

PART I: AN INSIDER'S GUIDE to Valve Sizing & Selection

The effect of control valve flow characteristics and valve sizing on controllability

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Editor's Note: This is Part I in a four-part series on key aspects of valve sizing and selection.

When selecting a control valve for a process, there are many things that must be considered, including the valve's flow characteristic, its size, noise, potential for cavitation or flashing damage, body and trim materials, actuator size and type, and its dynamic response to changes in the control signal. This article discusses the importance of selecting the correct flow characteristic and correctly sizing the valve in order for the valve to properly control the process.

Flow Characteristics

The discussion begins with control valve flow characteristics (the relationship between valve opening and flow). Actually, a control valve has two characteristics—an *inherent characteristic* and an *installed characteristic*.

The inherent characteristic of a valve is the characteristic published by the manufacturer, based on tests performed in a system where great care is taken to ensure that the pressure drop across the test valve is held constant at all valve openings and flow rates. The inherent characteristic, therefore, represents the relationship between valve flow capacity and valve opening when there are no system effects involved. Figure 1 shows the ideal inherent characteristics of the two most common flow characteristics, the linear and equal percentage. The source of the name of the linear characteristic is self-evident from the graph.

The name of the equal percentage characteristic comes from the definition: "Equal changes in valve position

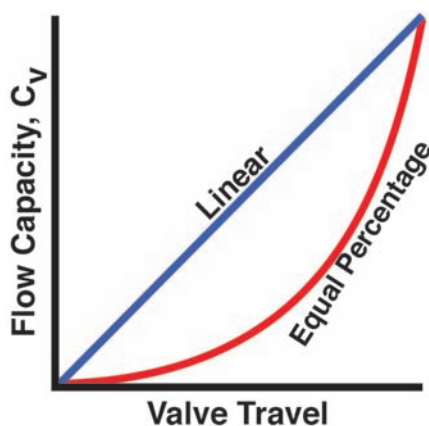


Figure 1. Linear and equal percentage inherent characteristics

cause equal percentage changes in flow." The result, as shown in Figure 1, is a characteristic where a small increment of valve position at small openings results in a small increase in flow capacity, while the same increment of valve position at large openings results in a larger increase in flow capacity.

Most control systems give the best performance when they behave in a

linear manner. In light of this fact, the question might be asked, "Why would you use an equal percentage valve which is not at all linear?" The answer is because of the *installed characteristic*. The installed characteristic is the relationship between valve position and flow in the specific system being considered, taking into account any changes in the pressure differential available to the control valve due to the flow squared relationship between flow and piping pressure losses and/or the behavior of a centrifugal pump's head curve.

The majority of fluid process systems include a significant amount of pipe and other pressure-consuming elements (elbows, pipe reducers, isolation

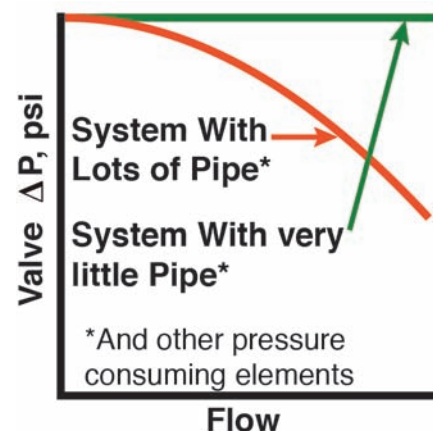


Figure 2. Valve pressure drop vs. flow

valves, heat exchangers, pumps whose pressure decreases with increasing flow,

etc.). This results in a relationship between system flow and pressure differential available to the control valve similar to the lower curve of Figure 2.

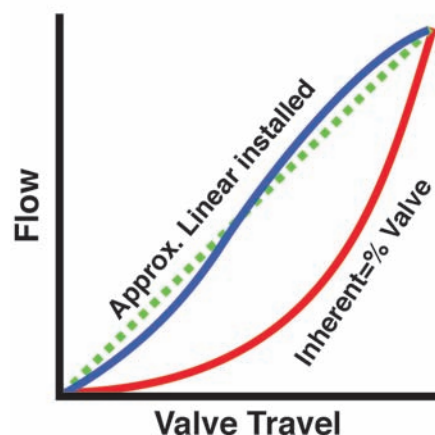


Figure 3. Installed characteristic of an equal percentage valve in the system with lots of pipe and other pressure-consuming elements of Figure 2

While referring to Figure 3, one must imagine a control valve with an inherent equal percentage characteristic installed in a system that has a characteristic like the lower curve of Figure 2. When the control valve is wide open, the flow will be at its maximum value. Moving the control valve in the closing direction of course causes the flow to decrease. As soon as the flow starts to decrease, it can be seen from Figure 2 that the pressure differential across the valve increases, resisting the decrease in flow through the valve. The result of this interaction between control valve and system produces a nearly linear installed characteristic and thus the popularity of the equal percentage flow characteristic and the fact that equal percentage valves are specified about 90 percent of the time. Because the equal percentage curve and the pressure drop curve are not exact mirror images of each other, the installed characteristic of an equal percentage valve in a system with a lot of pipe is not perfectly linear, but has a slight “S” shape as shown in Figure 3. Sometimes it will not be as symmetrical as shown. As a general rule, systems with a significant amount of pipe and/or other pressure-consuming

elements (the most common case) are best suited to equal percentage inherent characteristic valves.

When a control valve is installed in a system with very little pipe and/or other pressure-consuming elements, the pressure differential across the valve remains constant, or nearly constant, with changes in flow as shown in the upper graph of Figure 2. The situation is similar to the way valve manufacturers determine the inherent characteristics of their valves. Since the pressure differential across the valve remains constant with changes in flow, the installed characteristic will be the same as the valve’s inherent characteristic. In the case of a system where the pressure drop across the control valve remains constant with changes in flow, a valve with a linear inherent characteristic will

be linear. Upon start up of this system, if it was running at a low process load, the valve was around 25 percent open (Point 1) and after going through the process of tuning a PID controller, one can see that the slope of the valve’s installed characteristic curve is quite shallow, meaning that the valve’s gain (or the sensitivity of flow to changes in valve position) is quite low. To make up for this, the proportional gain of the controller would need to be set fairly high. As expected, when one makes a step change in the set point, there is a quick and stable response. Later, when the process load has increased, the valve might be around 50 percent open (Point 2). At this point, the slope of the valve’s installed characteristic curve (its gain) is higher meaning that the value of controller proportional gain previ-

“In the case of a system where the pressure drop across the control valve remains constant with changes in flow, a valve with a linear inherent characteristic will also have a linear installed flow characteristic.”

also have a linear installed flow characteristic. As a general rule, systems without a significant amount of pipe and/or other pressure-consuming elements are best suited to linear inherent characteristic valves.

The symptom of a misapplied control valve flow characteristic is a control loop that only gives good control at one end of its operating range and is either sluggish or becomes unstable at the other end of its operating range. An example of a misapplied valve inherent flow characteristic would be an equal percentage valve in a system with very little piping. The left-hand graph of Figure 4 shows the resulting non-linear (equal percentage) installed flow characteristic, which is very unde-

ously selected is higher than it should be when the valve is 50 percent open. When the set point is stepped up from the current 50 percent position there is an oscillatory response. When the process load increases to where the valve is around 75 percent open (Point 3) the slope of the valve’s installed characteristic curve is quite steep, meaning

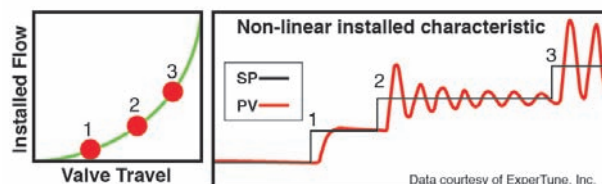


Figure 4. The non-linear installed flow characteristic caused by a misapplied inherent control valve flow characteristic yields a system that cannot maintain proper controller tuning throughout the entire flow range.

that the valve’s flow gain is quite high. The value of controller gain originally selected when the valve was 25 per-

cent open is now much too high, and when the set point again is stepped up there is a very unstable response. If the loop were instead tuned when the control valve was 75 percent open, a lower value of proportional gain would have been used, and there would be a fast, stable response to a step change in set point. However, if operated at lower loads, the response would be very sluggish.

If one had misapplied a linear valve in a system with a lot of pipe, the situation would be the opposite of what is shown in Figure 4. Just as the system with a lot of pipe pushes the equal percentage inherent characteristic upward into a linear installed characteristic, it would push a linear inherent characteristic upward into a quick-opening characteristic. With a quick-opening characteristic, a small increment of valve position at small openings results in a large increase in flow capacity, while the same increment of valve position at large openings results in a small increase in flow capacity. This system would be very sensitive at low valve openings and very insensitive at large openings. The system would still be difficult or impossible to tune so as to get fast stable response throughout the flow range.

On the other hand, a properly applied control valve inherent characteristic (an equal percentage valve in a system with a lot of pipe, or a linear valve in a system with little pipe) results in a linear, or at least nearly linear installed characteristic, as shown in the left-hand graph of Figure 5. A linear installed characteristic gives responsive and stable control throughout the entire flow range. This properly applied valve's installed flow characteristic has a slope (and sensitivity of flow to changes in valve position, that is, its flow gain) that is quite constant throughout the entire flow range. Regardless of what the operating point was during the controller tuning process, the PID tuning parameters selected would be appropriate at all points in the operating range.

Proper Sizing

Next, it's important to understand the importance of proper control valve sizing. If the right size valve is not selected, there are two possibilities: (1) The

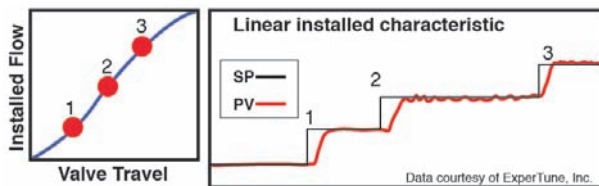


Figure 5. The linear or nearly linear installed flow characteristic that results from a properly applied inherent control valve flow characteristic gives good control with stability throughout the control range.

valve may too small. If it is, it won't be able to pass the required flow. In actual practice, undersized valves are fairly uncommon; (2) The valve may be too large, which turns out to be all too common. An oversized control valve will cost more than is necessary, although that is only a minor point compared to the real problem. The real problem with an oversized valve is that it will be very sensitive, meaning small changes in valve position will cause large changes in flow. This will make it difficult, or even impossible, for it to adjust exactly to the required flow.

Figure 6 shows graphs of the installed characteristics of two different valves in the same system. These are both segment ball valves, which have equal percentage inherent characteristics, and the system has a lot of pipe. Note that up to the specified maximum flow rate of 550 GPM both have reasonable linear installed characteristics. The 3" valve is a properly sized valve and the 6" valve is an oversized valve. The reason that the 3" valve is a properly sized valve is because it meets the criterion

of the rule of thumb of being between 60 percent and 80 percent open at the maximum required flow of 550 GPM. This rule of thumb has served valve us-

ers well because it gives a good balance between using as much of the valve's control range as possible, giving good flow resolution, while providing adequate safety factor. (The 3" valve can increase flow about 20 percent above 550 GPM which should be adequate, while the 6" valve can increase the flow about 60 percent above 550 GPM, which is more than should ever be required.)

Starting at 550 GPM, if the properly sized valve opens by 1 percentage point the flow will increase by 8 GPM. If the oversized valve opens by 1 percentage point the flow will increase by 20 GPM.

All valves exhibit a certain amount of stickiness. After a valve has been in service for a long time, especially if someone has been a little overzealous in adjusting the packing, it is not unusual to find that the smallest increment that the valve can move is 1 percent. If the best each of these valves can do is position themselves in 1 percent increments, the 3" valve will be able to control flow within 8 GPM increments, and the 6" valve will only be able to control flow within 20 GPM increments. In general, the more oversized a control valve is, the poorer the accuracy of control will be.

Although not always possible, it is

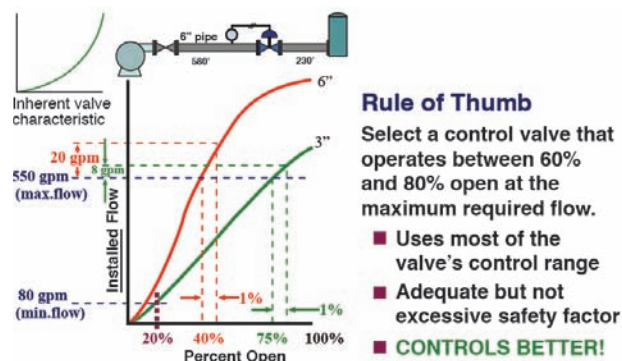


Figure 6. Comparison of a properly sized control valve and an oversized control valve

also preferable to have the minimum opening no less than 20 percent to provide some safety factor at the low end. Normally, control valve manufacturers

publish Cv values in 10 percent increments beginning at 10 percent open, so it's impossible to know what happens to the Cv below that point. It is also not uncommon for the inherent characteristic to start deviating from the ideal somewhere below 20 percent open.

“Although not always possible, it is also preferable to have the minimum opening no less than 20 percent to provide some safety factor at the low end.”

It is not unusual to find properly sized full-ball, segment-ball and high-performance butterfly valves that are two sizes smaller than the line and properly sized globe valves that are one size smaller than the line. This is not a rule, but just the way things often turn

out. If a valve is sized, and it turns out to be different than these, it is a good idea to check the work. A mistake may have been made. Additionally, the person who sized the pipe may have made a mistake.

Most people consider it poor piping practice to use a control valve that is less than one half the line size or larger than the line size.

Here are some points to remember:

- If a set of loop-tuning parameters only works at one end of the control range and not the other, the valve's flow characteristic is most likely the wrong one
- If a system has a lot of pipe and/or other pressure consuming elements, or a pressure source that decreases with increasing flow, an equal percentage valve will usually be the best choice
- If a system has very little pipe and/or other pressure-consuming elements and has a pressure source that doesn't decrease with increasing flow, a linear valve will usually be the best choice
- A control valve that is sized to operate around 60 percent to 80 percent

open at the maximum required flow and not much less than 20 percent open at the minimum required flow will give the best control

➤ Oversized control valves are very common **FC**



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