Importance of Control Valve Flow Characteristics – if any!

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Most HVAC controls' specifications call for certain type of valve characteristics and this has continued for decades. ASHRAE handbooks also recommend certain type of valve characteristics for different applications. But it seems to have missed the attention of most that times have changed and so have technologies, and what was a good solution yesterday is no more as good.

Control Valves

In HVAC systems, control valves are primarily used to control the flow of chilled water, hot water or steam. To understand the importance of valve flow characteristics in HVAC control it is necessary to understand a little bit of valve construction, type of valve flow characteristics and few basics of control theory.

Valve Components

• Body • Bonnet • Seat • Spindle / Stem • Stuffing box • Disc / Plug / Shoe

Body : The majority of the valve consists of the valve body, including most of the exterior. The valve body is the casing that holds the fluid going through the valve. Valve bodies are most commonly made of various metals or plastics.

Bonnet : A bonnet basically acts as a cover on the valve body. It is commonly semi-permanently screwed into the valve body.

Disc / Plug / Shoe : It is the movable part in the valve used to regulate the fluid flow through the seat by varying the opening.

Seat : It is the fixed opening in the body through which the fluid flows and a seal is formed when it is in contact with the plug.

Spindle/Stem : It is the rod which connects the external operator like hand-wheel or actuator to the plug.

Stuffing box : It consists of seals of flexible materials like rubber, asbestos to prevent fluid leakage from around the spindle.

Valve flow characteristics

The term valve flow characteristic refers to the relationship between the position of its flow controlling element, i.e., valve plug/shoe, and its resulting flow under constant pressure conditions.

As per Bernoulli's equation, under constant pressure conditions, flow rate is directly proportional to the orifice pass area, which is the opening between the valve plug and the seat, through which the fluid passes. The physical shape of the plug and the seat arrangement is often referred to as 'valve trim' which is so designed, or characterized, as to meet a variety of control application needs, as many control loops are inherently non-linear.

Different trim designs (*Figure 2*) give different orifice pass area for the same valve stroke thus resulting in different valve characteristics. Graphically, this is normally plotted with the valves resulting flow on the vertical axis vs. the valve plug's travel on the horizontal axis. The shape of the resulting output vs. input curve describes the type of valve characteristic.

The majority of valves for control applications are with quick-opening, linear or equal-percentage characteristics. *Figure 3* shows the curves representing the above characteristics. These curves are based on constant pressure drop across the valve and are called *inherent flow characteristics.*

The *quick-opening* valve allows nearly maximum flow at the beginning of the stem travel. This type of valve is most suitable for use as on-off or relief valve, where a large flow has to be achieved as quickly as possible.

The *linear* characteristic approximates a straight line, that is, flow through the valve is proportional to the stem travel. The steady state gain of this valve is constant.

With an *equal-percentage* valve the flow rate increases exponentially, each increment in stem travel increases the flow rate by a certain percentage of previous flow. This effectively means that for the same change in stroke the change in flow rate is less at smaller valve opening but is much more at larger valve opening.

The above definitions hold good only for applications where the pressure drop across the valve remains constant, which rarely is the case. When valves are installed in a system with pumps, piping and fittings the pressure drop across the valve may vary as the plug moves through its travel resulting in different installed flow characteristics. The change in pressure drop may push inherent equal

continued on page 132

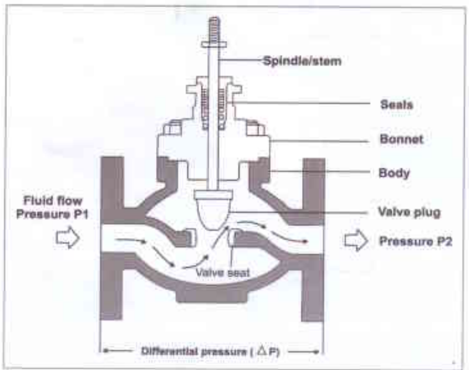

Figure 1 : Value components

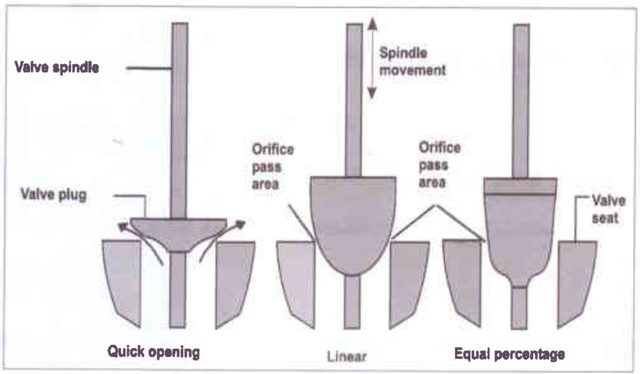

Figure 2 : Trim designs

continued from page 130

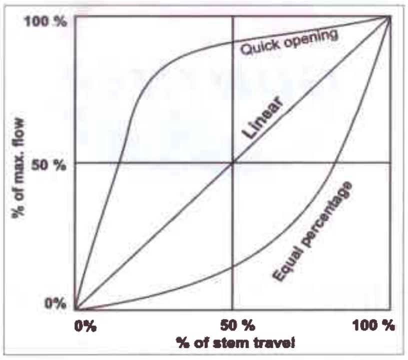

Figure 3 : Characteristics of different valve types

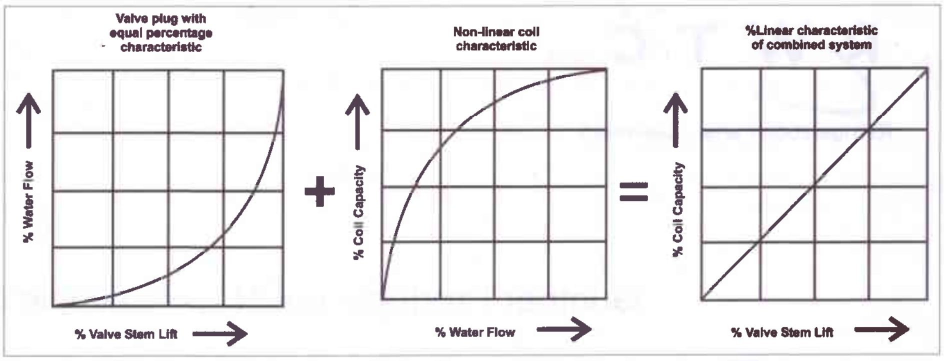

Figure 4 : ASHRAE - recommended characteristics

percentage characteristic towards linear characteristic and inherent linear characteristic towards quick opening characteristic. Thus the valve flow characteristic is not only a function of trim design but also of change in pressure drop.

ASHRAE recommends the use of control valve with equal percentage characteristics to achieve near best linear heat output relationship to valve plug travel as shown in *Figure 4*. This may be reasonably true for heating application while using 3-way valves, but a different valve characteristic may be required if using a cooling coil, whose characteristic may differ from that of a heating coil, and a 2-way control valve across which pressure drop is likely to change, a lot.

Valve plugs are designed for flow characteristics which can easily be expressed by simple mathematical equations, but HVAC system loads being highly non-linear few standard control valve characteristics can hardly do any justice. An alternative could be to design several plug types and select the right one to match the system characteristic, but fortunately with the advancement of technology better and easier options are possible.

Control Loop

The basic elements of a closed loop control system are

1. A sensor that measures the condition of the process or factor affecting the process
2. A controller that decides whether or not the process or factor affecting process condition is acceptable
3. An actuator that operates the controlled device
4. Controlled device or valve that applies a corrective action to the process
5. The process to be controlled

A sensor is used to convert a measured variable to a signal used by the controller. A controller compares this value to a preset value, set-point, and produces an output proportional to the difference between the two and sends it to an actuator/controlled device to change the process parameters so as to bring the process back to within the designed parameters.

Note the phrase "an output proportional to the difference" in the above definition; this has been in use for decades and needs to be rewritten. Most of the controllers, including DDC, even today use proportional control algorithms. When controls were mechanical, pneumatic or electrical this was the only choice as it was difficult to implement a more advanced algorithm and this trend has continued, because it is proven, is easy to understand and does not require any changes to be made to existing systems.

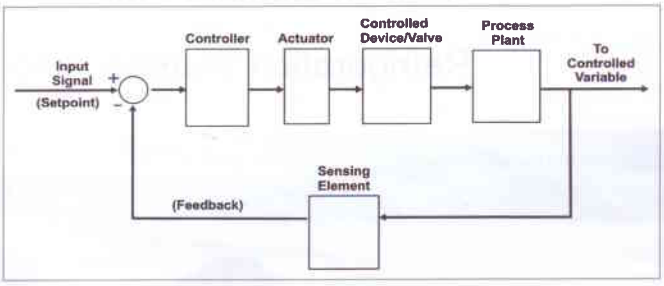

Figure 5 : Block diagram of a Control Loop

In proportional control each of the control loop elements like sensor, controller and actuator is selected to give output proportional to the change in load or measured variable. It was difficult to achieve and control non-linear outputs from the mechanical, pneumatic or electric controls, therefore, all the non-linearity required by the control loop was built in to the valve plug, valve characteristics were matched to the system load characteristics, and thus valve flow control characteristics became important.

But in today's world, nonlinearities are best left to the microprocessor based controllers. These controllers can easily be programmed, using mathematical equations or look-up tables, to give output to match system nonlinearities, making it imperative to rewrite the definition of controller, by replacing the word 'proportional' with the word 'manipulate', as under:

Based on the difference between the sensor input and the set-point, a controller manipulates the output to the actuator/controlled device to change the process parameters, so as to bring the process back to within the designed parameters.

With the availability of linear as-well-as non-linear outputs from the controller it is possible to change the valve flow characteristics by manipulating the valve stroke, or plug travel, instead of changing the plug shape and, therefore, it is much more sensible to take the burden of matching the flow rate to the system requirement off the valve trim and pass it to the controller.

Conclusion

To conclude, system characteristics may be linear or non-linear and may also vary from one load condition to another. Choosing valve plug to match system characteristic is only approximate, is plug design based, and not many variations are practical, whereas a controller's algorithm can be designed to match the system characteristic more accurately, can be changed at site, and most importantly can even be programmed to match changing system characteristics at different load conditions. ❖