# Guided Exercise for Control Module#2

*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 $\Delta P$, 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 red arrow up and down 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 50 *liter/min* $(kPa)^{-1/2}$. Hence, the conversion equation is

$$Q = 50\sqrt{\Delta P} \quad \Rightarrow \quad \Delta P = \left(\frac{Q}{50}\right)^2$$

Check whether this calibration equation is correct by comparing the readings of $Q$ and $\Delta P$ at various values. For example, at $Q=250$, should read as $\Delta P = 25kPa$.

2. Click on the reading display box for *DP Cell (P/I)*. The *Control Panel for DP Cell (PI)* should appear in the lower right corner of the screen. You should see various sub-boxes like *Input Range*, *Output Range*, *Span*, and *Zero*. The circuit in the cell coverts the pressure drop (0 to 100kPa) to a current signal between 4-20 mA. Hence, the *Span* (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 (4mA), is 0 *kPa* in this case.

Note that the *Square Root Extractor* sign is on (lighted in green). 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=250 liter/min,* $\Delta P$ *=25kPa* and therefore *I=12mA.*

Turn off 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=250 liter/min,* $\Delta P$ *=25kPa* and therefore *I=8mA.* However, in this case, the current signal no longer changes linearly with respect to the flow rate.

3. Click on the reading box for *I/V Transformer.* The *Control Panel for I/V Transformer* should appear in the lower right corner of the screen. This box simply converts the current signal (4-20mA) 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. Click on the reading box for *Noise Filter.* This box 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. Click on the reading box for *% Indicator.* The *Control Panel for % Indicator* should appear in the lower right corner of the screen. This box simply converts the voltage signal (1-5V) to a percent signal (0-100%) in a linear manner. Hence, the conversion equation is

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

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*.

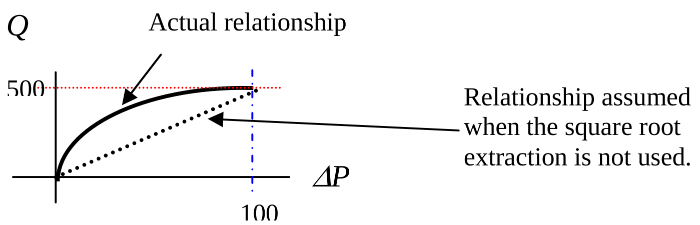
6. Finally, click on the reading box for *Flow Indicator*. The *Control Panel for Flow Indicator* should appear in the lower right corner of the screen. This box simply converts the flow rate displayed in percent (0-100%) to its engineering unit (*liter/min*). The applicable conversion equation is

$$Q_m = 500\frac{\%Indicator}{100}$$

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. Click on the reading box for *DP Cell (P/I).* In the control panel, turn off the *square root extractor*. As explained before, now the electric signals are proportional to the pressure drop $\Delta P$ and therefore $Q^2$. The situation can be depicted as below.




As we can see below, by converting $\Delta P$ 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.*

2. Click on the reading box for *DP Orifice.* Currently, the *Orifice Size* is set as "Fitted". Note that the DP Cell's range is 0-100 kPa. With the orifice size of $C_v$=50, this corresponds to the intended flow range of 0-500 liter/min.

3. Change the *Orifice Size* setting as “Smaller”.  Note that $C_v$ changes to 40 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 $\Delta P=100kPa$) is only *400 liter/min*.  See that as we change the flow rate slowly from 0 to 500, all readings ‘saturate’ at *Q=400 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 *400 liter/min*.  However, any flow rate beyond *400 liter/min* will be read as *400 liter/min*.

4. Change the *Orifice Size* setting to “Larger”.  Note that $C_v$ changes to 65 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 0-500 liter/min.  In fact, calculate that the maximum flow rate we can measure (corresponding to $\Delta P=100kPa$) is *650 liter/min*.  Note that as we change the flow rate to the maximum of *500 liter/min*, the readings reach only 76.9% 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 *500 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 “Fitted”.  Make the *Process Noise* setting from “None” to “Small (1%)” and observe.  Do the same for the settings of “Medium (5%)” and “Large (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 “Large”, 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 250 to 500.  Observe the fast response time.  Change the flow rate back to 250.  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).