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Considerations for Selecting Modulating Control Valves

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Selecting and sizing HVAC control valves can sometimes be a daunting task for many designers. In the past, control valves were primarily pressure dependent, meaning the flow is dependent on the differential pressure across the valve for any given valve position. Pressure independent control valves have gained market share in recent years. Today, we have many available devices to control fluid flow when deciding how to best control water heating and cooling loads.

This month I will briefly review control valve fundamentals and explain the differences between the two primary control valve technologies and other accessories used in water flow control to assist designers in selecting modulating control valves for their application.

Water System Valve Fundamentals

A control valve is used to control fluid flow by varying the size of the flow passage as directed by a signal from a controller. It is a variable orifice device positioned by the actuator and controller to control flow rate. It can be equipped with a throttling plug, V-port, or a rotating ball specifically designed to provide a specific flow characteristic. The control valve typically modulates to maintain coil air discharge temperature or space temperature setpoint. An ideal control valve would be able to precisely match the required flow with the load at all conditions.

Flow Characteristic

Valve performance is expressed in terms of its flow characteristics. Valve flow characteristic is the relationship between the stem travel of a valve based on a constant pressure drop, expressed in percent of travel, and the fluid flow through the valve, expressed in percent of full flow. Three common characteristics as shown in *Figure 1* include:

- **Quick opening.** A valve that provides maximum possible flow as soon as the stem lifts the disc from the valve seat.
- **Linear.** A valve that provides a flow-to-lift relationship that is directly proportional. It provides equal flow changes for equal lift changes, regardless of percentage of valve opening.
- **Equal percentage.** A valve that changes flow by an equal percentage (regardless of flow rate) for similar movements in stem travel (at any point in the flow range).

Different valve characteristics will give different "valve openings" for the same stroke position. Stroke is the distance the plug or stem moves to go from a full closed to a full open position. When comparing linear and equal percentage valves, a linear valve might have a 25% stroke for a certain pressure drop and flow rate, while an equal percentage valve might have a 70% stroke for exactly the same conditions.

Ideally, a control system has a linear response over its entire operating range. This makes the controls easier to tune and more stable. The sensitivity of the control to a change in temperature is then constant throughout the entire control range. For example, a small increase in temperature provides a small increase in cooling.

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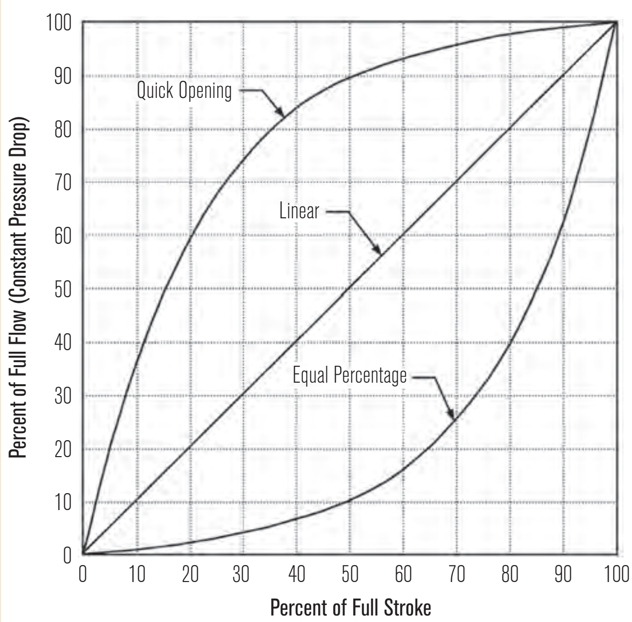

FIGURE 1 Typical flow characteristic of valves.[3]

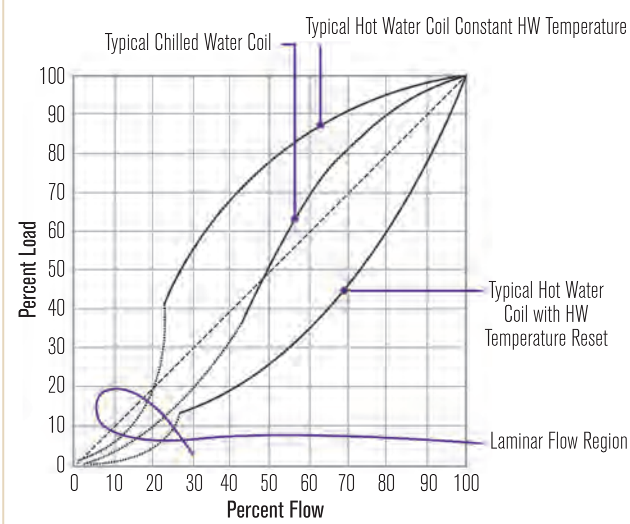

FIGURE 2 Coil capacity versus flow rate.[4]

A nonlinear system, like a convective air handler coil or an active chilled beam, has varying sensitivity. For example, a small increase in temperature can provide a large increase in cooling in one part of the operating range and a small increase in another part of the operating range.

To achieve linear control, the combined system performance of the actuator, control valve, and load should be linear. If the coil performance is not linear, a nonlinear control valve, such as an equal percentage valve, is appropriate to balance the system so resultant performance is closer to linear. But this discussion is largely theoretical because of real-life system dynamics. For instance, heating coils have very nonlinear flow vs. capacity performance characteristics as shown in *Figure 2*. This becomes more linear if hot water temperature is reset, which is common practice and often required by energy codes.

In most hydronic systems, the available differential pressure across the valve seldom remains constant due to the dynamic operation of variable flow systems. As flow through the valve decreases, pressure losses through the piping and coil decrease, so the pressure drop across the valve must increase. At the same time, the operation of other control valves varies available pressure across the valve. Good hydronic system design,[1] control valve sizing, and control can help minimize the differential pressure fluctuations. The hydronic system pressure fluctuations can cause the actual control valve performance to deviate from the published characteristic curve.[2]

The combination of the desire to linearize the coil/valve combined performance and to linearize the impact of valve stroke vs. pressure drop across the valve leads to the selection of equal percentage valve characteristic for all two-way valves in variable flow hydronic systems. For globe valves, this means using equal percentage plugs. For ball valves to exhibit equal percentage behavior, specialized ball or discs must be provided. These so-called characterized ball valves are increasingly popular because of their low-cost, high close-off pressure ratings, high rangeability, and ease to couple with a rotary electronic actuator.

Flow Coefficient

The flow coefficient, or C_v, is a universal capacity index and is simply defined as the number of U.S. gallons of water per minute at 60°F (16°C) that will flow through a valve with a pressure drop of 1 psi (6.9 kPa). When selecting a valve to control the flow of a specific media, the C_v factor needs to be determined by solving the formula:

$$C_V = Q\sqrt{\frac{SG}{\Delta P}} \quad (1)$$

Where

Q = flow rate in gpm

SG = specific gravity of the fluid (the ratio of the density of fluid to that of pure water at 60°F [(16°C)])

ΔP = pressure drop in psi

The C_v factor corresponds to the valve pressure drop at the full rated flow when the valve is wide open. The C_v factor on a modulating control valve will vary as the valve position varies based on its flow characteristic. The C_v factor on a coil or calibrated balancing valve (CBV) will be fixed. As flow is reduced by the control valve in a circuit with a coil and calibrated balancing valve, the pressure drop of the coil and calibrated balancing valve will decrease rapidly, requiring the control valve to compensate for the additional pressure drop required.

The control valve size should be selected by calculating the required C_v to provide the design flow at a design pressure drop. A pressure drop of 25% to 50% of the available pressure drop between the supply and return branch connections should be selected for the modulating control valve to provide adequate authority.[3] *ASHRAE Handbook—HVAC Systems and* [3] defines authority using the equation: Authority = Valve ΔP/(Valve ΔP + Branch ΔP).

This is often a difficult calculation because it is ambiguous where the "branch connections" are located, and the available pressure varies dynamically. So most engineers and control contractors typically use other rules of thumb, such as selecting valve pressure drop to be equal to the coil pressure drop or using arbitrary design pressure drops typically ranging from 2 psi to 5 psi (14 kPa to 34 kPa) without problems when system head is roughly 100 feet (25 kPa) or less.

Other Factors

Rangeability is the ratio between maximum flow and the minimum controllable flow at a constant differential pressure across the control valve. The minimum controllable flow is where the flow abruptly changes and the valve closes. Rangeability is measured in a lab by the manufacturer. Turndown is the ratio of maximum flow to minimum controllable flow of the valve installed in a system. The differential pressure across the control valve installed in a system will typically vary since it is installed in series with fixed orifice devices like coils and calibrated balancing valves.

These fixed orifice devices will cause the control valve to have higher differential pressure at lower flow rates. The turndown ratio is always lower than the rangeability ratio because it is dependent on the rangeability factor of the valve and its authority. Characterized ball valves typically have a rangeability of 100:1 to 300:1, much higher than typical globe type valves.

The close-off pressure rating is the maximum pressure drop a valve can withstand without leakage while in the full closed position. The valve close-off rating is independent of the actual valve body rating. The ability of the control valve to close off against the highest anticipated available differential pressure is an important feature for maintaining differential temperature, ΔT, in chilled water systems.[5] The fluid differential pressure does not affect the closing force for ball valves, for which close-off ratings are typically 200 psi (1379 kPa), but it is a factor for globe valves, since excessive pressure can cause the valve disc to lift off the seat. Close-off pressure will depend on the valve and actuator type ranging from 30 psi (209 kPa) to over 200 psi (1379 kPa). The dynamic close-off pressure rating is the maximum differential pressure allowed for smooth operation of the valve, particularly near shut-off. The control valve design turndown ratio will not be achieved if the differential pressure is above the dynamic close-off pressure rating.

Another important characteristic of the valve/actuator assembly is its cycle reliability, expressed as full cycles of expected service life. Most HVAC control valves with a service life of 100,000 full cycles will operate for at least 5 years without maintenance.

Another consideration is the size of the flow passage in the control valve and whether a strainer is required at each control valve to protect the valve from entrained dirt, scale, or other solid substances carried in the process liquid. This is typically only an issue with small valves, e.g., those with C_v less than 1. Consider placing a single strainer for reheat systems in a location that is easily accessible as opposed to placing strainers on each reheat coil in the ceiling space.

Refer to Hegberg[6] for additional control valve performance considerations.

Pressure-Independent Control Valves

Pressure independent control valves (PICVs) entered the market almost 20 years ago, and the author has seen more designs using these valves in recent years. The most common PICVs combine an integral differential pressure regulator with a standard two-way control valve as shown in *Figure 3*. The pressure regulator (e.g., spring and piston) maintains a constant differential pressure across the control valve regardless of the system differential pressure across the assembly. The constant pressure drop across the control valve provides essentially infinite control authority and much improved controllability compared to standard pressure dependent control valves. PICVs typically require a differential pressure operating range of 2 psi to 70 psi (14 kPa to 483 kPa) and provide a minimum 100:1 rangeability.

The outlet to the valve body typically includes a flow setting device. This enables the valve to be adjusted to maintain a maximum design flow rate, as specified by the designer, much like an automatic flow-limiting valve.* On some models, the required flow rate can be set using the flow setting dial incorporated in the valve body, while others would require a change in the cartridge. Typically, if the flow setting dial is combined with the pressure independent modulating control valve, as the flow setting is adjusted some of the travel of the control valve is used up in regulating the flow. Modulating flow control is only available across the remaining travel of the valve, after the flow has been set. Multiple pressure ports are built into the valve body for system pressure measurement and troubleshooting.

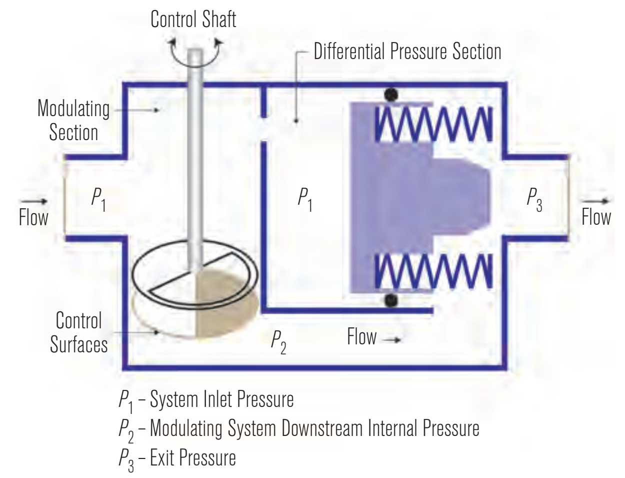

FIGURE 3 Typical PICV schematic.

* Some flow-limiting valve manufacturers claim that their valve plus a standard pressure-dependent control valve provide the same performance as a pressure-independent control valve. This is definitely not so. The flow-limiting valve essentially does nothing when flow is below design, as this is when the valve is throttling flow. So it does nothing to limit the differential pressure across the control valve. With a pressure-independent valve, the differential pressure across the control valve is always constant.

TABLE 1 Modulating control valve considerations.

CONSIDERATION	CONTROL VALVE WITHOUT CBV	CONTROL VALVE WITH CBV	PRESSURE INDEPENDENT CONTROL VALVE
EASE OF DESIGN AND SIZING	**Difficult**—It is hard to predict all ΔP dynamics in a variable flow system.	**Difficult**—It is hard to predict all ΔP dynamics in a variable flow system.	**Simple**—Determine maximum flow rate and differential pressure.
CONTROL STABILITY	**Worst**	**Better**[8]	**Best**
BALANCING	**Debatable**—Should at least verify ΔP across controlled device.	**Required** to set calibrated balancing valve.	**Debatable**—Should at least verify ΔP across controlled device.
EASE OF CONTROL TUNING	**Difficult** in systems where ΔP changes rapidly.	**Difficult** in systems where ΔP changes rapidly.	**Best**
COMMISSIONING (CX)	Likely requires ongoing Cx to ensure control valve is tuned.	Likely requires ongoing Cx to ensure control valve is tuned.	Only need to verify valve has enough ΔP to operate.
SYSTEM ENERGY COSTS	Control instability over time can lead to higher system energy costs.	Slight increase in costs over having no calibrated balancing valve.	Control stability likely leads to lowest system energy costs even with required minimum ΔP of 2 psi to operate.

Selection of pressure independent valves is simply a function of maximum design flow rate. Complex branch pressure drop and C_v calculations are not required.

Manufacturers claim this design increases system control stability, and this has been true based on the author's commissioning experience. Control stability for pressure dependent control valves is impacted by the magnitude of differential pressure change across the valve and how well the valve control loop is tuned. Manufacturers also claim that PICVs increase chilled water ΔT. If both standard and PICVs resulted in the same control stability, this would not be the case, since a single flow rate will result in the desired setpoint for a given set of coil entering water and air conditions. However, improved control stability will improve chilled water ΔT since coils are nonlinear, e.g., the average flow is lower when the flow through the coil is stable vs. flow that fluctuates widely to attain the same average setpoint. However, many factors, such as low entering air temperature, that cause chilled water ΔT degradation[7] will not be improved by the control valve.

Another type of pressure independent control valve uses a flow meter in conjunction with a standard control valve. It operates the same as a standard VAV box pressure independent controller: the control loop does not control the valve directly, but instead resets the desired flow rate setpoint. Then the valve is modulated to maintain that setpoint. This type of pressure independent valve has some advantages over the more common dual-valve PICV described above, including knowledge of flow rate. But it lacks the most important benefit: the infinite valve authority responsible for the improved controllability. This type of pressure independent control valve must be selected the same way as a standard pressure dependent valve using C_v. And, while it can improve controllability vs. standard valves, it will not perform as well as the dual-valve PICV.

Comparing The Options

Table 1 provides a general comparison of pressure dependent and dual-valve type pressure independent modulating control valves. *Figure 4* provides a first-cost comparison of characterized ball control valves (with and without a calibrated balancing valve) vs. dual-valve type pressure independent control valves. All three

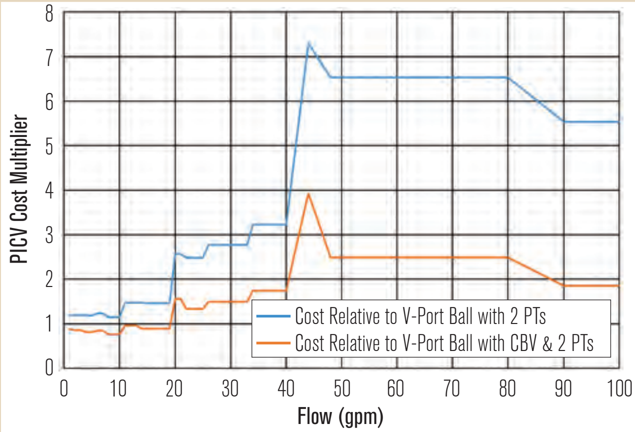

FIGURE 4 Pressure independent control valve cost comparison.

options include pressure/temperature (PT) ports for measurement. The author compared the actual cost premium for PICVs versus V-port ball control valves for air handler chilled water valves on three recent building projects and found that the average cost increase was insignificant at \$0.03/ft^2 to 0.05/ft^2 (\$0.32/m^2 to \$0.54/m^2).

Concluding Remarks

As designers of HVAC systems, it is critical we understand that an ideal control valve would be able to precisely match the required flow with the load at all conditions. Valve selection objectives include control stability, ease of design, ease of operation, and first cost. Today's pressure independent control valves can improve long-term system operation in variable flow hydronic systems.

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