Guided Exercise for Control Valve Sizing

This module shows how the choice of control valve size, trim type, and pumping affects flow characteristics.

Some Background: A control valve is used to adjust a flow rate according to the signal (usually pneumatic) sent by the controller. It is best that the relationship between the controller's command signal and the final achieved flow rate be as predictable and *linear* as possible. Usually, the command signal is converted to a pressure signal, which translates into an opening (inside the valve) of the corresponding size and affects the flow rate. The way the pressure signal affects the valve opening is mechanical in nature and can be highly non-ideal with problems like sticking and hysteresis. This problem is often handled by a *valve positioner*, a mechanism found inside most control valves, which monitors the current valve stem position and keeps adjusting the air signal until it is indeed at the position corresponding to the controller's command signal. Hence, we will focus here on the relationship between the valve opening and flow rate. This relationship, referred to as *installed valve characteristics*, is affected by many things like the valve size, trim type and the total pressure drop created by pumping.

In the module, it is assumed that the controller's command signal *4-20 mA* gets converted into a pressure signal of *3-15 psig* through I/P transformer and then this air signal is translated linearly into the valve opening of *0-100%*.

Lesson: Linear type valve trim does not result in a linear relationship between the valve opening and the flow rate, once installed.

1. First, note that the total pump discharge is simply the sum of the pressure drop across the process and that across the valve.

$$\Delta P_{total} = \Delta P_{process} + \Delta P_{valve}$$

$\Delta P_{process}$ is the pressure drop across the process and is measured to be *37 psi* at the nominal flow rate of *50 l/min*. Since the pressure drop is proportional to the square of flow rate, we can conclude

$$\Delta P_{process} = kq^2 = 37\left(\frac{q}{50}\right)^2 \quad \Rightarrow \quad \Delta P_{valve} = \Delta P_{total} - 37\left(\frac{q}{50}\right)^2$$

$$q = C_v f(\ell)\sqrt{\frac{\Delta P_{total} - 37\left(\frac{q}{50}\right)^2}{g_s}} \qquad f(\ell) = \begin{cases} \ell & \text{linear} \\ \sqrt{\ell} & \text{quick-opening} \\ R^{\ell-1} & \text{equal percentage} \end{cases}$$

Notice that the above is an implicit equation for q because the pressure drop changes with the flow rate.

The initial setting is given as Linear trim type, vale size of $C_v=40\ (l/min)/(psi)^{0.5}$ and pumping of $\Delta P_{total}=40$. Calculate the flow rate when the valve is half-open using the above equation and verify your calculation by setting the command signal at *12 mA* (corresponding to *50%* open). Next, calculate the flow rate when the valve is fully open. If the linear relationship holds between the command signal and the flow rate, the flow rate should double. You will see that it is far below twice of the first flow rate. In fact, we observe a very strong nonlinear relationship from the characteristic curve plotted (in red). Why do you think this happens despite the fact that we have the linear type of valve?

Lesson: The Equal Percentage type valve trim results in a more linear relationship between the valve opening and the flow rate, once installed.

2. Select the Equal Percentage valve trim clicking on it in the right-middle figure and choose valve characteristic as '*Installed*' in '*Implementation*' tab. Note the initial setting of $R=40$. Calculate the flow rate when the valve is half-open using the above equation and verify your calculation by setting the command signal at *12 mA* (corresponding to *50%* open). Next, calculate the flow rate when the valve is fully open. Is it approximately double the flow rate at the half-open position? Notice the characteristic curve (in blue) is much linear. Why do you think this is despite the fact that the expression involved is much more nonlinear? (You can look at the inherent characteristic of the valve – with constant ΔP_{valve} – by changing the '*Valve characteristic*' setting from '*Installed*' to '*Inherent*'.)

Lesson: The maximum flow rate can be increased by increasing the pumping (which increases the total pressure drop) or increasing the valve size. It is an iterative process to find a right combination. (Valve characteristic' setting should be 'Installed' mode.)

3. Notice that the current setting does not give the desired maximum flow rate, which is *50 l/min*. Keep the command signal at the maximum value of *20 mA*. Let's first increase the valve size (C_v). Notice that the flow rate does increase but very slowly and saturate. Make it really large (*~1000*) and see what the maximum flow rate you get is. You are still not much different from *50 l/min*. This means we definitely do not have enough pumping. We will now try to come up with a design that gives *50 l/min* maximum capacity.

   Set the '*Valve coeff.*' as *60* (a first guess) in the table of '*Control valve*' tab. Adjust the pump discharge until the maximum flow rate is about *50 l/min*. What is the pump discharge needed? Now adjust the command signal so that the flow rate is about *40 l/min* (the nominal flow rate).

   Read from the schematic diagram $\Delta P_{process}$ and ΔP_{valve} at the nominal flow rate. We learned that we want ΔP_{valve} to be about 1/3 of the total pump discharge. You will see that ΔP_{valve} is too large. This means the current valve size is a bit too small. Let's increase the valve size to *70*. Now, adjust the pumping again so that the maximum flow rate is about *50 l/min*. Again, bring the flow rate back to *~40 l/min* and see what the pressure drop distribution is like. Is ΔP_{valve} to be about ~1/3 of ΔP_{total}? Now adjust the *R* value of the Equal Percentage valve so that the curve is as linear as possible over the operating range. What is the *R* value you chose?

Lesson: The valve positioner helps reduce the bad effects such as sticking and hysteresis.

4. Notice that the current setting for '*Valve positioner*' in '*Implementation*' tab is checked which means hysteresis is removed by the valve positioner. However. If you uncheck the checkbox, it will turn off the valve positioner. Then you should observe that the valve doesn't respond for a small change and then jumps. This kind of nonlinear behavior is highly undesirable from the viewpoint of control.

   Again, check the '*Valve positioner*'. Then slowly change the command signal again. Move the command signal slowly and see that the valve position and the flow rate move smoothly with it. This is the effect of using valve positioner.

Lesson: Be clear whether you are using Air-To-Open or Air-To-Close type valve.

5. The current setting for '*Normal position*' in the '*Implementation*' tab is at '*Air-to-open (NC)*'. As the command signal increases, the flow rate should increase. Change the setting to '*Air-to-close (NO)*'. Notice how the relationship between the command signal and the flow rate gets reversed. Similar effect can be obtained by checking and unchecking the "*Inverted valve seat & plug*' checkbox.