristics are not all the same; some curves are so shallow that they can not control a coil well.

Pipe Geometry

When a smaller valve than the pipe size is installed, pipe reducers must be used. The resultant Cv value of the reducers and valve will be less than the nominal Cv of the valve. The friction loss associated with pipe fittings and reducers is Fp. Tables documenting the corrected Cv value for different combinations of valves and pipe sizes are published in product documentation and also in the Belimo Valve Sizing and Selection Guide.

The pipe geometry has a substantial effect upon valves which have a large Cv compared to their body size, such as full ported ball valves and butterfly valves; most globe valves and reduced port ball valves are less affected. The pipe geometry is influenced the most when the valve is fully open, but it is insignificant when the valve is almost closed. Cvc = Fp x Cv states that the corrected Cv equals the geometry factor times the Cv. Fp = 1 when the valve is the same as the pipe size. Reference Figure 12.

The formula used to correct C_v is $F_p \times C_v = C_{vc}$.

$$F_p = 1 / \sqrt{\{(1 + [\,1.5\,\{1 - (d2 / D2)\}\,] / 890)\ \ (C_v / d2)\ 2\}}$$

C_v is the rated sizing coefficient without reducers.
d = Nominal valve size in inches

D = inside diameter of the pipe in inches
C_{vc} is the corrected C_v

It is a theoretical approximation and based on average concentric reducer tests.

Figures 13 and 14 show examples of curves which are modified by pipe geometry. The curves of low capacity valves (globes and characterized control valves) are pushed down only a small amount. They are pushed down very little at the top position only. The higher the capacity of the valve the more the curve is distorted at the open positions.

Figure 14 shows a large Fp impact at full flow for butterfly valves and standard ball valves when the body size is one or two sizes smaller than the pipe size. In modulating butterfly valve applications, the stroke is typically limited to 60° or 70° rotation, and the Fp impact on Cv at this position may be inconsequential. The butterfly valve modulates in a portion of the curve that is unaffected by the reduction. Modulating applications that use standard ball valves with pipe reduction fittings should be sized by consulting corrected Cv tables when full stem rotation is used.

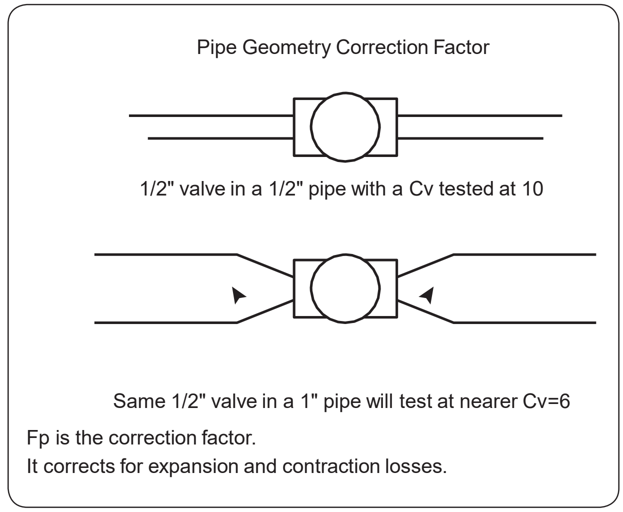


Figure 12 - Pipe Geometry

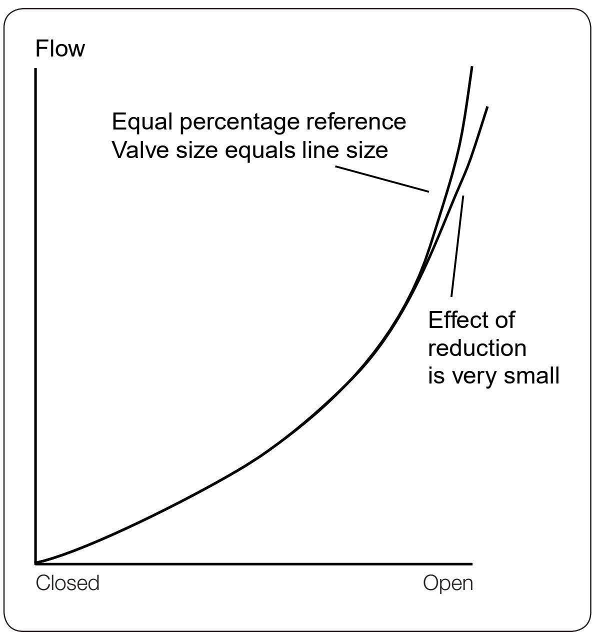


Figure 13 - Globe and Characterized Control Valve Response Curves Due to Geometry

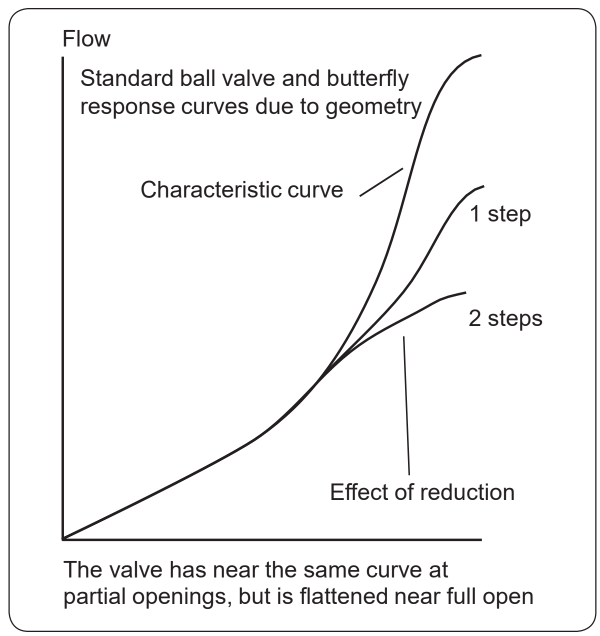


Figure 14 - Standard Ball and Butterfly Response Curves and Effect of Reduction

Resolution

Resolution or position accuracy is the number of movements an actuator will produce when the control signal is slowly changed from 0-100%. With a 2-10 VDC control signal, the span is 8 Volts. If an actuator has an 80 mV resolution, it requires 0.08 VDC signal increase to cause the actuator to move. Assuming a 90° rotary actuator received a slowly increasing signal from 2-10 VDC in 80 mV steps, there would be 100 movements. This number of movements over 90° provides position accuracy of .9° or approximately 1° rotation.

Rangeability Factor

Globe valves serve as a good example to explain valve authority. A globe valve has a contoured plug and a disc that operates against a seat. The largest diameter of the plug must be slightly smaller than the inside diameter of the seat. Otherwise the plug will get stuck in the seat. The clearance causes a minimum flow. Therefore, the contoured plug can only control the flow from a maximum flow down to a minimum flow. This is the "minimum controllable flow." When the plug is closed any further, the disc will stop the flow abruptly. The ratio between the full flow and the minimum controllable flow is the rangeability factor.

$$\text{Rangeability Factor RF} = \frac{\text{Maximum Flow}}{\text{Minimum Controllable Flow}}$$

It is important to realize that the rangeability factor is measured under laboratory conditions with a constant differential pressure applied across the valve. Rangeability is the characteristic of the valve design and manufacturing tolerances.

Turndown Ratio

The turndown ratio is the ratio between the maximum flow to the minimum controllable flow of a valve that is installed in a system.

$$\text{Turndown Ratio TR} = \frac{\text{Maximum Flow (installed)}}{\text{Minimum Controllable Flow}}$$

Example: In a laboratory, a constant differential pressure of 10 PSI is applied across the valve. We find that the maximum flow is 100 GPM, and that the minimum controllable flow is 2 GPM. Thus, the rangeability factory is RF = 100/2 = 50:1.

If we install this valve in series with a coil and apply 10 PSI across the valve and coil combination, we will find that the pressure drop across the coil reduces the pressure across the valve and thus the maximum flow. However, when the valve is almost closed, the pressure drop across the coil is zero and the full 10 PSI is applied across the valve. Therefore, the minimum controllable flow (2 GPM) will be the same as when there was no coil in series.

Let us say that the coil reduces the maximum flow to 70 GPM. The minimum controllable flow still is 2 GPM.

$$TR = \frac{70}{2} = 35:1$$

Many globe valves with commercial pneumatic actuation jump open. They seat with low leakage (typically .5% of Cv when new and 1% of Cv as the system ages) but they do not open smoothly. The minimum flow is .5% of Cv and then as soon as the pneumatic actuator moves at all they get 25% of flow. Modulating control at low openings is impossible, the result is 2-position control at low loads.

The actuator affects turndown. A Belimo actuator with high accuracy has a 200:1 possible rangeability (8V span / .04V response). Positioning accuracy greater than 1% is unnecessary for most applications where productive actuation is normally 2-3% of flow. Nevertheless, when required some Belimo actuators can match the accuracy of DDC controllers and precision valves, where other electric actuators and all commercial pneumatic actuators cannot. Hunting and dithering are possible with too small increments, for more information reference the section on control loop tuning below.

The turndown ratio is always smaller than the rangeability factor. Valve authority (A) is discussed in more detail below, and it impacts the turndown ratio per the formula, TR = RF x $\sqrt{A}$.

Given a rangeability = 30:1 and an authority of .5, the rangeability cannot be better than 30 x $\sqrt{.5}$ = 21 or 21:1. This is only 5% minimum flow at low loads.

The higher the turndown ratio is, the better the controllability will be.

Valve Authority & Pressure Dependent Valves

When installed, the differential pressure across a control valve changes when it is operated between open and closed. When it is closed, the full differential pressure in the system acts upon the control valve alone. When the valve is fully open, the flow will cause a pressure drop in all the other parts of the system (coil, balancing valve, pipes etc.), so there will be less differential pressure across the control valve. Depending upon the system, variations in the pump head may add to the pressure variation.

The valve authority (A) is the ratio between the differential pressure across the fully open valve and the fully closed valve. Or:

$$A = \frac{\text{Open Valve Pressure Drop}}{\text{Closed Valve Pressure Drop}}$$

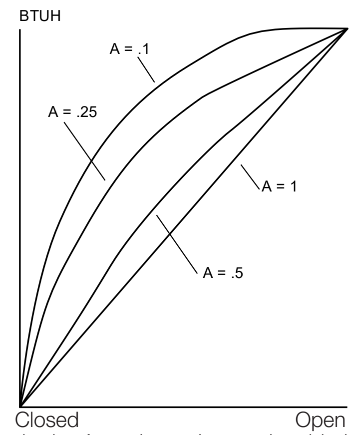
When A = 1 or A = 100% the valve is the only pressure drop in a sub-circuit. This is the inherent or intrinsic curve. As resistance is added in series with the valve, the authority curve changes. Adding series resistance lowers the full open flow more than it lowers the midpoint flow. Note that in a real installation the pressures in the supply and return vary with operation of other valves and that different types of valves have slightly different curve shapes.

Figure 15 shows how the valve authority (A) affects a linear valve. Linear characteristic is not suitable for modulating control in water systems, but it serves as a good example to clearly show how the characteristic is changed as the valve authority changes.

Figure 16 shows how a low valve authority (A = .1 and A = .25) distorts an equal percent valve characteristic. When the valve authority is low, the smallest stem movement will result in a disproportionately large change in the heat output and stable control is difficult to accomplish.

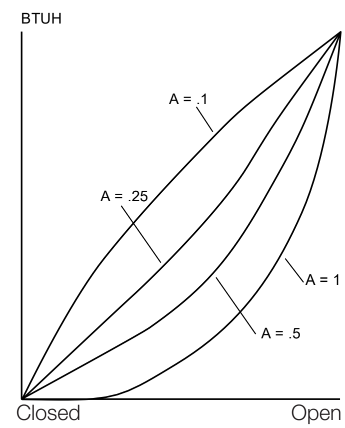
Figure 17 shows an example of a valve with almost 100% authority while Figure 18 shows a valve in a typical coil application with A = .4.

The pressure variation across a control valve is dependent upon the type of system. The differential pressure gradually increases as the valve is operated from open to closed. This will distort the valve characteristics. The variation is very large when a single constant speed pump is used, and it results in a poor valve authority. Pressure control and variable speed pumping will improve the valve authority and will help with controllability.



A is authority. As series resistance is added to the circuit, the valve has less of the total loss and the authority is lower. A = 1 means the authority is 100%

Figure 15 - Effect of Valve Authority on a Linear Valve



A is authority. As series resistance is added to the circuit, the valve pressure loss becomes a smaller portion of the total loss, which lowers valve authority. A = 1 means the authority is 100%

Figure 16 - Distortion of Low Valve Authority on Equal Percent Valve Characteristics

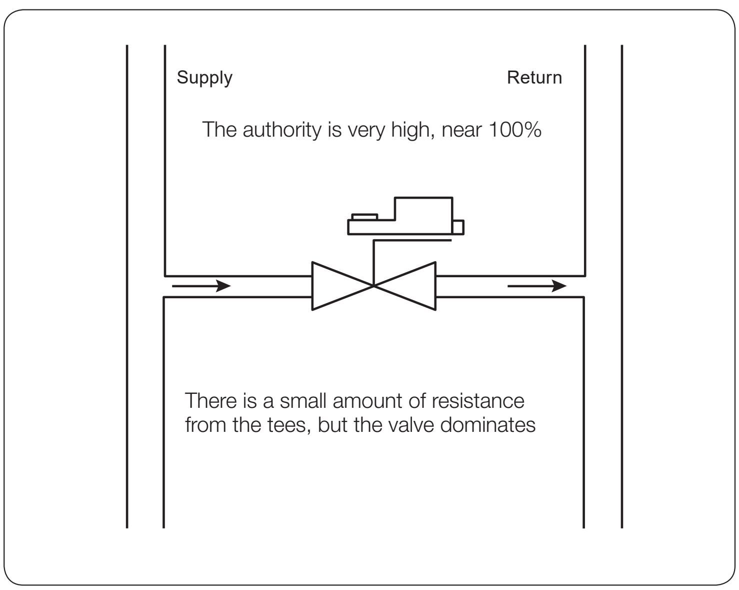


Figure 17 - High Authority Valve

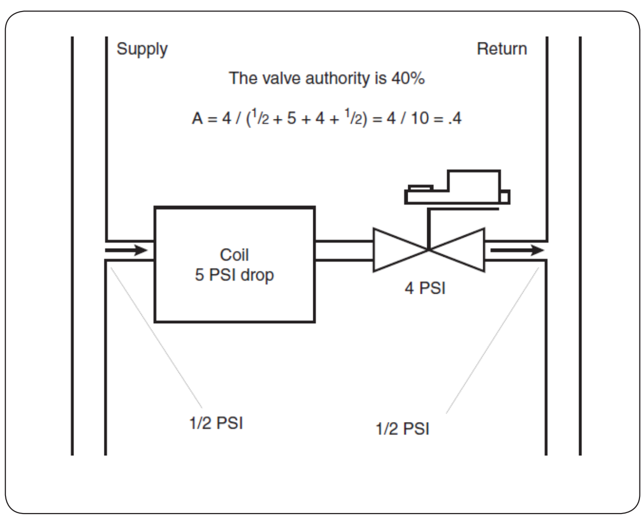


Figure 18 - Authority = .4

BELIMO

Pressure Dependent Valve Controllability

The best control stability is accomplished when there is a linear relationship between the position of the valve stem and the heat output from the coil. Almost all control systems default to a linear output signal to the actuator when tuning the control loop.

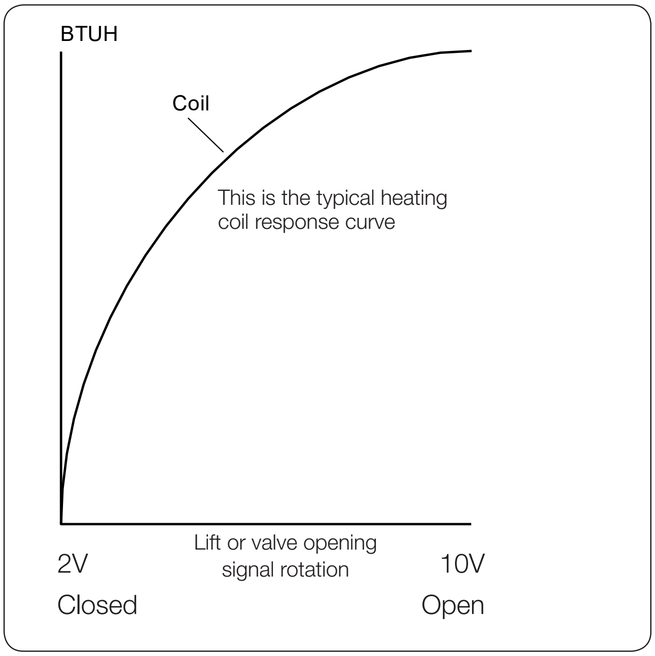


Figure 19 - Typical Coil Characteristic

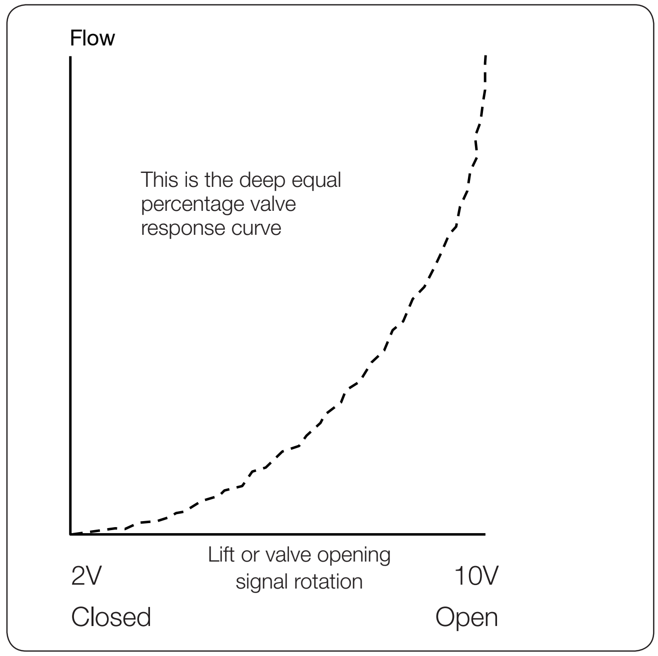


Figure 20 - Deep Equal Percentage Valve Response Curve

Figure 19 shows the typical coil characteristic. Figure 20 shows the deep equal percentage valve characteristic at A = 1.

Figure 21 shows the resulting relationship between the position of the valve stem and the heat output from the coil.

The coil characteristic is "convex" and an equal percent valve characteristics is "concave". The two complement and counteract each other, so that the relationship between the control signal and the heat output is essentially linear. This is only true as long as the valve characteristic is not distorted by a poor valve authority.

In order to achieve stable control, a high valve authority (A) is desirable as demonstrated in Figure 22.

Figure 23 shows the authority curves in a different way than all the other drawings. The absolute value of the flow is shown for each curve. In all the other drawings the flow quantity is not adjusted since it is the linearity of the curve that is discussed.

Pressure independent valve characteristic curves are not distorted by changes in pressure and the valve always produces flow equal to the control signal. The valve authority is equal to 1 within a 5-50 psid operating range.

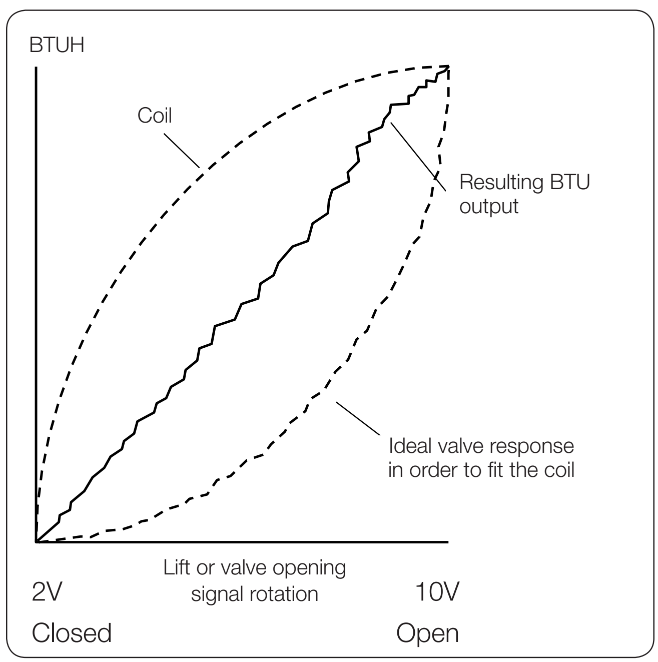


Figure 21 - Resulting BTU Output

Actuator Characterization

An actuator could be characterized also. Instead of the rotation being proportional to the signal it could follow a logarithmic curve. During the first volt of signal increase the actuator could move 3% of rotation; increasing in larger steps the last volt of signal increase could result in 25% of rotation. An example of this is found in the Belimo Energy Valve™ where the signal characteristic is selectable as either equal percentage or linear.

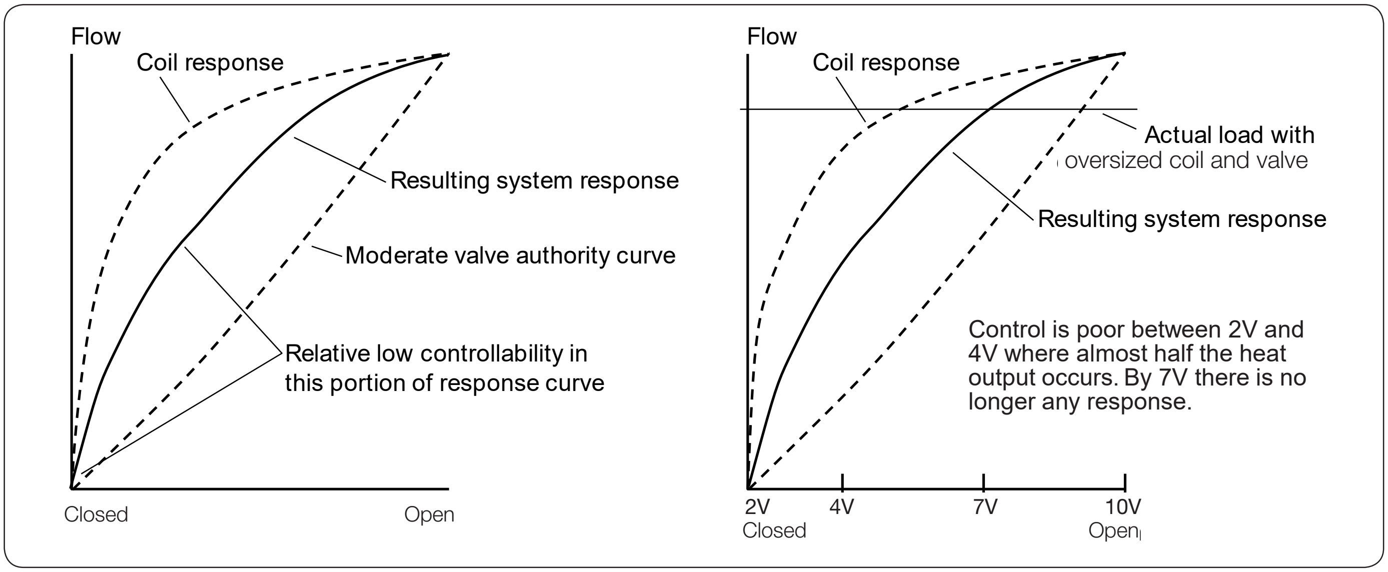


Figure 22 - Coil Response

Reset of Supply Water Temperature

The supply water temperature to the heating or cooling system is changed with respect to a parameter that is proportional to the load, usually the outdoor temperature. The reset function improves control when an oversized valve has been installed. When the temperature is reduced, the flow has to be increased in order to supply the same heating or cooling. Therefore, the control valves have to operate at a more open position. The reset schedule is the relationship between the outdoor temperature and the supply water temperature.

Example: the heating system has oversized coils, and the reset schedule is adjusted so the supply water temperature is 200°F at the design outdoor temperature. The coils will deliver full heat output when the control valves are only open 56% causing the valves to modulated in the steep part of the coil response curve. Refer to Figure 25. If the reset schedule is changed, so the supply water temperature is lowered, then the flow has to be increased in order to meet the load. Therefore, the control valves have to operate at a more open position. Control is improved with this technique for light load conditions.

Oversized heating coils will benefit from a reduced supply water temperature. For example, a coil that is 25% oversized at 200°F supply water temperature, will achieve design heat output when the supply water temperature is reduced to about 190°F.

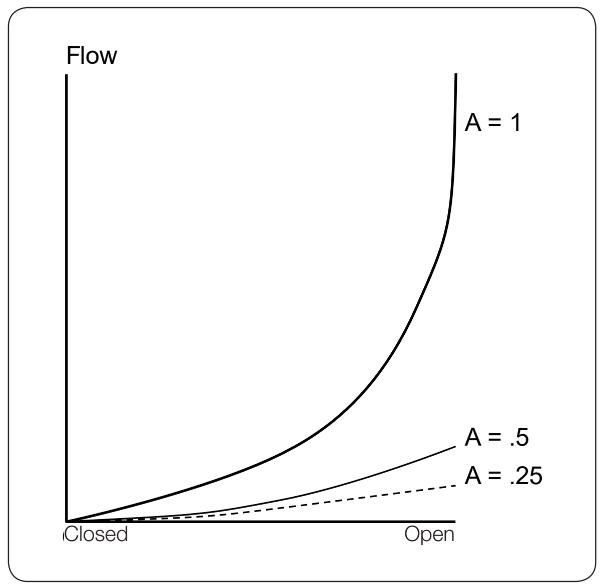


Figure 23 - Absolute Value of Flow

The increased flow through the coils reduces the risk of freezing the heating coils, and the surface temperature of the coils are more even. The drawback is that the pumping cost increases.

In cooling systems, the reset schedule is limited to ensure the chilled water temperature is cold enough to provide dehumidification.

Sequenced Valves

Instead of using one large valve, an inexpensive solution is to use two equal percentage valves piped in parallel and operated in sequence. A 1/3 - 2/3 capacity arrangement is when the Cv of valve #2 is twice the size as valve #1. Several sequences of operation are possible with a 1/2 - 2/3 arrangement. First, valve #1 is modulated open while valve #2 is closed; then valve #2 modulates open with an increase in demand. Or, valve #1 could open first, then close while valve # 2 opens, and if demand increases valve #1 could open again to add flow to a full open valve #2. The 1/3 - 2/3 valve arrangement has a higher rangeability than a single large valve. One or two analog outputs could be used depending on the desired sequence.

This solution is commonly used in steam systems, but is also used for hot water, chilled water, and air dampers also.

Controllability Versus Pumping Costs

To accomplish a high valve authority size the control valves for a high differential pressure. In a system with two-way valves, a valve authority of A = 0.5 is needed. When the pressure drop across the control valves is as large as the total pressure drop of all the other parts (pipes, coils, balancing valves etc.) in the loop, the valve authority A = 0.5 is desired because the distortion of the valve characteristic is quite small.

Controllability will be excellent, but at a cost. A pump must be selected, that can produce a sufficiently high pump head. The high pump head is energy consuming and results in quite high pumping costs.

In order to reduce the pumping costs, a lower valve authority must be accepted. A compromise should be found, that still gives an acceptable controllability. Modern controllers have advanced control algorithms, and can provide better control than older controllers. Pumping cost can be reduced by using selecting valves with low authority, but control stability will suffer if the valve authority is too low.

Different types of hydronic systems have different characteristics with respect to the controllability, so the type of system is an important consideration when the pressure drop across the valves is determined. The most simple and effective solution is to utilize pressure independent valves (PIV) because A=1; they automatically compensate for changes in pressure and provide the exact flow commanded by the controller.

Eliminate the Excessive Pump Head

Pipe sizing can be restrictive. The trade-off between first cost and life cycle costs is always present, but the piping system is most difficult to replace in the future when reconstruction takes place.

The payback of trimming the impeller (or replacing the pump) is very good, because of the savings in the annual operating costs of the pump. Furthermore, it is wrong to use the main balancing valve to eliminate excessive pump head, because it is effective only at the maximum total flow. At reduced flow the main balancing valve will have almost no effect and the full pump head will act upon the control valves. The control valves will be subject to very large pressure variations, and the authority of all the control valves is low. The valve authority and controllability of the whole system is improved, when the excessive pump head is eliminated.

Equipment Remarks Regarding The System Curve

The system curve shows how the required pump head varies with the total flow in a system when all the control valves are open. It is a quadratic relationship between the flow and the pump head (differential pressure), so if one point of the system curve is known, the rest can be calculated. Calculate the Cv value of the known point. This is the Cv value of the whole system. Apply different flow values to this Cv value and calculate the corresponding differential pressure using the formula $Q = Cv\sqrt{\Delta P}$.

Pump Curve

The pump curve shows how the pump head varies with the flow. Usually pump manufacture provides charts which show a number of pump curves at different pump speeds (RPM) or impeller diameters. The efficiency (%) is usually shown, so the best operating point can be determined.

Operating Point

By plotting the system curve on the pump curve chart, the intersection point between the system and pump curves can be found. This is the “operating point”, which is the flow and pump head of the system. The “operating point” usually refers to fully open control valves in the system. When the control valves begin to close and reduce the flow, the operating point moves back along the pump curve. Refer to Figure 30. When the speed or the diameter of the impeller is reduced, the operating point moves down along the system curve.

Constant flow systems are sized for an operating point at the point of highest efficiency. Variable flow systems are sized for the flat part of the pump curve.

The expansion tank absorbs the volume changes due to temperature variations of the water in the system. It also maintains the pressurization of the system, so cavitation is prevented. Some tanks have a pressurized bladder inside. The bladder should be sufficiently charged, so the correct pressurization is accomplished. The expansion tank and automatic fill valve should be connected close to the suction side of the pump. Refer to Figure 26.

Pump Location

The pump should be located just after the outlet of the boiler. Between the outlet of the boiler and the pump an automatic air separator should be located. The water leaving the boiler is very warm and the pressure is low at the suction side of the pump. The operating conditions for the air separator are therefore very favorable, because dissolved oxygen is released when the temperature is high and the pressure is low.

Expansion Tank and Fill Valve

The expansion tank will maintain a constant pressure at the suction side of the pump. Therefore, the automatic fill valve is subject to a constant pressure, regardless of the operating conditions of the pump. Water will be added only if the pressure of the expansion tank drops, which indicates that there actually has been a loss of water in the system.

It is important that the automatic fill valve does not add water when it is not needed, because it will overfill the system. The relief valve will eventually remove the excess water. However, a cycle where the auto flow valve adds water and the relief valve removes it, must be avoided because oxygen rich water is added to the system and corrosion will occur. Additionally, water leaks can be detected by closing the automatic fill valve; if pressure drops there is a leak in the system.

Balancing Pressure Dependent Valves

Pressure Dependent Valves

Although balancing valves are considered necessary by many industry professionals when applied to pressure dependent valves in heating and cooling systems, there are others that believe that balancing is unnecessary or even detrimental to maintain comfort in some zones under light load conditions. However, without balancing valves, if there is a disturbance during normal operation and a control valve opens, then there can be a large overflow (short circuit) at another terminal. When the system load increase, the system pressure drops, and all the control valves begin to open and compete for flow. A disturbance in one part of the system can spread to the whole system, and it will take some time before stability is restored.

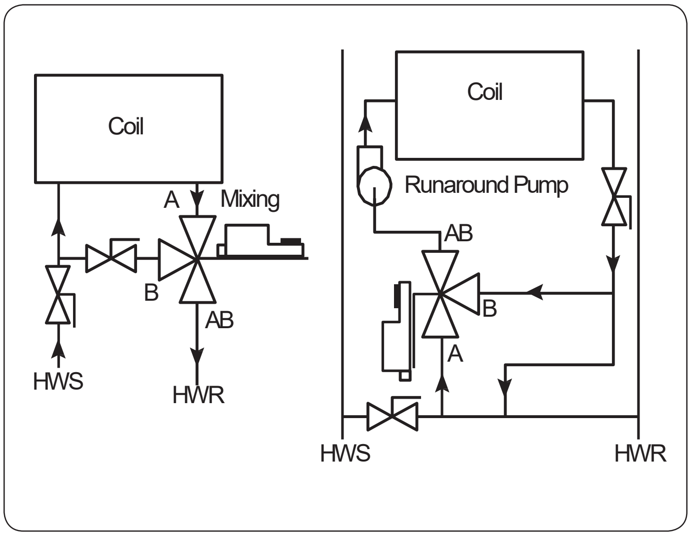


Figure 24 - Balancing Valve Locations for 3-way Valves

Most balancing valves also serve the purpose of a shut-off valve or isolation valve, so the additional cost of the device is quite small. Balancing valves are also an essential diagnostic tool that can demonstrate the control valve is providing the required flow. Balancing valves make it possible to confidently size the pump and control valves without any excessive safety margins, which may represent net savings in the total installation cost. The 2015 ASHRAE Handbook - HVAC Applications, page 38.8 states, “Any overflow increases pumping cost, and any flow decrease reduces the maximum heating or cooling at design conditions.” It also states “Often, reducing pump operating cost pays for the cost of water-side balancing.” The best way to optimize pump energy and achieve control stability is to pair a pressure dependent control valve with a balancing valve and perform a procedure for new construction and after renovations per standard BSR/ASHRAE 111 - Measurement, Testing, Adjusting, and Balancing of Building HVAC Systems.

Automatic balancing valves (ABV) are piped in series with the control valves and automatically limit the flow to the desired maximum value. They are automatic flow limiting valves, but are usually referred to as “Automatic or Self Adjusting Balancing Valves.” Some automatic balancing valves have a fixed setpoint while others have an adjustable setpoint or inserts are available to achieve the desired maximum flow. ABV's do a good job for design loads, but they interfere with control stability in moderate to light loads because the flow limiting mechanism is designed to “achieve” the maximum flow. When a control valve throttles to a low flow position the automatic balance valve response is to move open to its flow limit setpoint. This interaction requires the control valve to continue to close until temperature stability in the control loop is achieved. ABV's reduce stability at low loads and also reduce the resolution of the control valve. PIV's perform the same function and also work under all load conditions to deliver the flow requested by the controller. If PIV's are not used, then manual balancing valves are the preferred device.

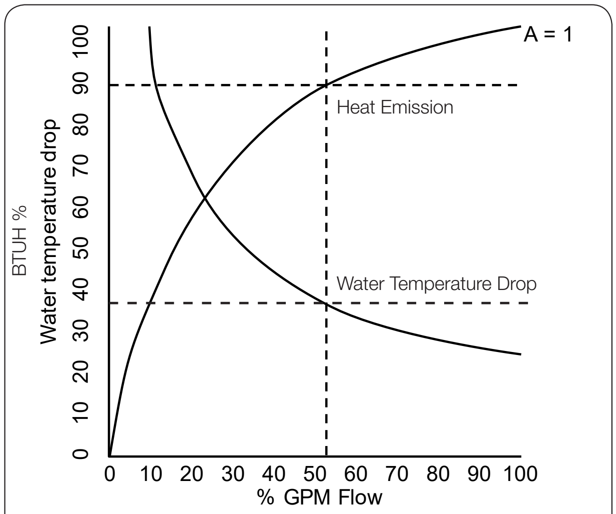
The manual balancing valve, or circuit setter, body has two pressure ports so the differential pressure can be measured as the valve is adjusted to any position between open and closed. The valve stem has a graduated scale so the stem position can be determined. A chart correlates the differential pressure and the stem position so the flow can be ascertained. The valve is adjusted to the desired flow when the associated control valve is fully open. For circuits with 2-way valves, the balancing valve is in series with the control valve. Reference Figure 24 for locations of balancing valves in systems with 3-way valves.

Balancing

To illuminate the need for balancing consider the scenario when calculated load falls between two coil sizes; it is natural that the next larger size is selected. Therefore, most coils are more or less oversized for the application. The needed maximum flow is very much dependent upon the installed coil and the operating conditions. Therefore, the coil manufacturer should be consulted to determine the true maximum flow requirements. To do this charts or software are available.

Example: The specification calls for a 90,000 BTUH load and a coil with a 20°F design temperature drop. (BTUH = BTU/hour. LBSH = LBS/hour. GPH = gallons/hour, 1 Gallon = 8.333 LBS). Reference Figure 25.

1 BTU raises the temperature of 1 LB water 1°F. Therefore, 90,000 BTUH/20°F = 4,500 LBSH/8.33 = 540 GPH/60 = 9 GPM. This is the specified flow. The nearest standard coil, has a design temperature drop of 20°F at a 100,000 BTUH load. This coil is installed, but it means that we are going to use only 90,000/100,000 = 90% of the capacity of the installed coil. The 90% BTUH line corresponds to a 36°F temperature drop per the dotted lines. When applied to the specified load: 90,000/36°F = 2,500 LBSH/8.33 = 300 GPH/60 = 5 GPM. The required flow design flow for the installed coil is 5/9 = 56% of the specified flow. In summary, a 10% oversized coil results in water flow reduction to 56%.



Typical coil heat emission vs. water flow and water temperature drop vs. water flow

Figure 25 - BTU% versus %GPM Flow

Balancing is thus seen as very important. Note that if the balancing valve is used to reduce pressure the authority of the control valve decreases. It would be better to carefully analyze the entire system initially. The control valves may be oversized when balancing reduces pressure a great deal. Fouling factors often accompany the decision to oversize coils because the heat transfer efficiency will degrade over time. The decision to select oversized coils has some merit over the live of the building.

Hydronic Balancing with the Proportional Method

In a system with many valves balancing can be a challenge because there is an interaction between the all the balancing valves in a system. There are many methods to balance a system and one common procedure that makes it possible is the "proportional method." Refer to the manuals published by the manufacturers of balancing valves for precise details. This method is outlined in the 2015 ASHRAE Handbook-HVAC Applications on page 38.10 and 38.11 as follows:

"Proportional water-side balancing may use design data, but relies most on as-built conditions and measurements and adapts well to design diversity factors. This method works well with multiple-riser systems. When several terminals are connected to the same circuit, any variation of differential pressure at the circuit inlet affects flows in all other units in the same proportion. Circuits are proportionally balanced to each other by a flow quotient:

$$\text{Flow quotient} = \frac{\text{Actual flow rate}}{\text{Design flow rate}}$$

To balance a system proportionally,

1. Fully open the balancing and control valves in that circuit.
2. Adjust the main balancing valve for total pump flow of 100 to 110% of design flow.
3. Calculate each riser valve's quotient based on actual measurements. Record these values on the test form, and note the circuit with the lowest flow quotient. Note: When all balancing devices are open, flow will be higher in some circuits than others. In some, flow may be so low that it cannot be accurately measured. The situation is complicated because an initial pressure drop in series with the pump is necessary to limit total flow to 100 to 110% of design; this decreases the available differential pressure for the distribution system. After all other risers are balanced, restart analysis of risers with unmeasurable flow at step (2).
4. Identify the riser with the highest flow ratio. Begin balancing with this riser, then continue to the next highest flow ratio, and so on. When selecting the branch with the highest flow ratio;
   - Measure flow in all branches of the selected riser.
   - In branches with flow higher than 150% of design, close the balancing valves to reduce flow to about 110% of design.
   - Readjust total pump flow using the main valve.
   - Start balancing in branches with a flow ratio greater than or equal to 1. Start with the branch with the highest flow ratio.

The reference circuit has the lowest quotient and the greatest pressure loss. Adjust all other balancing valves in that branch until they have the same quotient as the reference circuit (at least one valve in the branch should be fully open).

When a second valve is adjusted, the flow quotient in the reference valve also changes; continued adjustment is required to make their flow quotients equal. Once they are equal, they will remain equal or in proportional balance to each other while other valves in the branch are adjusted or until there is a change in pressure or flow.

When all balancing valves are adjusted to their branches' respective flow quotients, total system water flow is adjusted to the design by setting the balancing valve at the pump discharge to a flow quotient of 1.

Pressure drop across the balancing valve at pump discharge is produced by the pump that is not required to provide design flow. This excess pressure can be removed by trimming the pump impeller or reducing pump speed. The pump discharge balancing valve must then be reopened fully to provide the design flow.

As in variable-speed pumping, diversity and flow changes are well accommodated by a system that has been proportionately balanced. Because the balancing valves have been balanced to each other at a particular flow (design), any changes in flow are proportionately distributed.

Balancing the water side in a system that uses diversity must be done at full flow because components are selected based on heat transfer at full flow, they must be balanced to this point. To accomplish full flow proportional balance, shut off part of the system while balancing the remaining sections. When a section has been balanced, shut it off and open the section that was open originally to complete full balance of the system. When balancing, care should be taken if the building is occupied or if load is nearly full.

Variable-Speed Pumping.

To achieve hydronic balance, full flow through the system is required during balancing, after which the system can be placed on automatic control and the pump speed allowed to change. After the full-flow condition is balanced and the system differential pressure set point is established, to control the variable-speed pumps, observe the flow on the circuit with the greatest resistance as the other circuits are closed one at a time. The flow in the observed circuit should remain equal to, or more than, the previously set flow. Water flow may become laminar at less than 2 fps, which may alter the heat transfer characteristics of the system."

Pressure Independent Valves (PIV) Flow Verification

PIVs are very different from pressure dependent control valves (standard control valves). Pressure variations in the system do not affect flow through the PIV. PIVs do not require additional flow regulating devices (e.g. – circuit setters and automatic flow limiting devices). This makes the Testing and Balancing (TAB)/Commissioning process much different from standard control valves. The following information details the flow verification and commissioning procedures for a Pressure Independent Valve (PIV). These procedures are not mandatory to ensure proper operation of PIV.

When using PIV, Electronic Pressure Independent Valve (EPIV), or Energy Valve (EV), flow verification can be performed using the valve's built-in flow sensor and a hand-held tool (ZTH US) that connects to the valve. However, if independent verification is required, the use of 3 P/T ports is recommended.

Note: When using mechanical PIVs, Pressure Independent Characterized Control Valves (PICCV, PIQCV), it is essential that the mechanical contractor install three (3) independent pressure/temperature ports (P/T ports) if the PICCV or PIQCV is not supplied with integrated ports. For P/T port locations, refer to Figure A below.

External P/T ports allow for independent verification of proper PIV operation and these ports allow for future comprehensive troubleshooting and diagnosis.

For proper and accurate flow verification of mechanical PIV, it is essential that the mechanical contractor install P/T ports as shown in Figure A. Some PIVs may be ordered with integrated P/T ports.

- P/T port #1 and P/T port #2 are used to measure the pressure and temperature drop across the cooling or heating coil. This information in combination with the coil flow curves can be used to calculate flow and delta T.
- P/T port #2 and P/T port #3 are used to measure pressure drop across the PIV. PIVs must have 5 – 50 psid (11.5 ft. – 115 ft. H2O) (or per manufacturer's specification) pressure drop across the valve only. PIVs must be commanded to design flow position via analog or BMS (Building Management System) signal. Do not manually open the valve with the override handle to check for design flow or pressure. The required operating pressure drop range is necessary to ensure pressure independent operation of the PIV.

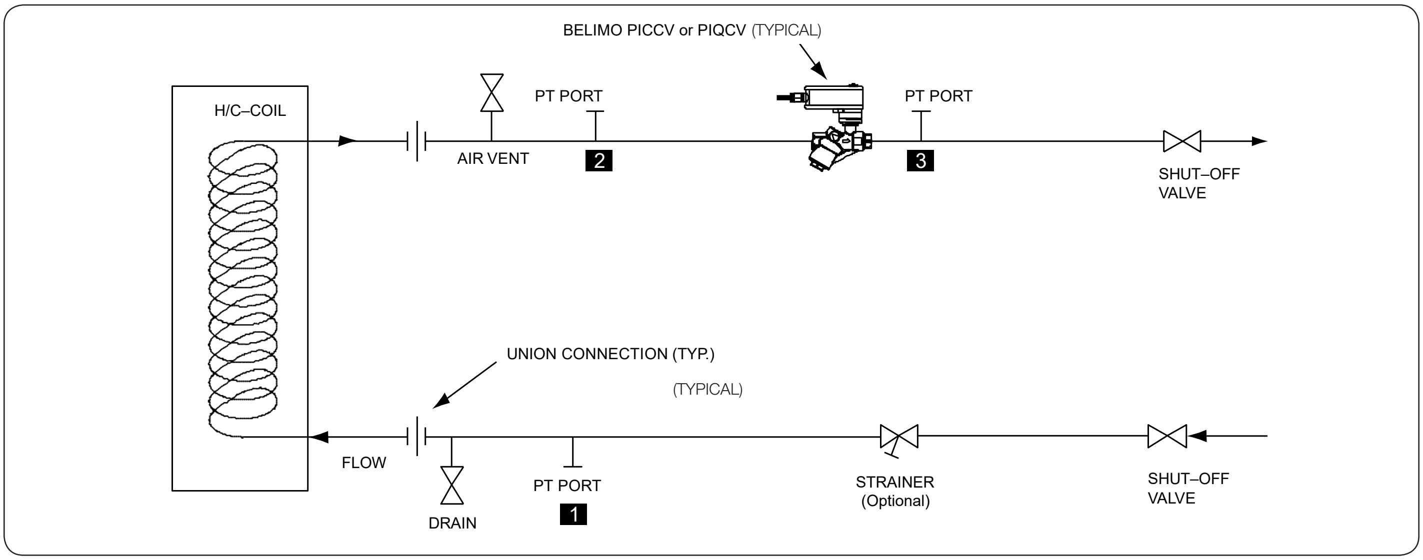


Figure A

Mechanical PIV Pre-Flow Verification Checklist

- Verify that system is purged of air and filled to proper pressure.
- Verify that each PIV has the manufacturer's required operating pressure drop range across P/T ports 2 and 3 (Figure A).
- Verify proper pump operation per manufacturer's specifications.
- Verify proper supply water temperature is available and is at design temperature.
- Proper air filter maintenance has been completed.
- Fan belts are in proper working order.
- Heat transfer devices (coils) are clean.
- Strainers are clean.
- All manual shutoff valves are open.
- All bypass valves are closed.
- No automatic or manual balancing valves exist. If they do exist, they must be set fully open and locked not interfere with the pressure independency function of the PIV.

Electronic PIV Pre-Flow Verification Checklist

- Verify that system is purged of air and filled to proper pressure.
- Verify that each electronic PIV is set to pressure independent/ flow control mode.
- If the PIV is an Energy Valve, the Delta T Manager™ must be disabled during the flow verification and commissioning procedure.
- Verify that each PIV has the manufacturer's required operating pressure drop range across P/T ports 2 and 3 (Figure B).
- Verify proper pump operation per manufacturer's specifications.
- Verify proper supply water temperature is available and is at design temperature.
- Proper air filter maintenance has been completed.
- Fan belts are in proper working order.
- Heat transfer devices (coils) are clean.
- Strainers are clean.

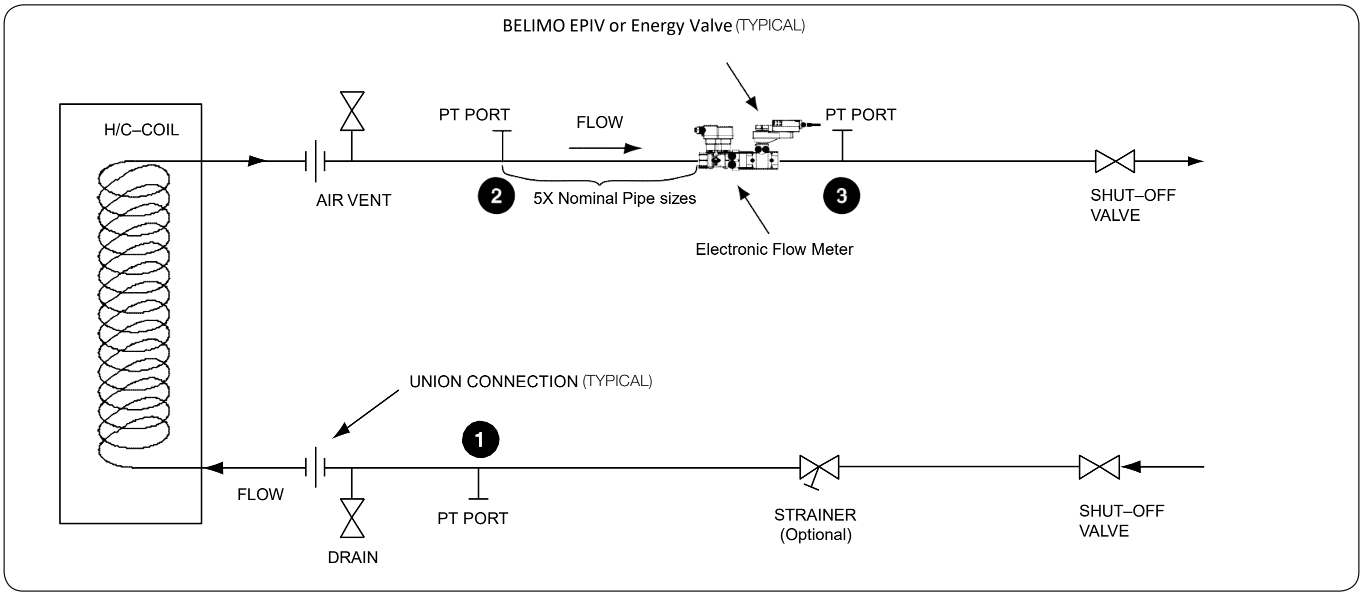


Figure B

Procedure #1 (System Verification) – Total System Flow Method I Verification for PIV Cooling/Heating

1. Verify that the system is in proper working order. Depending on the valves used, check the items listed for PIV Pre-Flow Verification Checklists.
2. If diversity factor = 100%, command open all PIV via the BMS system. Systems with less than 100% diversity need to have a percentage of valves closed to match design diversity.
3. Ensure that pumps are either manually commanded to sufficient speed to provide proper pressure drop across all valves or if pumps are under DDC pressure control ensure ΔP setpoint is sufficient to provide the above conditions.
4. Verify total system flow in main return line is at system design flow rate using one of the following methods:
   - Orifice
   - Venturi
   - Electronic flow meter
   - System-level Flow Device
5. Decrease the pump speed (or decrease ΔP setpoint if under control) until a measurable flow decrease occurs.
6. Increase pump speed (or increase ΔP setpoint if under control) slowly until design flow is reestablished. Make note of the resulting ΔP. This will be the maximum system ΔP operating setpoint.

Note: If total flow does not match design flow then troubleshooting must be completed to determine cause. This may involve verifying flows at the terminal level.

Procedure #2 (Terminal Level Verification) – Air Delta T Method I Verification for PIV Heating

1. Verify that the system is in proper working order. Depending on the valves used, check the items listed for PIV Pre-Flow Verification Checklists.
2. Ensure that water is at design temperature.
3. Ensure that terminal airflow is at design airflow rate (cfm).
4. Command open the PIV via analog or BMS control signal to maximum design flow position. Do not manually open the PIV.
5. Reference approved engineering document containing design air temperature drop/rise for design conditions.
6. Measure coil inlet air temperature and coil discharge air temperature.
7. Difference between coil inlet air reading (EAT) and coil discharge air reading (LAT) should equal or exceed design air delta T as shown on the contract documents.

Procedure #3 (Terminal Level Verification) – Water Delta T Method I Verification for PIV Heating

1. Verify that the system is in proper working order. Depending on the valves used, check the items listed for PIV Pre-Flow Verification Checklists
2. Ensure that water is at design temperature.
3. Ensure that terminal airflow is at design flow rate (cfm).
4. Command open the PIV via analog or BMS control signal to maximum design flow position. Do not manually open the PIV.
5. Reference approved engineering document containing design water temperature drop/rise for design conditions.
6. Measure water temperature differential of coil by using P/T ports #1 and #2 as referenced in Figure A.
7. Measured temperature differential should be equal to designed water temperature differential as shown on the coil manufacturer or engineering documents.

Procedure #4 (Terminal Level Verification) – Coil ΔP (Delta P) Method I Verification for PIV Cooling/Heating

1. Verify that the system is in proper working order. Depending on the valves used, check the items listed for PIV Pre-Flow Verification Checklists.
2. Command open the PIV via analog or BMS control signal to maximum design flow position. Do not manually open the PIV.
3. Reference approved engineering document containing design coil water pressure drop for design flow conditions (usually expressed in ft. of water). This value will be for the heating/cooling coil associated with corresponding PIV.
4. Measure coil ΔP by using P/T ports #1 and #2 as referenced in Figure A.
5. Formula to calculate flow is:

   $$\text{Actual GPM} = \text{Design GPM} \times \sqrt{(\text{Measured Coil } \Delta P/\text{Design Coil } \Delta P)}$$

Note: Coil ΔP and design ΔP expressed in feet of water.

Procedure #5 (Terminal Level Verification) – Electronic Coil Flow (EPIV/EV) Method I Verification for PIV Cooling/Heating

1. Verify that System is in proper working order. Depending on the valves used, check the items listed for Electronic PIV Pre-Flow Verification Checklists.
2. Command open the electronic PIV via analog or BMS control signal to maximum design flow position. Do not manually open the electronic PIV.
3. Reference approved engineering document containing design coil water flow in GPM for the coil.
4. Verify flow by connecting the valve to the handheld tool or computer software.

For additional information pertaining to the flow verification and commissioning, visit these organizations websites that promote the certification and continuing education of industry professionals in the Test and Balance discipline.

NEBB - National Environmental Balancing Bureau, http://www.nebb.org

TABB - Testing Adjusting Balancing Bureau, http://www.tabbcertified.org

Selecting the Pressure Drop of Pressure Dependent Valve

PIV's work automatically within a range of 5-50 PSID. The remainder of this section pertains primarily to pressure dependent valves.

On-Off Control

Sizing on-off control valves is very simple because line size ports are typically used. The valve characteristics are not an issue, but valves with a large Cv value relative to the size are preferred. Balancing valves are important because pressure variations can be very large depending upon how many valves are open at the same time. This is one application where automatic balancing valves perform well. Refer to Figure 26.

Valves reduced one pipe size from the line size may be used as long as 10% of the pump head is the maximum loss allowed from the provided valve Cv, or no more than a 1 psi loss through the valve. Too few valves used with 2-position control can cause pump pressure problems.

Diversity

Diversity refers to the variation in load on a system. There may be many valves all of which are not full open or closed. Some loads may be at 100% while others are at 25%. The closing of one valve has little effect on the pump head and system curve. Plants designed for diversity are purposely undersized because the system is expected never to require all loads to be at their design load at the same time

Systems with no diversity will have problems with surging where abrupt unloading of the chiller or boiler is accompanying with vibration and other issues. For example, if a system only had two valves, the operation of one valve has a major effect on the pump and system curve. As one valve closes, the pressure increase on the other valve will cause its flow to remain high.

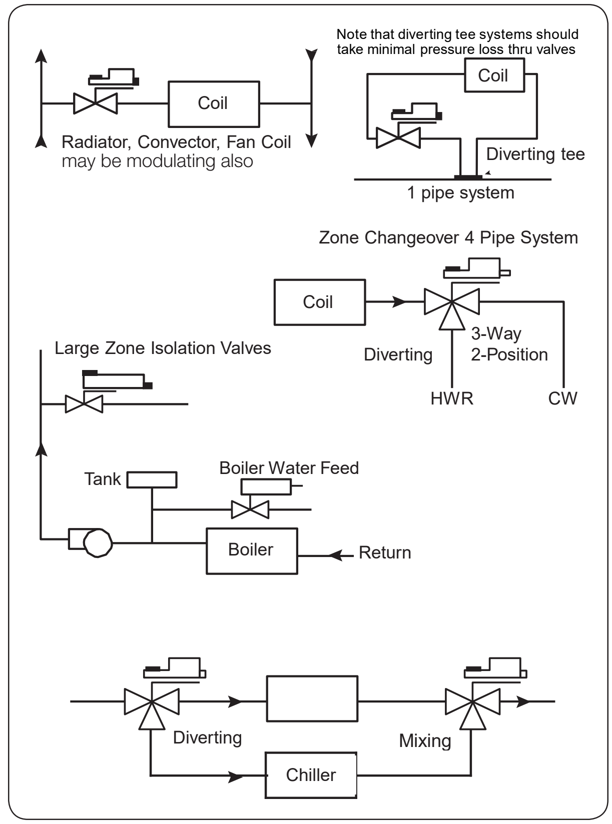


Figure 26 - 2 and 3-way Valves in 2-Position Application

Authority Variation Due to Pressure Variation

In most systems, the authority of the pressure dependent valve remains constant as long as the pressure drop change is minimal while the valve closes. If diversity does not exist, closing the valve may destroy the normal curve since pressure increases. Pressure independent valves are immune from this concern because the flow is not affected by changes in pressure within a 5-50 psid range.

Constant Flow System

Constant flow systems use three-way valves at the terminals, refer to Figure 27. Valves should be sized slightly more than the pressure drop of the coil. If this information is not available, use 4 psi. The valve sized for a Cv which produces this drop at the specified flow rate, Cv = GPM / $\sqrt{P}$. The drop could go as high as 9 psi if necessary. The square root of the pressure drop over a range from 4 to 9 psi gives a 2 to 3 multiplier times the Cv to achieve the GPM.

Without hard data from the Design Engineer, it will be difficult to state the actual available differential pressure across the circuit. Coils are manufactured with less than 1 psi drop (2.3') to as much as 6 psi (14'). Reheat coils tend to have low drops and air handling units tend to have higher drops, especially cooling coils. The goal is to have the authority near 50% or more to mechanically linearize the process. The coil characteristic response is quite similar to that of the variable flow system and equal percentage valves should be selected.

Constant flow systems that utilize a coil with a secondary circulating pump provide constant flow through the coil which prides many advantages over constant flow systems; refer to the lower drawing in Figure 27.

The flow is always turbulent which reduces fouling inside the tubes and also reduces the risk of freezing in cold climates. The heat transfer curve with a secondary circulating pump is more linear. The temperature over the surface of the coil is more even and the leaving air temperature is more uniform. It is possible to adjust the secondary flow, so the capacity of oversized coils is reduced. The pressure drop across the coil is taken care of by the secondary pump. Therefore, the head of the main pump can be reduced. Another way to reduce the capacity of an oversized coil is to increase the secondary flow and thereby decrease the water temperature drop across the coil.

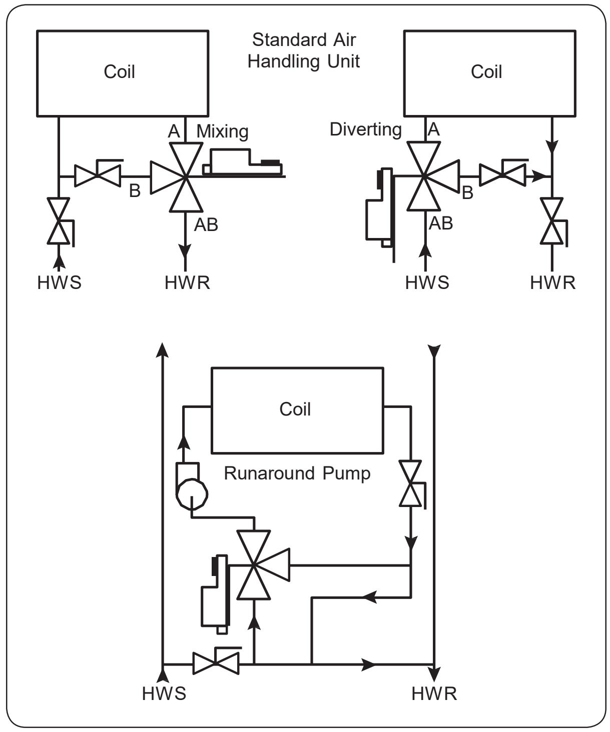


Figure 27 - Constant Flow Systems and 3-way Valves at the Terminals

Constant Speed Pump With 2-Way Valves

Variable flow coils with one constant speed pump use two-way valves at the terminals. The pump head varies significantly with the load. As any valve closes, the head goes up riding on the pump curve. There must be diversity in the system to keep the pressure from rising too high; otherwise a bypass must be used.

The control valves should be sized to be 50% of the loss in the circuit, for good valve authority. The default rule of thumb is to use 4 psi to 9 psi for the valve sizing. No less than this will produce authority that will control well. Equal percentage valves should be used. The differences in coil response curve should be considered. The 20°F heating coil design drop will respond differently than the 10°F cooling coil design drop. However, in both cases, an equal percentage valve curve is best. It matches the coil curve and provides good resolutions when the valve operates in light load conditions; which is most of the time. Resolution near full open is not as good, but the valve will seldom modulate in this area of the curve. Refer to Figure 28a and Figure 28b.

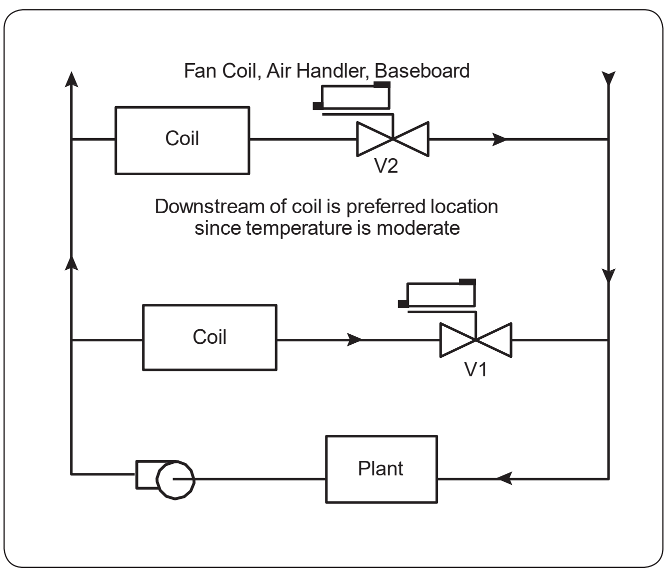


Figure 28a - Variable Flow System and 2-way Valves at Terminals

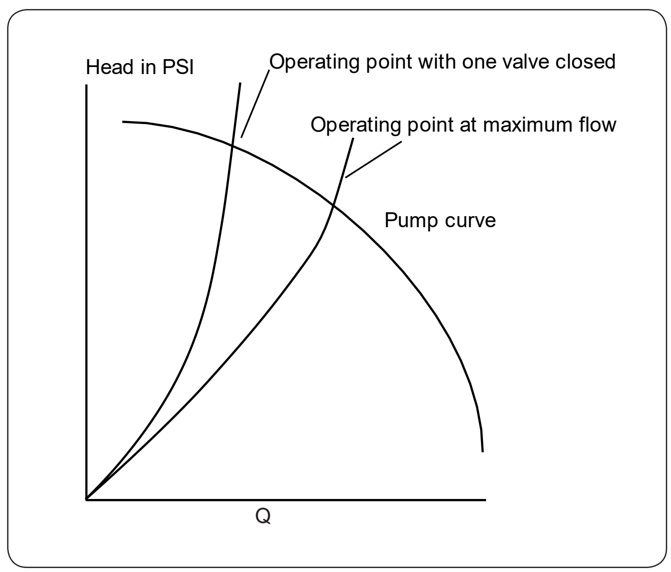


Figure 28b - Variable Flow System Pump Curve

Variable Flow / Variable Speed Pump With 2-Way Valves

Large systems may use staged pumps, variable speed pumping or primary-secondary pumping. The pump head pressure is controlled in these systems based on the flow demand or system differential pressure. The 2-way valves should be sized as stated above with proper authority and an equal percentage curve. As long as the authority of the valve remains constant; a reduction in system flow will be inconsequential. When an air handling unit fan is off the valve should remain closed unless there is a risk of freezing, then the valve should be commanded open. Otherwise, the variable speed system will run at maximum speed; energy is wasted, and the pump head will be very high.

Variable Flow System - Critical Zone Reset

Critical Zone Reset (CZR), or demand based response, control logic can be applied to variable flow systems. The logic of the CZR system will override the pump pressure controls which normally respond to the system differential pressure setpoint. Under normal operation, the speed of the pump is controlled by the position of the actuators. One of the valves has to be almost 100% open to satisfy the load – this is the critical zone. Refer to Figure 29.

Only an electronic pressure independent control valve's position feedback signal will work as intended because a wide open valve will cause the pump speed to increase. In response, the critical zone actuator will move the valve position to less than wide open for all load conditions, including full load.

In contrast, a pressure dependent control valve or mechanical pressure independent valve will stay wide open at full load; regardless of changes in pump speed.

Critical zone reset systems require an advanced BAS installation that can analyze and quickly communicate the actuator position of the ePIV or Energy Valve. However, one anomalous feedback signal may upset the whole system; any outlier zones should be corrected during the commissioning process or deleted from the CZR algorithm. Additionally, the BAS should remove valves from the CZR logic when the AHU is off, i.e., chilled water valves may be commanded full open under low-temperature conditions to mitigate freezing risk.

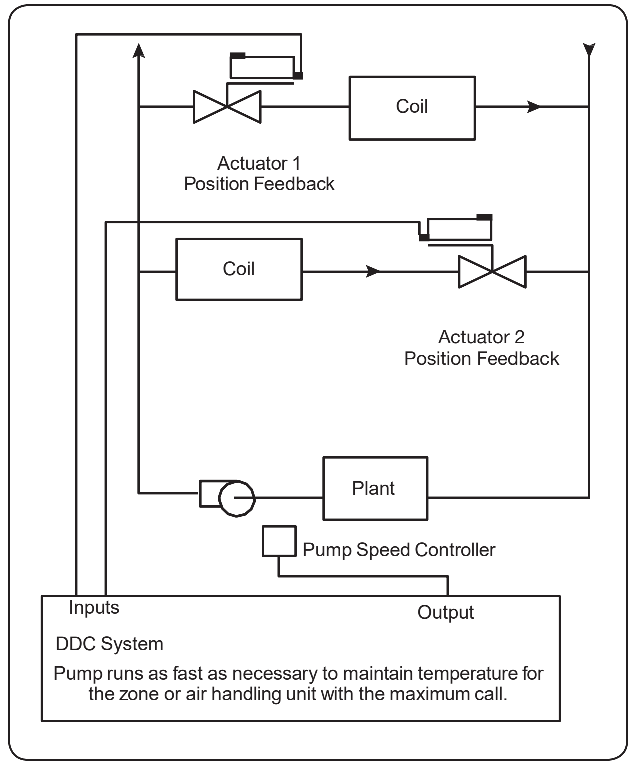


Figure 29 - Variable Flow Critical Zone Reset System

Selecting the Valve Size

Calculate the Cv value using the formula $Cv = GPM / \sqrt{\Delta P}$ and apply the relevant flow (GPM) and differential pressure (ΔP). Control valves are available with a limited number of Cv values. Chances are that the calculated value falls in between two standard Cv values.

Select cooling valves for the next higher Cv. The cooling temperature drop is typically only 12° to 8° which makes them quite sensitive to undersizing.

If you have to use the originally specified flow, select a heating valve with the next smaller Cv value. When you can use a corrected flow that reflects the actual conditions, select a valve with the next higher Cv value. The "consequences" section goes into details about decreasing the valve size and shows that there is little danger when applying heating valves.

In general, when estimating the size of modulating valves at terminal units and air handling units select a model one size smaller than the pipe. Two position applications and some unique applications use line size valves.

When the Cvc's of commercially available valves do not meet the requirements, select an MFT actuator with an adjustable start and span adjustment, or a limit on signal output to the actuator is needed. Cvc's for globe valves and CCV's do not change significantly. The Cvc at rotated positions for the standard ball valve and butterfly valves are found below in Chart 4.

The 90% open ball or butterfly has about the same Cvc as a one size reduction in pipe size. The 80% open ball or butterfly has about the same

Cvc as a two size reduction in pipe size. A 90% open butterfly reduced one pipe size has about the same Cvc as an 80% open valve. Understanding the implications of Cvc and operating range allow the proper size valve to be selected.

THE GOLDEN RULE IS NEVER REDUCE THE VALVE TO BELOW HALF THE LINE SIZE. When reducing, use pipe and or valve supports since reducers weaken the structural strength of the assembly. Do not risk mechanical integrity.

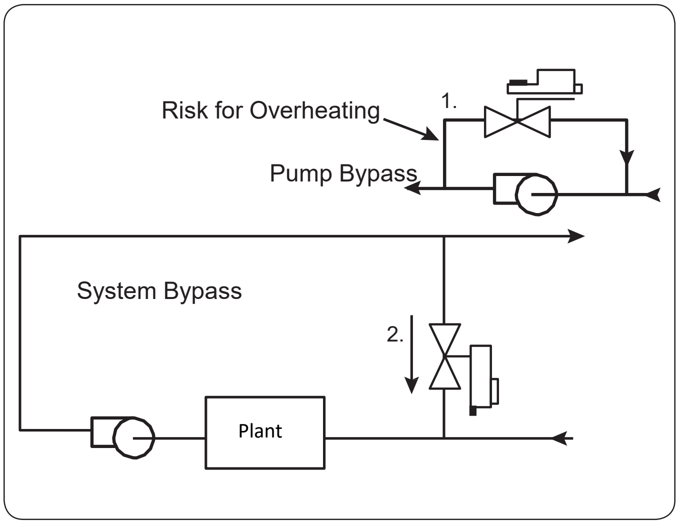


Figure 30a - Bypass Applications

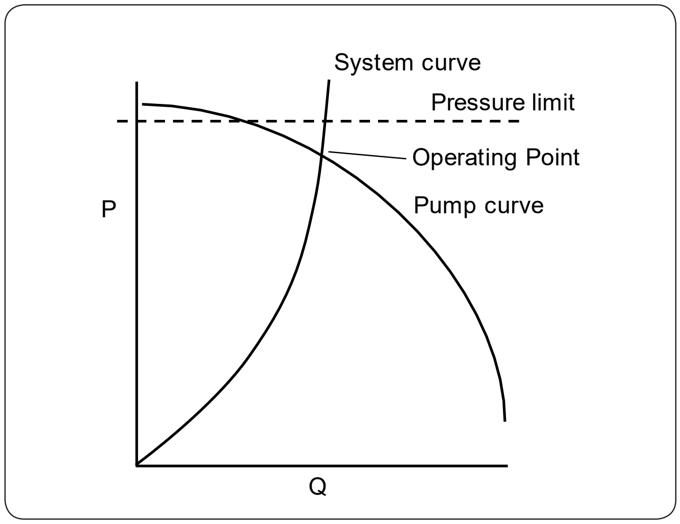


Figure 30b - Pressure Limit and Operating Point

Bypass Applications

The purpose of the bypass valve is to maintain the required minimum flow to the plant during light load conditions. Two common bypass applications are shown in Figure 30a. Its purpose is to keep the pump differential from rising too high. A limit is selected, which is typically 10-20% above the operating point pressure. Above this point, the flow is too restricted, and the system pressure is deemed too high. When the differential pressure rises, the controller modulates the bypass valve open. Refer to Figure 30b.

For example, assume the limit setpoint is 20 psi for the pump capacity at operating design point of 200 GPM. Assume the bypass valve must be able to pass 100 GPM of water at 20 psi differential, while the load consumes the remaining 100 GPM. These parameters are quite different from the requirements for air handling unit and reheat coils. The design engineer should be consulted if the specification does not indicate what sizing parameters to use for a bypass valve.

Common 3-way valve applications which control temperature, not flow, require different sizing techniques, refer to Figure 31.

In the cooling tower application, the valve will respond to the needs of the chiller's condenser by maintaining about 80°F water. The valve should be as linear as possible. Linear globe valves are available, but butterfly valves are often used here, and they are shallow equal percentage. More important is that the outlet pressure to the spray nozzles (if used) be high enough. The inlet pressure and the nozzle and piping pressure losses must be known to size the valve. A balancing valve should be placed in the circuit going to the sump to equalize the pressure loss spray nozzle. This valve may not be sized without a known pressure drop. Failure to verify the allowable drop will lead to problems. Estimate one pipe size less for estimating purposes, but do not engineer the valve without verification.

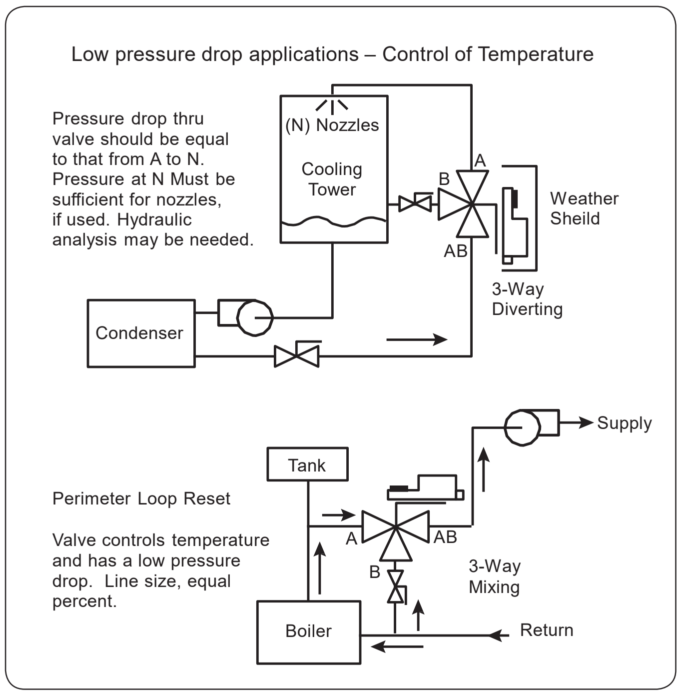


Figure 31 - 3-way Valve Applications Controlling Temperature

Figure 31 also shows a perimeter loop reset or boiler bypass which is another 3-way application controlling temperature. The flow is constant but the temperature is varied by mixing return with supply water. The valve is linear and is sized equal to the line size. A balancing valve should add the same drop as the boiler circuit adds.

Consequences of Increasing Differential Pressure

If the pressure dependent control valves are sized for a larger differential pressure, in accordance with the above rules, we will get smaller valves and an improved valve authority (A). This is of course good, but can we satisfy the maximum flow requirements? The consequences of an increased pressure drop over the control valves will depend upon the circumstances in each case.

Alternate 1 – Coils are sized correctly, not oversized, and actual flow is as specified.

This is an unlikely example. It means that the installed coils are exactly as specified, without any oversizing at all. Nevertheless, this is a very interesting example, that highlights the inherent nature of hydronic systems.

Although the valves are sized for a higher than the originally specified pressure drop, all of the flow requirements will essentially be satisfied in most systems. This may sound strange at first. Instinctively, it would make sense that, if for example, the pressure drop for a valve is doubled, then the flow goes down to 50%. However, this is not the case.

First, because of the quadratic relationship between flow and pressure, the Cv-value of a valve is reduced by just 29% and not 50%. Secondly, the control valves are not the only resistance to the flow in the whole loop. In comparison to the rest of the loop, the increase in resistance of the control valves is relatively small, so the effect upon the whole loop is minimal. Thirdly, an increase in the total resistance moves the operating point back on the pump curve. This increases the pump head, counteracting some of the increased resistance, so the resulting flow reduction is about half of what it otherwise would have been. The system does have some self correction.

Lastly, it is only the few valves in the least favored circuits that are “at risk”. The majority of the valves are located closer to the pump, and are subject to a higher differential pressure. It is extremely unlikely that a valve ever needs to be replaced.

Example

For simplicity, the following example has only one coil, control valve, balancing valve, piping, boiler and pump. This of course is unrealistic, but nothing is gained by a complicated example with multiple loops and valves. The conclusion will be essentially the same.

System Operating Point Q=100 GPM

Pressure Drop = 16 psi

System Cv = GPM/$\sqrt{\Delta P}$ = 100/$\sqrt{16}$ = 25

Total “Original” valve. Q = 100 GPM, ΔP = 3 psi. Cv = 58

System Pressure Drop, minus control valve 16-3 = 13 psi.

System without control valve Cv = 100/$\sqrt{13}$ = 27.7

“Original” valve is replaced with a valve with Δp = 6 psi

“Replacement” valve Q = 100 GPM, ΔP = 6 psi. Cv = 40.8

New system Cv = $\left(\frac{1}{40.8}\right)^2 + \left(\frac{1}{27.7}\right)^2 = \left(\frac{1}{Cv2}\right)^2$

Cv Total = 22.9

The new system Cv is 22.9, which is 91.9% of the original value (Cv=25), so it would seem that the flow will be 8.1% less than specified. However, the operating point backs up on the pump curve, and increases the pump head. With a typical pump, the new operating point will give a flow that is about 95% of the specified value.

The increase in pressure drop across the control valve went from 3 to 6 psi, but the reduction in the flow is only 5%. When applied to the heat transfer curve of a coil, (see Figure 25) a 5% reduction of the flow will not result in a noticeable reduction in the heat emission.

This is just one example, but the increase in pressure drop must be quite large before any significant reduction in the heat output will take place.

Alternate 2 – Most coils are slightly oversized, but we stay with the originally specified flow for selecting the valves and pump.

As we know from Alternative #1, the valves can supply 95% of the specified flow, which is more than what the oversized coils will need. Actually the valves are probably larger than necessary

Alternate 3 – The size of the valve is reduced to reflect the oversized coils, but the original specification for the pump is used.

The valves are correctly sized, but the pump is needlessly large. Therefore, flow requirement can easily be met. In most cases if not all, the valves are larger than necessary.

Alternate 4 – The size of the valve is reduced to reflect the oversized coils and the specification for the pump is corrected with a smaller pump.

Both the valves and the pump are correctly sized, so the flow requirement can be met.

It is possible for a valve to be six times too large using the traditional sizing methods.

Example:

A coil with a 20°F temperature drop is specified.

The load is 1,000,000 BTUH

The calculated flow is 1,000,000/20°F = 50,000 LBSH

50,000 LBSH/8.33 = 6,005 GPH

6,005 GPH/60 = 100 GPM

The pressure drop is 4 psi, so Cv = 100 / $\sqrt{4}$ = 50

Suppose that the installed coil is 20% too large. This means that the actual temperature drop is 50°F instead of 20°F. (See Figure 25). Look at 80% BTUH. The actually needed flow at 50°F temperature drop will be 1,000,000/50°F = 20,000 LBSH/8.33 = 2,402 GPH/60 = 40 GPM.

This is 40% of the specified flow of 100 GPM. At 40% flow the pipe losses is very small and the pump head is higher, so the differential pressure across the valve has increased to 25 psi. (See the diagram in Figure 28, and you will see that this is possible.)

The correct Cv value should be based upon 40 GPM and 25 psi.

Cv = 40 /$\sqrt{25}$ = 8.
Cv = 50 is 50/8 = 6.25 times larger than Cv = 8.

When the traditional sizing rules are used, the valves are often many times too large, so they can satisfy the maximum load already when they are $\frac{1}{3}$ open.

Direct Return or Reverse Return

The direct return system, has pathways of different length through the different loops (loop = pump - riser - coil - return - boiler - pump). The loops closest to the pump are "favored", and the differential pressure across these terminals is larger than at the remote terminals. Proper balancing is therefore especially important.

Reverse return requires extra piping. The advantage is that the loops are of the same length. Contrary to popular belief, this does not mean that the piping network is "self balancing". Without balancing, the first and last terminals will get an overflow, while the mid terminals will get less. Reverse return is an improvement over direct return, but balancing valves are still needed. Direct return with manual balancing valves is a less expensive alternative. The piping is less, which is a savings in itself and because the pipe losses are smaller, a smaller pump can be used.

In addition, because of the lower pipe losses, it is easier to achieve a higher valve authority in direct return systems.

Determining the Required Valve Pressure Ratings

After selecting the hydronic valve Cv, there are two additional pressure ratings to consider, one is the body pressure rating, and the other is the seat close-off differential pressure rating. Body pressure rating is the amount of total pressure the body and stem seal must hold against to safely contain the fluid within the valve, and avoid leakage out of the stem packing. Typical specifications are ANSI Class 125 and ANSI Class 250; the pressure rating is relative to the temperature of the media. Close-off is the maximum differential pressure allowed across the valve surface to maintain the leakage specification from the inlet to the outlet of the valve. Typical specifications are zero percent and ANSI Class VI. Refer to the example in Figure 32 for the following pressure considerations.

Steam valve sizing is discussed below, but the pressure ratings should be selected from the boiler rating. For example, if a 15 psi boiler pressure is maintained, then the valve must hold against 15 psi, and the body rating must meet 250°F temperature rating associated with the steam pressure.

Static head

The pressure on the pump when the system is off is the weight of the column of water above it. V1 has almost no pressure on it because it is on the top floor and there is no piping above it. The system has a fill pressure which is typically 20 psi. V2 has 100' of water pressure on it. Regardless of the pipe size, there is 1 psi per 2.3' column height. With 100' there is 100/2.3 = 44 psi static pressure. The column of water pressure is equal on both sides of the valve when the system is off, so this impacts the body rating, but not the close-off rating.

Fill Pressure

By applying a fill pressure that is 20 psi higher than the static pressure, sufficient pressurization is achieved. This gives 44 + 20 = 64 psi for valve V2. Valve V1 has only the fill pressure of 20 psi.

Pump Pressure

When the pump is running, and the valves are full open, then the head pressure at the valve inlet is the sum of the various heads. There is about 130' of pipe on the way to V1, and the piping loss typical average is 4' per 100' of pipe run, so the loss is about 5'. V1 has the pressure of the pump or 45' less the piping losses of 5' on the way to the valve, or 40'. V1 pump pressure equates to 40/2.3 = 17 psi. V2 has about 25' of pipe between it and the pump for 1' of friction loss. V2 pump pressure equates to 45 - 1 = 44' of pump head or 44/2.3 = 19 psi.

Total Pressure = Valve Body Pressure Rating

The total pressure for V1 is 17 psi pump + 20 psi fill pressure = 37 psi. The total for V2 is 44 psi column height + 19 psi pump + 20 psi fill pressure = 83 psi. The body pressure rating of V2 needs to be 83 psi or higher to contain the total pressure. The required body pressure rating of the valve, is the sum of the column pressure, fill pressure, and pump pressures. Typically ANSI 125 Class body pressure rating is sufficient for low to medium rise buildings. High rise buildings have the same close-off as low rises, but the static pressures could be high for valves in lower levels, and an ANSI 250 Class rating may be required.

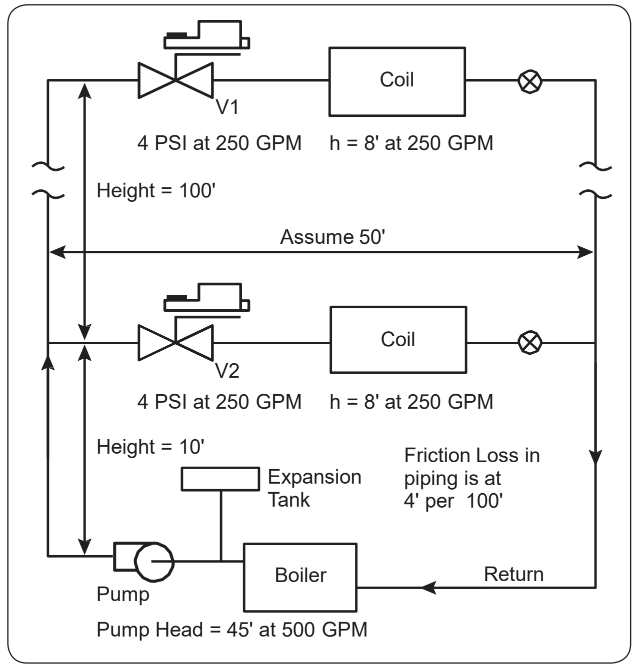


Figure 32 - Boiler, Pump and Piping System

Dead Head Pressure

Many systems do not have a supply to return bypass pressure control, but it is rare to allow the pumps to deadhead against the valves because there are usually many valves in the system which provides diversity; they are never all closed at the same time. In Figure 32, if both valves were almost closed each valve would see the full pump pressure. If V1 and V2 are both closed, the whole pump pressure appears at the inlet of V1 and V2. In this system there is no bypass pressure control such as 3-way valves or a supply to return bypass valve; and the pump would be in a dead head state. In a dead head situation the pump curve is important. Typically the pump curve has from 30 to 45 degree slope, refer to Figure 30b. At no or very low flow, the pump pressure could rise to double the design operating point, or 90'. The valves would have to withstand pump pressure of 90/2.3 or 40 psi.

Close-Off Pressure

Close-off pressure is the maximum allowable differential pressure across the valve disc and seat to maintain the leakage rating. Close-off pressure is not affected by the weight of the column pressure because the supply and return pressure are the same; this includes the fill pressure too. When the pump is off, there is no differential pressure across the valve.

In normal operation with both V1 and V2 full open, the only pressure across the valve is the pump differential head, less the friction loss on the way to the valve. Both valves have a specified pressure drop when full open, a typical value is 4 psi. If one valve were closed while the other valve was open, the pump pressure would rise as flow volume went down. The pump curve determines the pressure rise in the system. If pressure control exists, then the pressure may not increase or will increase to a specified level, which would be the required close-off pressure.

With pressure dependent valves, the position of one valve affects the flow output of the other valve, and is why pressure independent valves are a superior technology.

As both valves close against full pump pressure, the worst close-off condition exists which could be near 40 psi pump pressure as discussed previously. Although dead head conditions are rare, some systems experience this condition.

In a constant flow system with 3-way valves, the differential pressure across the valve is essentially constant because water is always flowing and the valve will never see the full pump pressure. To achieve a safety margin, the calculated the close-off pressure is 1.5 times the differential pressure. Since the valves above are sized for a 4 psi drop, 6 psi is the close-off required.

Variable flow systems that use 3-way valves to provide minimum flow at the furthest terminals are subject to a variable differential pressure. The maximum differential pressure is the pump head minus the pressure drop across the balancing valve. These valves see more of the pump pressure as the 2-way valves close down.

Cavitation

Cavitation is the formation of vapor bubbles in areas of low pressure in a piping system. It can occur whenever a restriction and expansion occurs; it is not limited to valves and pumps.

When water passes through the restriction in a valve the velocity increase along with the velocity pressure, which lowers the static pressure. When the static pressure is low air bubbles can become entrained in the water if the fill pressure is not high enough.

After the water flows beyond the restriction, the velocity decreases and the static pressure goes back up. Air bubbles in the water are crushed with the rise in static pressure, the bubbles implode in a pointed shape, and some hit the sides of the pipe as far away as 20 pipe diameters from the valve. Cavitation makes the sound like gravel glowing inside the pipe, and it can eat away the pipe material from the inside. Refer to Chart 1 and Chart 2 for cavitation information.

Cavitation can be predicted by solving this equation:

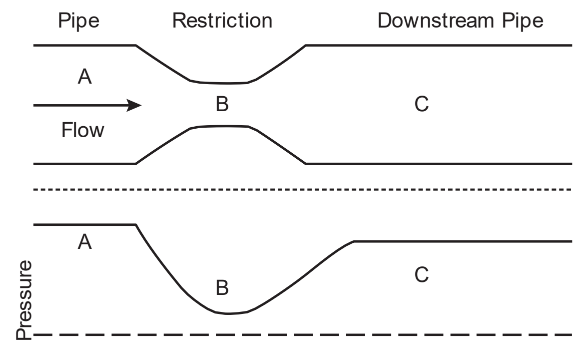
Maximum allowable $\Delta P = FL^2 (P1 - FF \times VP)$

FL is the liquid pressure recovery factor

P1 is the inlet pressure psia

FF is the liquid critical pressure ratio factor (.96 for water)

VP is the vapor pressure in psia at inlet temperature



At A the pressure is higher than at B or C
At B the pressure drops due to high velocity
At C the pressure again goes up. If it goes above a certain point and air was released, then cavitation occurs.

Figure 33 - Cavitation

The vapor pressures in Chart 2 indicate that hot water cavitates easier than cold water because more fill pressure is required to overcome the vapor pressure.

Liquid Pressure Recovery Factor F_L in Chart 1 is a function of individual valves. F_L values decreasing as the valve opens, and the risk of cavitation increases.

Normally cavitation is not a problem as long as the pressure drop is kept low. Closed systems present few problems because the outlet pressure stays high. The problem application is open systems – the primary one being cooling tower bypasses.

Chart 1
Liquid Pressure Recovery Factor

F_L	Valve Type	Amount Open
1	Globe	All positions
1	CCV	All positions
0.75	Butterfly	10° open
0.65	Butterfly	70° open
0.5	Butterfly	90° open
0.9	Standard Ball	10° open
0.75	Standard Ball	70° open
0.5	Standard Ball	90° open

Chart 2
Vapor Pressure of Water

°F	psia
32	0.09
40	0.12
50	0.18
75	0.43
100	0.95
125	1.9
150	3.7
175	6.7
190	9.3
200	11.5
210	14.1
212	14.7

The pressure drop must be kept below the ΔP calculated above. Cavitation is eliminated by increasing the pressure in the system. If the pressure is increased sufficiently, the lowest pressure inside the valve will exceed the vapor pressure, no air bubbles are formed and cavitation is avoided. The system pressure decrease with increasing building height. Therefore, valves located at the top of a building are especially vulnerable to cavitation.

The expansion tank (pressure tank) should be sufficiently charged, so the fill pressure is always high enough to prevent cavitation at the highest point in the building. Another way to limit cavitation is to select a valve with a high liquid recover factor, such as CCV's or globe valves. If standard ball or butterfly valves are used in modulating applications, it is common practice to size the valve Cv at less than full open (60° to 70°) to achieve a higher liquid recovery factor. Refer to Chart 4.

Miscellaneous Water Valve Considerations

Leakage

Leakage through control valves should be avoided because it reduces plant Delta T, increases operating cost, and decreases occupant comfort. Excessive leakage will occur if the actuator is not strong enough to close the valve, or if the valve linkage is not correctly adjusted. Leakage also depends upon the type of valve and the differential pressure at close-off and is expressed as a percentage of the rated Cv value.

Example:

Rated Cv = 400, leakage = 0.5%, differential pressure = 25 psi.

Leakage = $400 \times 0.005 \times \sqrt{25} = 10$ GPM.

Materials

The following will give some understanding of why the choice of materials is so important.

Water: There is dissolved oxygen in the water which makes it aggressive. In a closed hydronic system, there is some corrosion at first when the system is filled, but the corrosion stops after all of the dissolved oxygen has been absorbed. The water is no longer perfectly clean, but it is not aggressive, which makes it possible to use cast iron, and regular brass in the valves. It is therefore vital that leaks are eliminated because when new water is added, there will be some corrosion.

Deionized (DI) Water: Copper-zinc alloys containing more than 15% zinc are susceptible to dezincification. Simply, zinc atoms are easily given up to solutions with certain aggressive characteristics. During dezincification the more active zinc is selectively removed from the brass, leaving behind a porous copper-rich metal. Regular brass (copper & zinc), may be subject to “dezincification” if they are used in water with dissolved oxygen or certain additives. The zinc molecules are leached out, leaving a porous copper surface. There are special brass alloys, usually with an extra high copper content, that are “dezincification” resistant. Bronze (copper, tin, zinc) valves are used in domestic hot water systems because the potable water supply has lots of dissolved oxygen.

Potable Water (drinking water): Water that is safe to drink or to use for food preparation. NSF certification is required for this service. It regulates all materials that come in contact with the water.

Galvanic Corrosion: Also called bimetallic corrosion. Occurs when two different metals are in contact in a corrosive environment: One of the metals experiences an accelerated corrosion rate. The contacting metals form a bimetallic couple because of their different affinities (or attraction) for electrons. Galvanic action between dissimilar metals can also occur. Movement is from iron to bronze and the small amount of bronze in a valve will not affect the high amount of iron in piping.

Temperatures

Valves being used for alternate hot and cold service must be able to handle the extremes. Temperature limitations exist in some common applications including chilled water systems below 35°F and steam boiler feed valves, which are typically at 200°F or higher. Actuators mounted onto valves in these applications must include a thermal isolation linkage.

Condensation of water may occur in the actuator when its temperature drops below the dew point of the surrounding air. The condensate will gradually fill the actuator with water. Some Belimo actuators have semi-permeable membranes to protect against condensation, while others have a NEMA 4 rating for outdoor mounted applications.

There are a few cautions necessary when feed valves for steam boilers are selected because the temperature of the water is often above 200°F and the valve is frequently mounted near a hot boiler. The actuator may experience ambient temperatures above 122°F unless the valve assembly is located away from the boiler or condensate tank. Hot pipes must be insulated, and an actuator heat shield may be necessary to reduce the effects of radiant heat. The valve may open slowly but should close quickly to avoid overfilling. A spring return actuator may be required. The settings of the float switches may allow slow action in both open and close operation. Overfilling is possible if a slow valve is used and the float switch is set for a fast response. If a slow actuator is used, change the float switch to compensate.

Belimo actuators are thermally isolated from the valve in all cases to increase the lifespan of the actuator.

Steam Valve Sizing

Introduction

Steam systems have a boiler which produces steam which fills the pipes of the system. Pumps are not needed. The supply steam goes through the valve, then the coil. When the steam cools it condenses back into water which gathers in the trap. From there it flows through the condensate pipes back to the boiler. In large systems a receiver holds the water until a boiler water level switch turns a pump on and the condensate goes back into the boiler.

There are a number of variations but this is the system used most in commercial applications. Refer to Figure 34.

P1 is Inlet Pressure.

P2 is Outlet Pressure, which is the return header pressure after the trap.

There are some systems with vacuum in the return which require slightly different calculations. Typically P2 is zero, that is atmospheric pressure.

P1 - P2 is the differential pressure across the valve, coil, and trap. h = P1 - P2

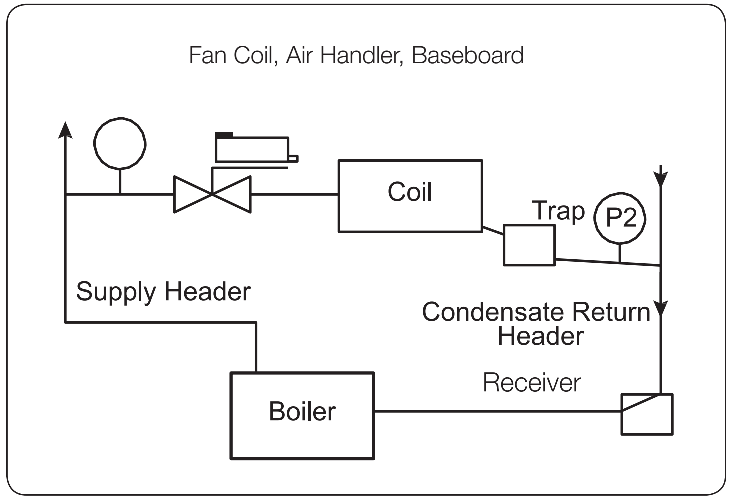


Figure 34 - Steam Valve Applications

"h" is the valve pressure drop and is used to size the valve. Low pressure systems, less than 15 psi, are sized using gauge pressure or psig – pounds per square inch gauge. High pressure systems are sized using absolute pressure or psia (sometimes called atmospheric pressure). Inside the pipes the gauge pressure is less than it would be if exposed to atmosphere. Absolute pressure adds the pressure of the atmosphere to the gauge pressure.

psia = psig + 14.7 psi

Pounds per square inch absolute = pounds per square inch gauge + 14.7 psi which is the weight of the atmosphere of the earth.

High pressure systems require valves with stainless steel trim and low pressure valves may also use stainless steel trim. Erosion of the seat and disc due to high velocity steam when the valve is near closed is always a possibility. This is referred to as wire draw or tunneling. Wire draw in bronze takes place above a 30 psi pressure drop. Wire draw in stainless steel takes place above a 50 psi pressure drop. Low pressure steam systems can use bronze trim without problems.

It is important to distinguish between low and high pressure applications in order to size correctly. This formula is used to size valves:

$Cv = (W * \sqrt{V}) / (63.3 * \sqrt{h}) * Y$

W = #/hr It is sometimes written as Q

V = specific volume using psig

h = pressure drop. This is P1

Y is an expansion factor. It varies and is typically equal to .8

Chart 3 Specific Volume Ft³ / lb.		
psig	psia	√V
0	14.7	5.2
10	25	4.0
20	35	3.4
30	45	3.1
40	55	2.8
50	65	2.6
60	75	2.4
70	85	2.3
80	95	2.1
100	115	2.0
120	135	1.8
140	155	1.7
160	175	1.6
200	215	1.5
300	315	1.2
400	415	1.1

2-Position Control of High and Low Pressure Steam

For 2-position control the steam valve is sized for as low a pressure drop as possible. A line sized valve is used in most cases. 10% of P1 is also a valid method for both high and low pressure systems.

Modulating Control of Low Pressure Steam

LOW PRESSURE < 15 psi

For modulation, 80% of the difference between the inlet and outlet pressures is used as the valve pressure drop. Assuming atmospheric pressure at the outlet, this means 80% of the inlet pressure can be used as the drop. (Some vacuum systems may use more than this drop.)

Use the following equation to size the valve: h = 80% (P1 - P2)

Equal percentage characteristic is generally best for low pressure steam. As the valve closes the inlet pressure increases. The reduction in flow will not be as great as might be expected. An equal percentage valve counteracts this tendency. Steam coils themselves respond linearly with an increase in flow. Unlike water coil response, steam coils are linear.

<u>HIGH PRESSURE > 15 psi</u>

The maximum flow through a valve occurs when the drop is about 42% of the absolute inlet pressure. After this there is no increase in flow. psia = psig +14.7 .

Use the following equation to size the valve: h = .42 psia

High pressure steam valves are best using linear response. The density of steam does increase at low opening, but not enough to matter. The limit on flow velocity and the linear coil response result in a linear valve operating best.

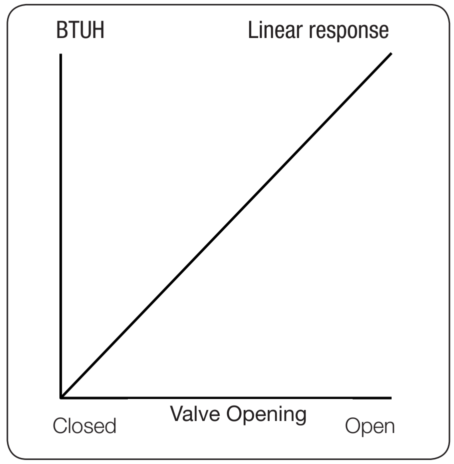


Figure 35a - Steam Coil Response

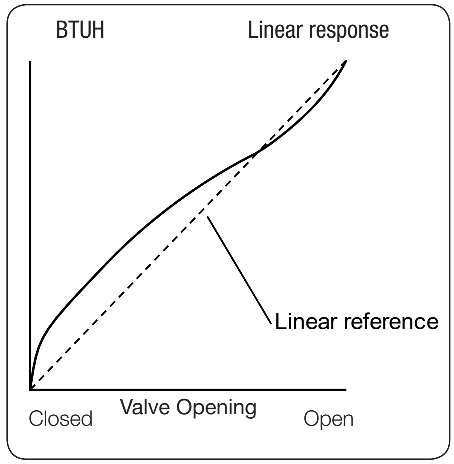


Figure 35b - Steam Flow

Choked Flow at Sonic Velocity

When steam or any compressible fluid is flowing through a restriction (valve), the flow quantity increases as the downstream pressure is reduced. The reduction in pressure is sensed as a wave traveling back upstream. This wave travels at the speed of sound. The reduction below the point where the flow travels at the speed of sound is impossible because the wave cannot travel back to the valve.

This is called choked flow. It is the reason why high pressure steam cannot increase flow above .42 psia.

At about 15 psig the .42 psia value = .8 of P1 - P2. Cavitation is not involved in this process and does not occur.

Sizing the Valve

After deciding what pressure drop, h, to use, it is then necessary to find the correct Cv by using a chart. Use of the formula is possible, but difficult. Charts giving quantity of flow at various Cv and steam pressures are found in the Belimo Valve Sizing and Selection Guide.

Superheat and Saturated Steam

The charts and formula above are for saturated steam. Just after steam boils the water content is as high as possible. If the steam is heated further, the water content is less in proportion, and the heat output is less. When this occurs, the Cv must be corrected.

The formula for correction with superheated steam is New Cv = Cv calculated x (1 + [.0007 x F superheat]). For each degree of superheat increase the required Cv by 1 plus superheat x .0007.

Summary of Valve Sizing Criteria

Sizing Information:

Pipe size

Flow rate in GPM or # of steam

Density of medium, assumed to be water = 1 in this guide

Pressure drop through coil and piping at design

Desired pressure drop through valve in full open position

System and valve pressure ratings

Selection Information:

Allowable leakage

Turndown required

Temperature of medium and ambient

Environment (NEMA 4 required, etc.)

Space constraints

Actuator control signal definition and any special needs

Characterized control valves are designed for control purposes. The standard ball valve is not designed for modulating control.

Actuation

Control Signal Type

One of the first considerations is to be sure that the actuator can be positioned accurately so that the control is accurate. Actuator accuracy cannot compensate for improper valve sizing or bad control loop tuning. Most control uses 2 to 10V signal output from the DDC or analog controller.

Resolution is the smallest change in the control signal that is required to make an incremental movement of an actuator. In general, the positioning is within .1V using an 8V span from 2V to 10V (.2 mA for 4 – 20 mA control). Some actuators use a .03V resolution. Others use .2V change required to reverse direction and .04V change is required to move (reposition) if the signal change is in the same direction. This is a form of signal anti-oscillation protection called asynchronous differential.

About .1V accuracy gives an 80:1 positioning accuracy; assuming good repeatability and no hysteresis. The circuits are all positive positioning, the actuator can stop at any intermediate position from fully open to closed without damaging the motor. Overload protection exists on all Belimo actuators. Floating control can be accurate depending on the performance of the controller. The time to drive from fully closed to open is generally 1 minute to 2.5 minutes. This allows time for the controller to position the actuator carefully, but most controllers use simple algorithms for control and do not receive loop tuning attention. This is the case with reheat valves where large numbers are installed and time to tune each loop is not given in the original installation contract.

Floating control is not positive positioning unless auxiliary position feedback is used.

Pulse Width Modulation (PWM) control can be as accurate as 2-10V if loops are tuned actuators are positive positioning. Various other signal start and span voltages can be used. Control accuracy varies depending on the controller. The actuators have the same resolution accuracy regardless of signal span. Which means that the use of a 6-9V signal gives a 3V span with .1V resolution; 30:1 is the highest system rangeability possible.

The system rangeability is a function of the worst component's accuracy in the chain of control; sensor, lag times, software, digital to analog output electronic, actuator, and valve are all involved. Repeatability may be more important than overall response characteristic in many systems.

Adjustable start and span actuators allow sequencing actuators from the same control signal. The heating valve is fully open at 2V and closes at just short of 6V. The cooling valve then starts to open at a bit over 6V and is fully open at 10V. This saves an analog output from the DDC system and the number of points are restricted. This limits the rangeability. It is better to use separate analog outputs for each valve whenever possible.

A variation on the above is to use two valves, either steam or hot or chilled water, for the same coil. The valves are staged open. The first valve is sized for about 1/3 the design and the 2nd stage is 2/3. If high accuracy at partial load is the biggest issue, the first stage could even be less of the proportion. A variation on this, which takes special programming is to modulate the 1/3 valve at low loads. At medium loads, when more flow is required the 2/3 valve modulate and the 1/3 valve is driven closed. As the load increases further, the 2/3 remains fully open and the 1/3 valve is modulating. This practice produces superior flow regulation and is common for steam valves, but can be used for any fluid flow control including dampers and air flow. Programming cannot use simple PI control during the changeover periods, since the coordination of the stages is necessary when one is closing and the other opening.

Torque and Force

Ball valves and CCV's operate by a quarter turn motion and provide high close-off ratings. The torque requirement for ball valves depends on stem torque, ball-seat torque caused by friction, and differential pressure. Differential pressure pushes the ball into the seat and increases torque requirement. Closing torque is normally 20% less than opening with soft Teflon seats. After prolonged disuse, Teflon slowly creeps into pores of the metal ball and increases breakaway torque; the first time the ball again rotates. Refer to Figure 36.

Butterfly valves have high dynamic forces when modulating. Dynamic forces act upon the disc and produce either positive or negative torque depending upon the position of the disc. When closed the pressure on the two sides of the disc are mostly balanced, but the rubber seals require a high actuator torque at close-off. Refer to Figure 36.

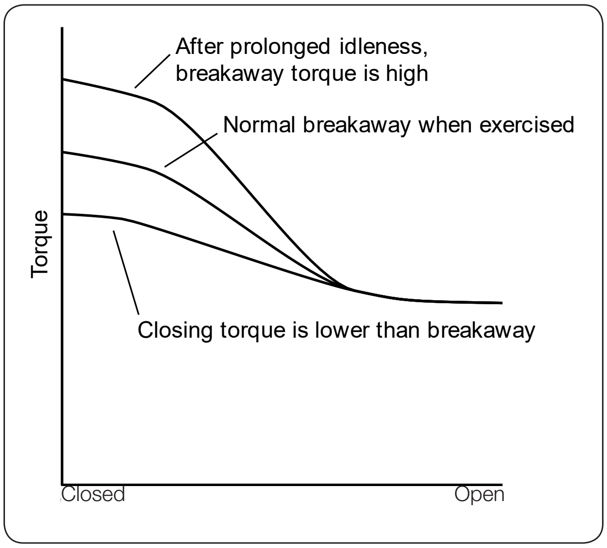


Figure 36 - Torque requirements for ball and butterfly valves

In a typical globe valve, the differential pressure acts upon the plug and produces a lifting force. The force is calculated by multiplying the area of the seat with the differential pressure. The actuator force must be strong enough to overcome the lifting force and friction in the stem packing to produce the required close-off pressure. To calculate the necessary globe valve close-off force, determine the area of the seat which is usually the size of the valve ports. Then subtract the force of the valve packing, assume 15 lbs.

For example, assume a 1.5" valve with seat area = 1.5" (radius = 1.5"/2), and 150 lbs rated valve linkage:

Area = A = Πr2 therefore 3.14 x $(1.5/2)^2$ = 1.77 sq-in. The required actuator close-off force = (150 - 15)/1.77 = 85 psi.

Limiting Ball or Butterfly Valve Opening to Control Cv

Standard ball or butterfly valve Cv is reduced when the body size is less than the pipe size. Characterized control valves and globe valve Cv are not affected. When the Cv is diminished, it is called a corrected Cv and is labeled Cvc. Cvc values for specific valve models can be found in the product documentation, and are summarized in Table 7. An example of Cvc values based on the valve size, pipe size, and valve percent open for a typical butterfly valve or standard ball valve, refer to Chart 4.

Chart 4											
Valve Pipe	Pipe Size	Cvc @ Valve Percent Open									
		100	90	80	70	60	50	40	30	20	10
2	2	210	147	96.6	63	44	27	16	8.4	4.2	2.1
2	2½	166	133	90	60	43	24	16	8.2	4.1	2.0
2	3	134	113	82	57	42	24	16	8.2	4.1	2.0
2	4	111	98	75	54	41	23	16	8.2	4.1	2.0

When a 2" valve is installed in a 2" pipe, the published Cv is 210, and by definition, the flow is 210 GPM with a 1 psi pressure drop across the valve. With the same pressure drop it will flow 147 GPM at 90° open, and at 60° the flow is 44 GPM; which is similar to the flow capacity of an equal percentage globe valve at full open. For modulating applications, determine the Cv required to meet the design flow. Use the Cvc values in Chart 4 to determine the required rotation based on the valve size and the pipe size. Belimo Multi-Function Technology (MFT) actuators can be programmed for the required rotation or can undergo an adaption routine which scales the 2-10 VDC control signal over the available mechanical rotation. The actuator's mechanical rotation can be set with and end-stop at 70°. As stated in the cavitation section, limiting the stroke to 60° or 70° has the added benefit of increasing the liquid pressure recovery factor. Refer to Chart 1.

Control Loop Tuning

Belimo actuators are designed to operate for the average expected life of the equipment; many remain operable after fifteen to twenty years of service. Unstable control loops can decrease the service life in a few years. Unstable control loops can oscillate, hunt, or dither. Oscillation is constant changes in position; hunting is constant wide swings in control signal, and dithering is small unproductive or even imperceptible changes in signal. Unstable control loops can cause premature failure of the actuator, increase maintenance cost, and decrease occupant comfort. The opposite of an unstable control loop is a sluggish loop which can also lead to poor occupant comfort. The actuator movement does not occur soon enough, or the action is too small for a sufficient change in flow. A properly tuned control loop will adjust the valve flow to achieve the setpoint of the controlled variable with minimal overshoot or undershoot. The control loops will cause productive changes in flow with each movement of the actuator.

The controllers proportional integral derivative (PID) loop is the logic used for tuning a control loop. The constants associated with each term of the PID loop should be set so that continuous movement of actuators does not occur. Actuation should not occur before the effects of the previous actuation have had time to affect the sensor; this may be ten minutes for a space sensor or one minute for a mixed air sensor. If a space sensor is located in a conference room filled with people, it will take at least five minutes for one-degree temperature change, and it may take another five minutes for a wall sensor to register the change. Mixed air is another very stable process because the outdoor air or average return air temperatures are stable. In both cases, fast actuation with adjustments is not necessary. Movement of the valve actuator when space temperature is within a half degree of setpoint or when discharge air is within one degree of setpoint is normally adequate.

During start-up periods more actuator movements may be necessary to find the correct operating points. During these periods the space is not occupied, and tight control is unnecessary. Time exists for the control loop to find the right valve positions and many fast responses are unnecessary.

For floating point actuators time of pulse instead of signal voltage is the control output, but the result is the same. When floating control is used the total run time of the actuator should be entered into the program logic. When the actuator is at either full open or full closed position, continual pulsing of the actuator against end stops (end stop dithering) should not occur.

Each control loop should be individually tuned. A variety of methods exist to tune a control loop properly. Time constants may be increased, and gain constants may be decreased. Where the control loop is not fully adjustable, it may be necessary to find a method particular to the individual controller. Adjusting or resetting the deadband is a possibility. In all events, the actuator must be protected from premature failure due to unstable control loops.

Glossary

Air Separator
Device placed at high point of system to remove dissolved air from the water so potential for oxidation of metals, air pockets and cavitation are reduced.

Angle Body
Right angled or L shaped valves which are primarily used for radiation.

Angle of Opening
The degrees or percent of opening of a disc or ball in a rotary valve.

ANSI Class
Temperature and pressure ratings of a valve.

Authority
The ratio of the wide open pressure loss through a pressure dependent valve to the system pressure loss (including the valve) across the sub-circuit in which the valve is installed.

Automatic Balancing Valve
Valve connected in series with the control valve and coil to limit the flow to the adjusted maximum value. It will be fully open when the flow is less than the setpoint.

Ball Material
Ball material is frequently a chrome plated bronze ball, or an stainless steel ball.

Ball Valve
Rotary valve whose turning element is a ball with a whole drilled through it. Several types are used. Standard port and reduced port ball valves were originally made for balancing and shut off purposes.

Body
The outer case of the valve which contains the water, steam, or air medium.

Body Rating
Maximum allowable system pressure, within a specified temperature range. The nominal rating is the ANSI class. In some cases the actual rating varies. Check all specs to ensure the ratings meet the service.

Boiler
Hot water or steam generator.

Booster Pump
Small circulating pump often used as a secondary pump or a runaround pump.

Bonnet Thread
The bonnet has thread to which a nut is often attached to allow mounting of the linkage. In retrofit applications the thread type must often be determined to allow selection of adapters to mount the Belimo linkage.

BTUH
British Thermal Units per Hour (BTUH) is the amount of heat necessary to raise one gallon of water 1°F.

Butterfly Valve
A quarter-turn valve used to regulate flow; with a metal disc in the valve body is positioned perpendicular to the flow in the closed position and rotated one-quarter of a turn to be parallel to the flow in the fully opened position.

Bypass
A pipe path which bypasses water around a boiler, chiller, or valve and coil.

Cavitation
In pumps and valves, air entrained in water is released when a restriction causes static pressure to be lowered. The air bubbles implode when the water has passed the restriction; velocity decreases and the pressure again increases. The imploding vapor bubbles erode the surrounding material and cause an intense noise.

Characterized Control Valve (CCV)
A ball valve which incorporates a characterizing disc. The disc provides an equal percentage valve characteristic; the size of the disc opening determines the Cv of the model.

Choked Flow
When velocity of steam reaches the speed of sound, it can't go any faster, this flow is referred to as “choked.”

Circulating Pump
Small pump used in residential, light commercial, or coil runaround service.

Close-Off Pressure
The maximum differential pressure against which a valve can close-off and keep any water from passing through.

Common Port
The port in a diverting or mixing valve which is common to the other two.

Composite Seat
Soft seat, often Teflon, used instead of metal. Leakage is reduced from the firm contact with the disc.

Compressible Flow
Steam is a compressible fluid while water is not. Air is compressible but not at the velocities found in HVAC service.

Contoured Plug
A plug shaped to achieve a particular flow characteristic.

Corrosion
Hard water and other chemicals in water will gradually eat away metals in valves and piping elements.

Cv
See flow coefficient

De-coupled
A part of a hydronic system is de-coupled from the rest of the system by an “equalizer bridge” between supply and return. Variations in the differential pressure in the primary circuit will not be transmitted to the secondary circuit.

Density
Mass per unit volume.

Differential Pressure
The pressure differential between two points in a hydronic system.

Direct Acting
A valve which increases flow with an increase in signal.

Diverting
A valve with 2 inlets and one outlet is mixing. A valve with one inlet and 2 outlets is diverting.

Dynamic Pressure
Pressure due to flow of water as opposed to its weight.

Energy Valve™
Similar to an ePIV with two additional sensors for supply and return water temperature measurement. Patented Power Control and Delta T Manager logic built-in optimizes the available energy of the coil by maintaining Delta T.

ePIV
The ePIV is a pressure independent characterized control valve with an integrated electronic flow meter and a powerful control algorithm. The ePIV integrated control signal maintains flow set point regardless of system pressure variations with its powerful algorithm that modulates the valve based on its measured true flow.

Equalizer Bridge
A bypass pipe between supply and return which de-couples two different parts of a system.

Erosion
The loss of material due to cavitation or a too high flow velocity. Generally velocity limited to 6 fps in copper and 10 fps in steel.

Expansion Tank
A tank which maintains the pressurization of the system. It absorbs the volume changes due to temperature variations of the water. Some expansion tanks have a pressurized bladder inside.

EPDM
Material used in seats, particularly butterfly valves.

Equal Percentage
Logarithmic response curve. In valves usually refers to a deep curve. Globe valves and CCV's have equal percentage curves. Standard ball valves and butterfly valves have shallow logarithmic curves, not normally considered to be equal percentage.

Flanged
Larger valves use flanges to bolt to pipes instead of screw threads.

Flared
Flare fittings are used in direct copper to copper valve connection. Small zone and terminal valves may have flared connections.

Flow Coefficient
Cv. GPM of 60°F water that flows through a valve at a 1 psi differential pressure. Usually thought of as full open valve flow, but can be used at partial openings.

Kv. Cubic meters/hour, m3/h of water, flowing through a valve with 100 kPa differential pressure.

Flow Resistance
Resistance to the flow in pipes, fittings, coils, and valves. It is often expressed as a pressure drop, although not theoretically correct. K is the loss coefficient.
$\Delta Pt = K \times Pv$

Fp
Piping geometry factor. See pipe geometry.

Globe Valve
Designed with a valve plug which is connected to the valve stem. As the stem's linear travel is raised or lowered by the actuator, the plug interfaces with the seat to open, close, or modulate flow.

Guide
Portion of valve which guides the stem and disc onto the seat.

Hysteresis
The required change in the control signal to reverse the movement of an actuator.

High Pressure Steam
Inlet steam pressures above 15psi.

Inherent Characteristic
The valve flow response characteristic or curve when the pressure drop across the valve is maintained constant.

Isolation Valve
Manual valves before and after a control valve or other pipe element which allow disconnection without water leakage.

Leakage
Water leakage through the seat and disc of the valve. Could be a leaky stem, but not normally used in this context. The leakage inside a shut valve is usually shown as a percentage of the Cv value.

Lift
In a globe, the inches of travel necessary to lift the disc off the seat and go to full open. Typically ½” to 11/2”.

Line Size
A valve whose inlet and outlet are the same size as the pipe.

Linear Characteristic
A valve response curve is linear if an equal amount of lift, rotation, or signal change always produces the same change in flow quantity.

Low Pressure Steam
Inlet steam pressures 15psi, or less.

Manual Balancing Valve
Also referred to as circuit setters, are used to adjust the flow resistance in the different parts of a hydronic system, to obtain the desired flow distribution. It is manually adjusted and has a calibrated stem/hand-wheel. The valve has two ports to facilitate measurement of the differential pressure across the valve.

Materials
Brass, Bronze, Chrome plated, Cast Iron, Composites, EPDM, Stainless Steel, Teflon, TEFZEL, Viton, Zinc, etc. Materials used in valve construction.

Medium
Water, steam, air, etc. which run through the valve.

Most Resistive Circuit
The loop with the largest pressure drop.

Normally Open
Valve that is open when the signal to the actuator is low or when power is lost.

Normally Closed
Valve that is closed when the signal to the actuator is low or when power is lost.

NPT
National Pipe Thread. Screwed end valves are sometimes referred to as NPT. Plumbing pipe uses inside diameter.

Pipe Losses
The pressure drop along a certain length of pipe. It is dependent upon the distance, size, flow velocity and the inside surface roughness. The resistance of pipe bends, fittings etc. are often expressed as "equivalent pipe length" which is added to the pipe losses. K value loss coefficients are more accurate.

Pipe Geometry
Typically, a properly sized modulating control valve is smaller than the pipe it is connected to. Pipe reducers are used and the change in the cross section area, results in a lower Cv value. This is especially true for ball and butterfly valves (globe valves and CCV's are affected very little). The control valve manufacturer should supply a table showing the "corrected" Cv values for the different valve and pipe sizes. Cvc is the corrected Cv. Cvc = Fp x Cv where Fp is the piping geometry factor.

Pressure Drop
The pressure differential across a resistance to the flow, for example a valve.

Pressure Independent Valve
Pressure independent valves directly control the water flow required by the coil and are not affected by pressure fluctuations in the system. The valves are selected based on the flow requirements of the coil, and no valve authority or Cv calculations are needed.

Pull Pump
Coil pump. Also called runaround pump.

Pump Head
The pressure increase between the inlet and outlet of a pump.

Pump Performance Curves
The relation between the flow and pump head at different impeller diameters. Curves showing the efficiency % and horse power at different operating points.

Radiator Valve
Either manual or self-contained valves used to control flow through a radiator.

Rangeability
The flow through a control valve follows a certain characteristic down to a "minimum controllable flow" where the flow abruptly changes and the valve closes. The rangeability factor is the ratio between the maximum flow and the minimum controllable flow. Laboratory valve characteristic. See turndown.

Reverse Acting
Valve which decreases flow with an increase in signal. Typically a function of the actuator.

Reset Schedule
The supply water temperature to the heating or cooling system is changed with respect to a parameter that is proportional to the load, usually the outdoor temperature.

Resolution
The finest positioning change of an actuator when discreet changes of the control signal are made. Electronic actuators have a far greater resolution than commercial grade pneumatic actuators.

Runaround Pump
Coil pump. Also called pull pump.

Seating Torque
Torque necessary to close valve.

Secondary Pumps
Pumps used to provide circulation in secondary loops that are de-coupled from the main loop.

Self Contained Valve
Valve with built in operator. Used for baseboard, radiation.

Service Temperature Range
High and low temperatures which a valve can withstand and still function properly.

Soft Seat
Resilient seat versus the metal to metal or hard composite.

Stainless Steel
Strong hard steel which withstands corrosion and high temperatures.

Static Pressure
The combination of column pressure and fill pressure when the system is off, expressed as gauge pressure (psig).

Static Pressure Rating
Pressure rating of a valve against weight of water against the body walls.

Stem Travel
For butterfly and ball valves the stem travel is up to 90° rotation. For globe valves the travel is up/down; see lift.

Sweat
Soldered connections to valve inlet and outlet.

System Curve
A curve showing the relationship between flow and pressure in a system served by a pump. An exponential curve representing the system pressure loss versus the flow quantity.

Throttling
Proportional or modulating movement of the valve in response to the control signal.

Trim
Inside components of valve which have contact with medium. The seat, plug, stem, and ball are all trim components.

Turndown Ratio
The turndown ratio relates to an installed valve. It is the ratio between the full flow and the minimum "controllable" flow of the valve. The turndown ratio always is less than the rangeability factor because it is dependent upon both the rangeability factor of the valve itself, and its valve authority. In addition the full flow required is usually less than the capacity of the valve.

Union Valve
Valve with a built in union coupling on one fitting end to facilitate installation.

V-port
Machined ball with free-area contoured to achieve a parabolic flow characteristic.

Variable Speed Pumping
The pump is operated at a variable speed by a variable speed drive, which can be adjusted manually, or controlled automatically. It reduces the operating costs of the pump significantly and improves pressure control.

Welded End
High pressure end fitting on process valves.

Wire Draw
Erosion of the plug or seat of a valve due to high velocity steam when the valve is near closed. Also called tunneling. The damage looks like a sharp cut along the side of the plug or seat.
Bronze wire draws at 30 psi ÆP. Stainless at 50 psi ÆP. A 50% safety factor recommended.

Zone Valve
Small flow capacity valves with 2-way and 3-way configurations motorized by non fail-safe or fail-safe actuator.

Tables & Formulas

Table 1: Inside Flow in Inches		
Size	Steel - 40	Copper K
1/2	0.3	.22
3/4	0.53	0.436
1	0.86	0.78
11/4	1.5	1.22
11/2	2.04	1.72
2	3.36	3
21/2	4.8	4.66
3	7.4	6.6
4	12.7	11.7

Table 2: GPM at Typical Velocities										
Ft/Sec	3		4		5		8		10	
Size	Steel - 40	Copper	Steel - 40	Copper	Steel - 40	Copper	Steel - 40	Copper	Steel - 40	Copper
1/2	2.8	2	3.7	2.7	4.7	3.4	7.5	–	9.3	–
3/4	4.9	4	6.5	85.4	8.2	6.8	13.1	–	16.4	–
1	8	7.3	10.7	9.7	13.4	12.1	21.4	–	26.7	–
11/4	14	11.4	18.7	15.2	23.3	19	37.3	–	46.6	–
11/2	19	16	25.4	21.4	31.7	26.7	50.7	–	63.4	–
2	31	28	41.8	37.3	52.2	46.6	83.6	–	104.4	–
21/2	45	43	60	58	75	72	119	–	149	–
3	69	61	92	82	115	103	184	–	230	–
4	118	109	158	145	197	181	316	–	395	–

Heat Transfer Formulas

Air

Sensible Heat, BTUH = CFM X 1.085 X ΔT
Latent Heat, BTUH = CFM X .68 X grains of moisture per lb standard air
= CFM X 4.5 X (Entering Air Enthalpy – Leaving Air Enthalpy)
Total Heat (BTUH) = CFM X 60/Cu.Ft./LB X (Entering Air Enthalpy – Leaving Air Enthalpy)

Water Coils

GPM = BTUH air side load / BTUH water side sensible capacity
GPM = BTUH / ΔT X 60 X 8.34 lb/gal
GPM = CFM X 1.085 X ΔT air / ΔT water X 500 (or K from Table 3)
= D Enthalpy X CFM X .075 X 60 / ΔT X 500 (or K from Table 3)
(Total cooling)
Alternately, GPM = CFM X BTU/lb dry air/113 X ΔT water side

1.085 is a scaling constant. It is derived from .24BTU/lb air °F X 60 min / hr x 1lb air / 13.4 cu.ft.

For other conditions, substitute 13.4 with other specific volume

Table 3: Constant K for Heat Exchangers and Coils	
Water Temp F	K
60	500
100	496
150	490
180	487
200	484
250	479
300	473

Water to Water Heat Exchanger

BTUH supply side = GPM X 500 X ΔT water load side
Note that 500 in formulas above could be replaced by a constant factor K.

Tables and Formulas

Radiation (Reference Table 4)

Radiators and convectors are sized according to equivalent direct radiation or EDR.

When EDR is known, calculate the steam supply quantity needed, W.

W = .24 EDR where .24 is # steam/ unit EDR

Steam Coils

W = Steam in lb / hr = BTUH air side load / Latent heat of steam

= CFM X 60 X .075 X .24 X DT / 970
= CFM X ΔT / 890
= BTUH air / 1000 BTU/lb steam

Approximate heat of vaporization of steam = 1000BTU/lb

Steam to Water Heat Exchanger

W = Steam in lb / hr = GPM X ΔT X .5

Steam Jet Humidification

Q = 4.5 x ΔW lb/hr moisture

Where ΔW = (lb of moisture per lb of air leaving)/hr – (lb of moisture per lb of air entering)

Valve Cv is then sized directly from charts for the boiler pressure and the # per hour needed. Use the same sizing rules already given for low and high pressure systems.

Superheat

The formula for correction with superheated steam is New Cv = Cv calculated x (1 + [.0007 x F superheat]). For each degree of superheat increase the required Cv by 1 plus superheat x .0007. Tables and Formulas

Metric System

c = specific thermal capacity = kJ/kgK and for water is 4.196 ≈ 4.2

4.2 [kJ/kgK] = 4‘200 [J/kgK] = 4‘200 [Ws/kgK]

Joule = 1 watt-second

kw = kilowatt

N = kg-m/s^2 = .225 lb force

Pa = N /m^2

Nominal thermal power Q^{100} is in kW

Q = heat flow in kW

Q = m x c x ΔT with m in kg/s and c in kJ / kg-K

Q = V x r x c x ΔT with V in m^3 /s and c in kJ / kg-K

Q = 4190 x m^3 /s x ΔT

Q = 1.2 X L/s X Δh

Where Δh = enthalpy difference in kJ/kg dry air; requires metric psychometric chart.

Sp. Gr. = Specific gravity, water = 1

Specific Heat Water = 4190 J/kg-K

V = Flow (liquid) = m^3/h, m^3/s

p = Density = kg/m^3

1 m water = 9.9 kPa

1 mm Hg = 133.3 kPa

100,000 Pa = 1 bar

Table 4: Average Temp BTUH / EDR		
°F	Cast Iron (Room Ambient)	Convector (65 °F inlet)
215	240	240
200	209	205
190	187	183
180	167	162
170	148	141
160	130	120
130	76	70
100	30	27

Table 5: Saturated Steam Pressure - Temperature Table				
psig	psia	T °F	T °C	kPa gauge
0	14.7	212	100	100
1	15.7	215	102	107
2	16.7	219	104	114
3	17.7	220	104	120
5	19.7	227	108	134
7	21.7	232	111	148
10	24.7	239	115	168
15	29.7	250	121	202
20	34.7	259	126	236
25	39.7	267	131	270
30	44.7	274	134	304
35	49.7	280	138	338
40	54.7	287	142	372
50	64.7	298	148	440

Valve Sizing

Kvs= V_{100} / $\sqrt{\Delta P_{V100}}$ by definition

ΔP_{V100} at 1 bar

V_{100} in m^3/h

ΔP_{V100} = Kvs = (V_{100} / Kvs)^2

Kvs = V_{100} / $\sqrt{\Delta P_{V100}}$ is analogous to

Cv = GPM/$\sqrt{\Delta P}$

Example:

Given: V_{100} = 4 m^3/h and ΔP_{V100} = 0.3 bar

Kvs = V_{100} / $\sqrt{\Delta P_{V100}}$

Kvs = 4/$\sqrt{.3}$ = 7.3

A valve with a Kvs = 7.3 m^3/h is required.

Tables and Formulas

Conversions

1 bar = 14.7 psi = 29.9 in. Hg = 33.9 ft. w.g.
1 BTU = 3.14 watts
°C = (°F - 32°)/1.8 [Fahrenheit to Celsius]
1 kJ/kg = .43 Btu/lb dry air
1 joule = .738 ft-lb = .00095 BTU
1 kg = 2.2 lb
1 kg/m^2 = .0624 lb/ft^2
1000kg / m^3 = 62.4 lb/ft^3
1 m/s = 197 fpm
1m = 3.28 ft.
1m^3/hr = 4.4 GPM
1 N = kg-m/s2 = 8.85 lb force
1 Pa = .000145 psi = .004 in. w.g. = .004 in. w.g.
1 kPa = .145 psi = .296 in Hg
1 W = J/s = 3.41 Btu/hr
1m^3/hr = 4.4 GPM

Table 6: Properties of Saturated Steam

Vacuum in Mercury	Steam Temp or Boiling Point °F	Specific Volume	
psig	cu.ft./lb	V	$\sqrt{v}$
29	77	705	26.6
20	161	75	8.7
12	187	43	6.6
6	201	33	5.7
2	208	29	5.4
0	212	27	5.2
2	219	24	4.9
4	224	21.4	4.6
5	227	20.4	4.5
8	234	17.9	4.2
10	239	16.5	4.1
12	244	15.4	3.9
15	250	13.9	3.7
20	259	12	3.5
25	267	10.6	3.3
30	274	9.4	3.1
40	287	7.8	2.8
50	298	6.7	2.6

Table 7: Comparison of Various Valves at Rotated Positions with Fp Factors

Valve Size	Pipe Size	Cv/Cvc	Cvc								
Percent Rotation		100% Open	90	80	70	60	50	40	30	20	10
Ball Valves											
1/2"	1/2" to 1"	(1) 1	0.88	0.68	0.48	0.35	0.25	0.15	0.1	0.07	0.02
1/2"	1/2"	(2) 9.8	6.9	4.5	2.9	2.1	1.3	0.8	0.4	0.15	0.02
1/2"	3/4"	7.4	2.9	4.4	2.9	2.1	1.2	0.8	0.4	0.15	0.02
1/2"	1"	6.3	5.3	3.8	2.6	1.9	1.2	0.8	0.4	0.15	0.02
2"	2"	210	147	96	63	44	27	17	8	4	2
2"	2.5"	166	133	90	58	42	26	17	8	4	2
2"	3"	134	113	82	56	38	25	17	8	4	2
2"	4"	111	98	75	53	37	25	17	8	4	2
Butterfly Valves											
2"	2"	166	151	123	96	71	50	33	20	10	5
2"	2.5"	141	128	104	82	61	40	30	20	10	5
2"	3"	121	110	90	70	52	38	30	20	10	5
3"	3"	340	309	252	197	146	100	65	30	15	8
3"	4"	282	257	209	164	121	90	60	30	15	8
3"	5"	241	219	180	150	111	80	55	30	15	8
Belimo Characterized Control Valves and Globe Valves (3)											
1/2"	1/2" to 1"	1	0.7	0.49	0.34	0.22	0.17	0.11	0.07	0.05	0.01
1"	1" to 1.5"	10	7	5	3	2	2	1	0.7	0.5	0.25
2"	2" to 2.5"	40	28	20	14	9	7	4	3	2	1

This chart is for study and comparison purposes. Not all Cv's are representative of Belimo products.
(1) Note that use of 1 for full Cv gives the decimal equivalents of the Cv's at the rotated positions.
(2) Note the large amount of reduction in Cv at the full open positions, but no effect at near closed positions.
(3) There is negligible effect on the Cv at reduced pipe sizes for low capacity valves.
Inlet conditions can reduce Cv. Elbows or fittings near the valve inlet can cause reduced Cv.

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