Guided Exercise for DP cell transducer

This module shows how flow rate is measured and converted to signals that can be displayed and also read by the controller. Here the flow rate is measured by an orifice meter, which in fact measures the pressure drop across an opening. The module demonstrates the importance of sizing the orifice correctly in respect to the flow range and DP cell pressure drop range and also shows the tradeoff associated with noise filtering.

To begin, note that the flow rate Q gets measured as pressure drop ΔP, which then gets converted to current I and voltage V. The voltage reading conveys the flow rate information and can be displayed in percent (with respect to the total flow range) or in actual engineering unit for flow rate (Q_m). Start by changing the flow rate around by moving the blue arrow up and down in the right-upper widow and see how the various signals change accordingly.

Lesson: Physical property is converted into another physical variable and then various types of electric (or pneumatic) signals before it read in by the computer and is displayed in the operator console.

1. Examine how the flow rate is converted into pressure drop. The applicable equation (you learned in the transport course) is

$$Q = \frac{C_d A_2}{\sqrt{1-(A_2/A_1)^2}}\sqrt{\frac{2g_c\Delta P}{\rho}} \quad \rightarrow \quad Q = C_v\sqrt{\Delta P}$$

   where A_2 is the cross-sectional area for the orifice and A_1 the cross-sectional area for the pipe. C_d is the friction coefficient, which is about 0.6 in most cases. We can lump all the constants into one term C_v, which here is assumed to be 5.0 *liter/min* $(kPa)^{-1/2}$. Hence, the conversion equation is

$$Q = 5.0\sqrt{\Delta P} \quad \rightarrow \quad \Delta P = \left(\frac{Q}{5.0}\right)^2$$

   Check whether this calibration equation is correct by comparing the readings of Q and ΔP at various values. For example, at $Q=25.0$, should read as $\Delta P = 25$ *kPa*.

2. Check on the 'Show individual display' in the 'Noise filter' tab to see the digital display of each component. Also, you should see a table in the 'Zero/Span' tab showing *Zero, Span, View min* and *View max* (*View min/max* are the values for display range in right-upper figure.) The circuit in the DP cell receives the pressure drop (0 to 100*kPa*) and convert to a current signal between 4-20 *mA*. Hence, the *Span* of DP cell (defined as the range of the input corresponding to the total range of the output signal) is *100 kPa*. *Zero*, which is the value of the input corresponding to the minimum value of the output (4 *mA*), is *0 kPa* in this case. Note that the '*Use SQRT Extractor in DP cell'* is checked in 'Orifice' tab. In this case, the conversion is done so that the signal is proportional to the square root of the pressure drop (and

therefore proportional to the flow rate). Hence, the conversion equation with the square root extraction is

$$I = 16\sqrt{\frac{\Delta P}{100}} + 4$$

Check at various flow rates whether this is indeed the conversion equation. For example, at *Q=25.0 liter/min, ΔP =25kPa* and therefore *I=12mA*.

Uncheck the *Square Root Extractor* and the conversion is done in the following manner:

$$I = 16\frac{\Delta P}{100} + 4$$

Check again at various flow rates that this is indeed the conversion equation when the *Square Root Extractor* is turned off. For example, at *Q=25.0 liter/min, ΔP =25kPa* and therefore *I=8mA*. However, in this case, the current signal no longer changes linearly with respect to the flow rate.

3. If you see the '*I/V transm'* row in the table, this row simply converts the current signal (*4-20 mA*) to a voltage signal (1-5V) in a linear manner. Hence, the conversion equation is simply

$$V = 4\frac{(I-4)}{16} + 1$$

The *Span* is *16 mA* (since *4-20 mA* corresponds to the full output range) and the *Zero* (the input value corresponding to the minimum output reading of *1V*) is *4 mA*. Make sure the above conversion equation is valid by comparing the values of *V* and *I* at various flow rates.

4. With '*Noise Filter'* tab, you can see the filtering effect. This filter does not convert one type of signal to another. Instead, its function is to filter out noise. The main parameter you input here is the filter time constant. The larger, the more filtering it will do. We will explore the role of filtering in depth later.

5. If you see the '*% Reading'* row in the table, this row simply converts the voltage signal to % reading. This element simply converts the voltage signal (*1-5V*) to a percent signal (0-100%) in a linear manner. Hence, the conversion equation is

$$\%Reading = 100\frac{(V-1)}{4}$$

Hence, the *Span* is 4 V (since *1-5 V* corresponds to the full output range) and the *Zero* (the input corresponding to the minimum output reading of 0%) is *1 V*.

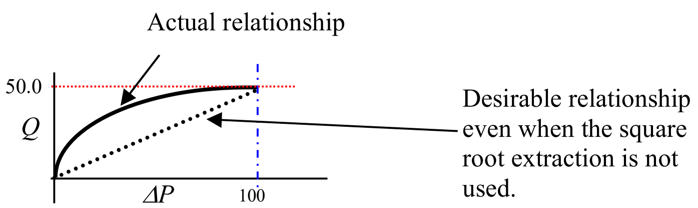
6. Finally, if you see the '*Measured Flow'* row in the table. This element simply converts the flow rate displayed in percent (0-100%) to its engineering unit (*liter/min*). The applicable conversion equation is

$$Q_m = 50.0\frac{\%Reading}{100}$$

Hence, the *Span* is 100% and the *Zero* is 0%.

Lesson: With an orifice meter, Square Root Extraction is needed to construct a signal that is proportional to the flow rate.

1. In the '*Orifice'* tab, you can turn off the *square root extractor*. As explained before, now the electric signals are proportional to the pressure drop ΔP and therefore Q^2. The situation can be depicted as below.



As we can see below, by converting ΔP signal linearly into flow rate without the square root extraction, the final reading will be accurate only at the zero-flow rate and the maximum flow rate. In the middle, the reading will underestimate the actual flow rate. See that this is true by setting the flow rate at various values and comparing them with the final readings.

Lesson: Size of Orifice should be determined correctly in respect to the range of flow rate and the range of pressure drop measured by the DP cell. (SQRT extractor on)

1. Change to 'Orifice' tab. Currently, the *Orifice Size* is set as "Normal". Note that the DP Cell's range is *0-100 kPa*. With the orifice size of $C_v=5.0$, this corresponds to the intended flow range of *0-50.0 liter/min*.

2. Change the *Orifice Size* setting as "Under-sized". Note that C_v changes to 4.2 with this setting. With the smaller opening, we have more pressure drop. Hence, the range of flow rate we can measure will be less than before. In fact, we can easily calculate that the maximum flow rate (corresponding to $\Delta P=100$ *kPa*) is only *42.0 liter/min*. See that as we change the flow rate slowly from 0 to 42.0, all readings 'saturate' at $Q=42.0$ *liter/min* and do not change further. Also, notice that the final reading gives an error. This is because the span of the *DP Cell (P/I)* is incorrectly set. Adjust the span appropriately and see that the final reading indeed matches

the actual flow rate up to *42.0 liter/min*. However, any flow rate beyond *42.0 liter/min* will be read as *42.0 liter/min*.

3. Change the *Orifice Size* setting to "*Over-sized*". Note that C_v changes to 5.8 with this setting. With the larger opening, we have less pressure drop. Hence, the range of flow rate we can measure will be larger than *0-50.0 liter/min*. In fact, calculate that the maximum flow rate we can measure (corresponding to $\Delta P=100kPa$) is *58.0 liter/min*. Note that as we change the flow rate to the maximum of *50.0 liter/min*, the readings reach only 86.2% of their full range. That means we are not taking full advantage of the signal range available to us. Hence, we would be losing sensitivity of the signals to flow rate changes unnecessarily. If you make the orifice size extremely large, you can imagine that the pressure drop will become virtually insensitive to flow rate changes, and we won't be able to get any reading. Also, notice that the final reading gives an error. This is because the span of the *DP Cell (P/I)* is incorrectly set. Adjust the span appropriately and see that the final reading indeed matches the actual flow rate up to *50.0 liter/min*.

Lesson: Noise filtering makes the final reading less sensitive to noise but increases the response time to changes in the flow rate.

1. Reset the *Orifice Size* back to "*Normal*". Make the *Process Noise* setting from "*None*" to "1%" and observe by clicking "*Start'* button. Do the same for the settings of "5%" and "10%". Observe how the signals are affected by noises at different levels. Obviously, with large process noise, the final reading fluctuates a lot despite that the actual flow rate is stationary. This presents a problem for control as the controller would respond to these fluctuations unnecessarily.

2. With the *Process Noise* setting at "10%", change the *Noise Filter* from "*None*" to "*Light*" and observe. Also try the settings of "*Medium*" and "*Heavy*". Observe that, with more filtering, the fluctuations in the final reading progressively diminish.

3. Change the *Noise Filter* back to "None" and change the flow rate from 25.0 to 50.0. Observe the fast response time. Change the flow rate back to 25.0. Now set the *Noise Filter* to "*Light*" and do the same. Do you notice that the response of the final reading has slowed down? Try the same with the *Noise Filter* set to "*Heavy*". You should definitely notice that the response has gotten extremely slow. Hence, filtering involves a tradeoff. With heavier filtering, you filter out more of harmful signals (noise) but you also lose some useful signals (actual change) and therefore increase the response time of the whole measurement device. (In fact, filters are often defined in terms of time constant, which are directly related to the response time of the filtered signal).