PRODUCT APPLICATION REVIEW

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Combining Multi-Function Displays with Liquid FLO-SENSORS for Exceptional Accuracy

APPLICATION

A research & development laboratory requires a liquid flow system with extreme precision to monitor liquid flow rates in the 13 mL/minute up to 10 L/minute range.

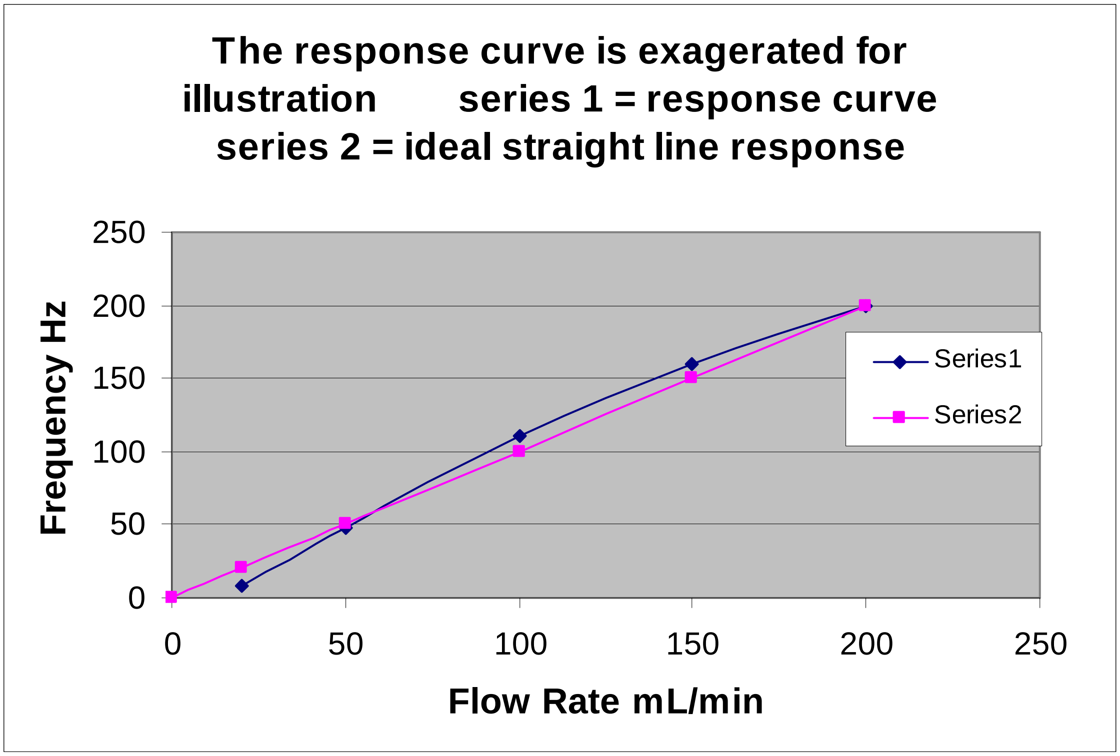
MCMILLAN PRODUCTS CONSIDERED

Any Model 10x Liquid FLO-SENSOR (101, 102, 104, 106, 108)
Model 220 Rate Meter/Totalizer or Model 25x Multi-Function Display (250, 251)

METHOD

This article describes a method of obtaining linearity better than ±0.5% of full scale (FS) for McMillan Liquid FLO-SENSORS with pulse output, or a combination of analog and pulse output. Generally, the pulse output specifications are ±3% FS. Analog outputs are typically ±1% FS. It is reasonable to expect accuracy as good as ±0.3% FS because of the excellent repeatability of ±.2% FS. However, a steady, repeatable reading requires that the flow be free of pulsations and the FLO-SENSOR not be damaged in any way.

If a multi-function display is used such as the Model 250 or 251, or a data acquisition system with multi point correction, then linearization and accuracy has already been accomplished. Accuracy can be ±0.5% or ±0.3% FS depending on the method of calibration. For a user with a simpler rate meter or frequency meter, an alternate method can give a significant improvement in accuracy. The data sheet supplied with the FLO-SENSOR documents three or four data points, each point giving a frequency for a corresponding flow. This response is nearly linear but not perfect due to friction in the sensor of water molecules, bearings, and viscosity effects which cannot be eliminated entirely. This results in a response curve that deviates somewhat from an ideal, straight-line response and is usually linear to ±1% FS best-fit straight line that does not cross through zero, but it is repeatable (see Figure 1). So, if the FLO-SENSOR is repeatable to ±0.2% FS, and the data sheet gives 3 or 4 points of frequency vs. flow, then the stated ±3% FS pulse accuracy can be narrowed to at least ±0.5% FS or better.



EXAMPLE

Assuming that the response is repeatable at all points, then the frequency output should be repeatable to ±0.2% FS at any flow. If a full scale frequency is 200 Hz, and the full scale flow is 200 mL/min, then the scaling is:

200mL / 200Hz = 1mL / 1 Hz.

If the frequency is 190Hz, then flow is:

190Hz x 1 mL / Hz = 190 mL / min.

…Or is it?

Taking the data from a typical 101-5T flow sensor pulled from the records, the recorded data of flow vs. frequency is as follows:

Flow	Frequency (Hz)	Error	Slope mL/Hz
500 mL/min	383	0	1.305
250	195	+0.91%	1.282
100	78	+0.37%	1.282
50	37	-0.34%	1.351

The fourth column is added to indicate the changing response of the flow (slope of the curve, Flow / Frequency) at each data point. If the slope is taken at full scale and applied as a factor to the frequency obtained at various flow rates, it can be seen that there will be error for flow rates at other than full scale. For example, the slope at full scale is 1.305 mL/Hz. Using that ratio to calculate the flow at a frequency of 195 Hz will be

195 x 1.305 = 254.48 mL/min.

That is an error of 0.90% as calculated by flow. The actual flow at 195 Hz is 250mL.

254.48 – 250 / 500 x 100 = 0.90%

Using this full scale ratio applied against the frequency of any flow in a simple rate meter will give an indication of flow rates within the ±3% rating. We can use each data point with its own slope value but that would improve accuracy only at that data point and error would increase at flow rates between those points. If we have an indicated frequency of 200Hz, for example, what is the flow?

FIRST SOLUTION

We can calculate by the following method:

The error at 195 Hz is +0.91%. This is close to 200 Hz so the slope of the curve at 195 and at 200 Hz will be nearly identical.

383Hz X 0.91% = 4.55Hz (to calculate error in Hz at 195 Hz)

So taking the full scale factor of

1.305 X 200 mL = 261.00mL.

Subtracting the error gives:

261.00 mL – 4.55mL = **256.45 mL/min**

The offset of 4.55 mL was subtracted from the flow rate because the error at 250 mL was positive. Notice that if the frequency would be near the middle of the data points, the actual error would be different.

SECOND SOLUTION

Find the 2 data points nearest to 200 Hz and use those data points of 500mL/minute at 383 Hz and 250mL/minute at195Hz.

(500 – 250 mL) ÷ (383 – 195Hz) = **1.330** mL/Hz (slope)

200 – 195 Hz = **5 Hz** (frequency above lower point)

5 x **1.330** = **6.65 mL**

6.65 mL + 250.00 mL = **256.65 mL/min**

THIRD SOLUTION

Another method is proposed that will allow relatively easy calculation of flow at any indicated frequency, utilizing the chart and trend functions of Microsoft EXCEL program.

STEPS (see chart below for example)

1. Access the EXCEL program
2. Enter the data from the flow sensor data sheet with the frequency in column A and flow rates in column B.
3. Choose > Chart Wizard

   XY (scatter)

   chart sub-type = curved lines connecting dots

   Finish
4. Chart will be displayed:

   Right click on trend line

   Add trend line

   Polynomial (2nd order)

   Options: check box "display equation on chart"

   OK

The equation for the curve is displayed near top of the chart.

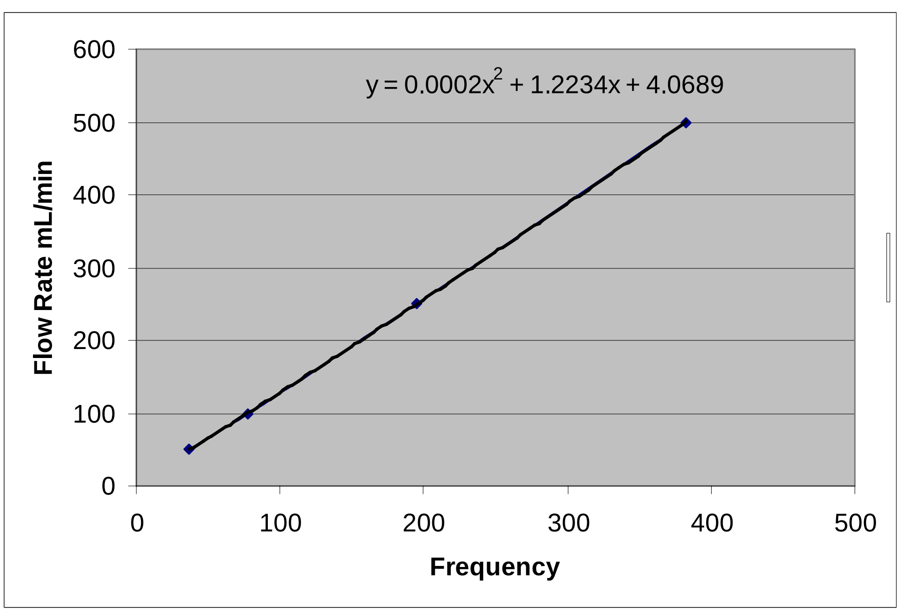
The equation developed from the previous data is:

$$y = 0.0002x^2 + 1.2334x + 4.0689$$

Where y = desired flow rate, x = frequency

$$y = (0.0002 \times 200^2) + (1.2234 \times 200) + 4.0689$$

$$= \quad 8.00 \quad + \quad 244.68 \quad + \quad 4.07 \quad = \quad 256.75 \text{ mL/min}$$



CONCLUSION

It would take careful actual flow measurements to determine the true flow rate but as seen, the 3 methods differ by a maximum of 0.30 mL/min or 0.06% of full scale.

Due to the limitations of each of these methods to absolutely predict the actual flow rate because of the small vagaries of the response curve, maximum limits of error will be the ±0.2% repeatability of the sensor plus the difference between the value generated by the equation and the actual flow rate that generally would not exceed ±0.1%. Be aware of the sign of the components of the particular equation, whether they are + or -.

Methods of obtaining accuracy:

GOOD
A system that will give an accuracy of ±3% FScan be a flow sensor with a Model 220 display or pulse output to a data acquisition system scaled for the full scale mL/Hz ratio.

BETTER
A system with an accuracy of ±0.3 to 0.4% FS can be achieved by using a frequency counter (such as the Model 220 programmed for Hz /sec.) and performing the hand calculations previously described. This can be useful if ±3% accuracy is sufficient for most if the time but occasional higher accuracy is needed.

BEST
A system with an accuracy near the ±0.2% FS spec can be achieved with the Model 251 Multi-Function Display programmed with up to 9 data points directly from flow rates at those points. The error between the multiple adjacent data points will not be significant. It is recommended that this system be calibrated at the factory to achieve multipoint generated accuracy. A Model 251 calibrated for the 3 or 4 data points listed on the data sheet can be expected to be accurate to ±0.5% FS. A Model 251 Display can be added at any time by programming the Model 251 for the 3 or 4 data points and then hooking up the display to the FLO-SENSOR. There is also the option of a linearized analog output and relay outputs for alarms and process control.

Note: A Model 250 Multi-Function Display calibrated against the analog response of a FLO-SENSOR is also a viable option.

A McMillan microturbine Liquid FLO-SENSOR combined with a Model 251 Multi-Function Display will give an accurate, reliable system at a very competitive price.

NOTES

The above information is derived from data from a typical flow sensor response calibrated for DI water. Absolute accuracies are not guaranteed due to differences in characteristics of different liquids and other influences that cannot be accounted for here. However the above methods will improve the accuracy of data as applied to the output generated by the flow sensor.

For more information on the excellent repeatability, reliability, and long life of the McMillan pelton wheel flow sensors, see the article *Turbine Flow Sensors….The Best Choice For Liquid Flow Measurement,* by R.D. McMillan.