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Micro Motion Pressure Drop Testing

MICRO MOTION

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Introduction

Micro Motion has traditionally taken a very conservative approach to pressure drop, with single pressure measurements up- and downstream of the Unit Under Test (UUT). There are two issues with this:

1. Any asymmetric flow profile on the inlet side or outlet side is unquantified and can create large errors.
2. Pipe pressure loss is included in the meter loss. Depending on where the pressure taps are, this error can be large or small.

To minimize errors associated with no. 1 above, it's common to place the taps approximately 10D along the length of the pipe away from the last disturbance. There is still no quantification of whether asymmetric flow is occurring at either tap, and it almost by definition includes a significant amount of pipe-length pressure loss in the measurement. This paper describes a methodology to:

- Quantify the extent of any asymmetry
- Measure and subtract the pipe pressure loss for a precise pressure loss between the flanges.

Baseline Equation

Micro Motion pressure drop on all products is predicted by the Darcy-Weisbach equation[1]:

$$h_L = \frac{fL}{D}\frac{V^2}{2g} \qquad [1]$$

Where:

$h_L = \text{head loss}$

$\frac{fL}{D} = \frac{(\text{friction factor})(\text{length})}{\text{diameter}}$

$V = \text{velocity}$

$g = \text{gravity}$

$\rho = \text{mass density (usually simply referred to as density)}$

$\gamma = \text{weight density}$

Note "f" is the Darcy Friction Factor.

Pressure drop is equal to the head loss scaled by the fluid weight density:

$$dP = \gamma \frac{fL}{D}\frac{V^2}{2g} \qquad [2]$$

Weight density is related to density by:

$$\rho = \frac{\gamma}{g} \qquad [3]$$

Substituting equation [3] into equation [2] results in:

$$dP = \rho \frac{fL}{D}\frac{V^2}{2} \qquad [4]$$

The only difficulty in using equation [4] is that the $\frac{fL}{D}$ term is not constant. At high Reynolds number, the term is asymptotic to a constant value, but at low Reynolds numbers, $\frac{fL}{D}$ increases. Micro Motion sizing tools (Product Advisor and ToolKit) break $\frac{fL}{D}$ into several components to make the curve-fit easier. This paper does not describe the curve-fit methodology.

A typical relationship between $\frac{fL}{D}$ and Reynolds number is shown in Figure 1.

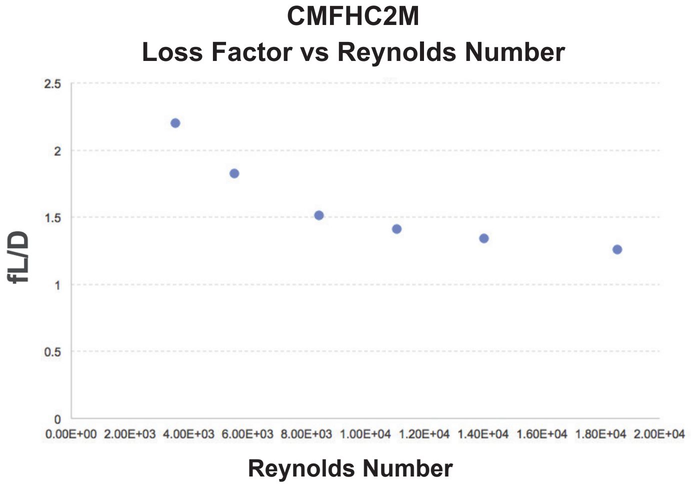

Figure 1 - $\frac{fL}{D}$ *(pressure loss factor) for a CMFHC2M vs. Reynolds Number*

Note that the loss factor is asymptotic to approximately a value of 1.25.

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[1] Fluid Mechanics, Ninth Edition, page 284. Streeter, Wylie & Bedford, 1998.

Reynolds number is defined as:

$$\mathrm{Re} = \frac{\rho D V}{\mu} \qquad [5]$$

Where:

$\rho = density$
$D = normalizing\ diameter\ (tube\ internal\ diameter)$
$\mu = viscosity$
$V = velocity$

The curve "$\frac{fL}{D}$ vs Re" must be monotonic; that is, the slope is trending toward the asymptote (zero slope) but it is always negative and cannot have an inflection and switch to be positive.

Baseline Equation

Significant errors can be made when measuring pressure drop due to swirl and asymmetric flow profile. Although this statement is always true, it's especially important to mitigate the effects of an asymmetric flow profile when the Reynolds number is high. This is true because disturbances that are introduced to the flow by elbows, bends, tees, etc. travel for many pipe diameters downstream. Physically, Reynolds number describes the ratio of the inertial forces to the drag (or viscous) forces. A high Reynolds number therefore depicts a flow that is dominated by inertial forces. Therefore, a disturbance introduced to the flow carries for a long distance down the pipe because there is no drag to "slow down" the disturbance.

Practical measures are common to ensure a good pressure drop measurement. They include:

- Long straight runs. In gas measurement it is common to require at least 10D. For precision orifice flow measurements 100D is sometimes required.
- Flow conditioning (plates, tube bundles, etc).
- Multiple pressure measurements radially around the diameter of the pipe, as shown in Figure 2. This helps ensure a good average pressure measurement; for instance, if the velocity is high on "top" of the pipe (due to swirl) and low on the "bottom" of the pipe, a pseudo-average measurement results when a radial manifold is used.
- Multiple pressure measurements along the length of the pipe, shown in Figures 2 & 3. This helps to visualize the integrity of the data. Refer to the following section.
- The pressure tap into the pipe should be small (1/8" diameter is typical) and should be de-burred inside the pipe.

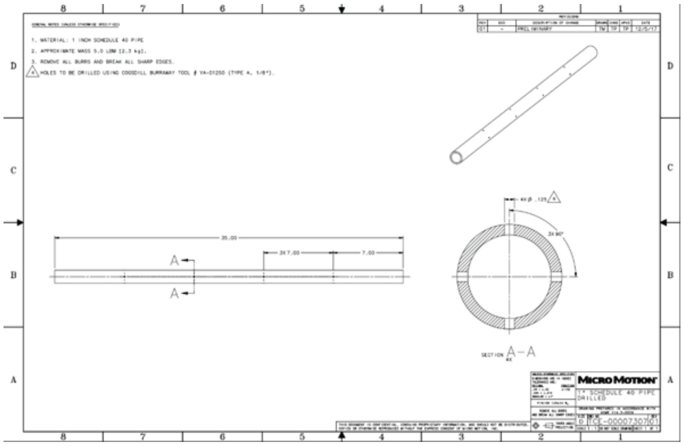


Figure 2a -- A pressure tap is made up of 4 radial pipe penetrations, 90° apart

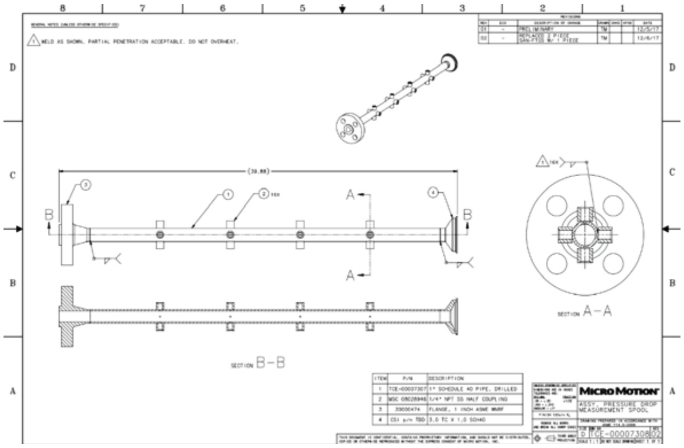


Figure 2b – Multiple taps make up the complete measurement

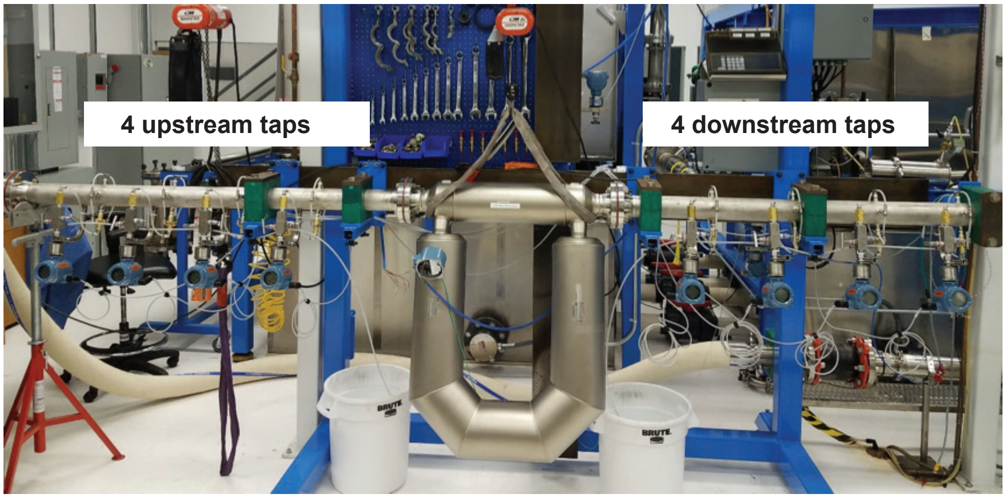


Figure 3 – 4 taps upstream, 4 taps downstream

Precision Pressure Drop Measurement

Figure 4 shows diagrammatically how pressure drop data should be distributed along the pipe. Note that the slope of each line represents the pressure loss across the four measurement locations upstream and downstream of the meter (1 through 4 and 5 through 8, respectively). If the slope of these lines are linear and parallel, there is no asymmetry in the flow profile. Note that pressure can be absolute or gauge, as long as all measurements use consistent units. There need to be at least three measurement points upstream and three downstream to assess uncertainty (two points would always make a perfect line, regardless of flow profile). Micro Motion chose four measurement points to further increase confidence in the data.

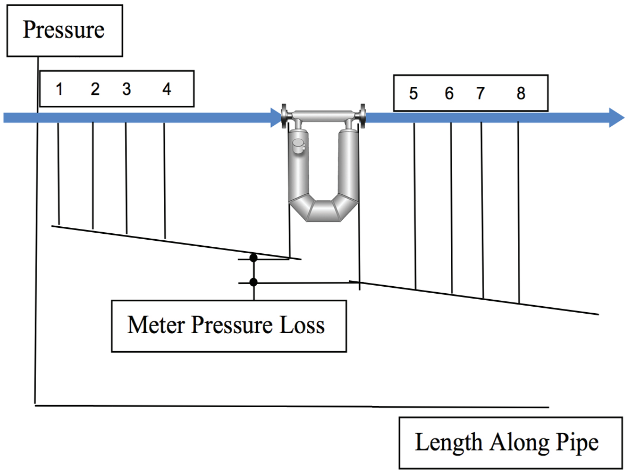
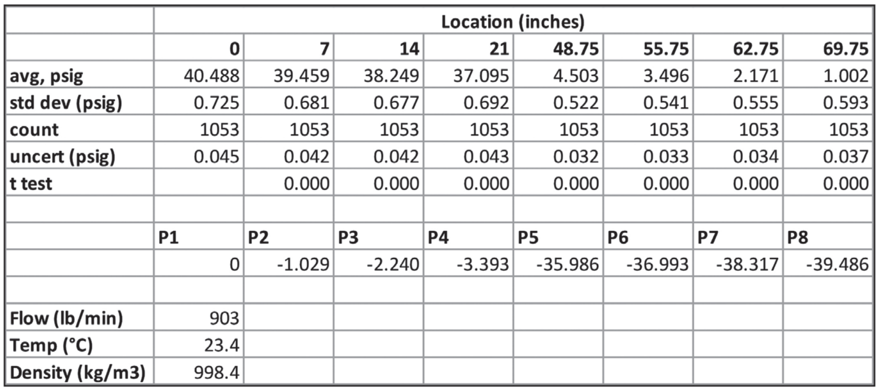


Figure 4 – Pressure drop measurement set-up

Measurements are made at locations 1 through 8. If all the data falls predictably on the downward-sloping lines, the data is good. If points are scattered, data integrity is poor. The most likely points to have problems are 1 and 5. The pressure at point 1 is a function of the upstream conditions; if there is significant flow disturbance upstream of the test section, point 1 may be suspect. In a similar way, if point 5 is too close to the meter under test, its pressure measurement will not be accurate. If all points have good data integrity, the inlet pressure of the meter is the forward extrapolation of data points 1 through 4; the outlet pressure is the reverse extrapolation of the data points 5 through 8.

Data Collection and Analysis

Data collection was made using a portable DAQ system reading at once per second for five minutes (approximately 300 data points). A sample of the output is shown on next page:



	Location (inches)							
	0	**7**	**14**	**21**	**48.75**	**55.75**	**62.75**	**69.75**
avg, psig	40.488	39.459	38.249	37.095	4.503	3.496	2.171	1.002
std dev (psig)	0.725	0.681	0.677	0.692	0.522	0.541	0.555	0.593
count	1053	1053	1053	1053	1053	1053	1053	1053
uncert (psig)	0.045	0.042	0.042	0.043	0.032	0.033	0.034	0.037
t test		0.000	0.000	0.000	0.000	0.000	0.000	0.000
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
	0	-1.029	-2.240	-3.393	-35.986	-36.993	-38.317	-39.486
Flow (lb/min)	903							
Temp (°C)	23.4							
Density (kg/m3)	998.4							

Figure 5 – Pressure Drop Data

Notice in this example that the pressure at the last tap (no. 8 at 69.75 inches) measures only 1 psig. Care must be taken to make sure pressure is high enough to eliminate flashing or air being 'pulled' from solution in the water. The pressures (labelled P1, P2 etc) are plotted vs. Location in Figure 6 below.

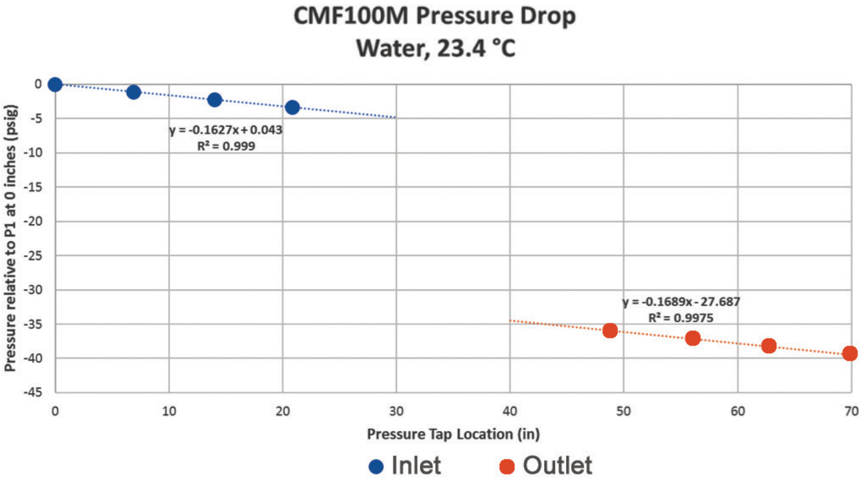


Figure 6 – Pressure Drop Data from Figure 5, Plotted and Regressed

The meter is located between 30 and 39.5 inches, resulting in a pressure drop of 29.2 psi. Note that the current sizing tools predict a pressure drop of 34.2psi, or 17% high. The over-estimate is likely a result of errors based on traditional pressure loss measurement as described at the beginning of this paper.

As discussed previously, the data in Figure 1 must be monotonic and decreasing vs. increasing Reynolds Number. Deviations indicate poor pressure measurements resulting from poorly calibrated transmitters, flow profile problems, and/or flashing due to low pressure. Note that flashing may occur when air is pulled from the solution and is not necessarily boiling of the water.

A very important reason for normalizing the pressure drop as shown in Figure 7 is that it allows for any fluid to be used to establish the "$\frac{fL}{D}$ vs Re" curve.

Other Fluids

Any fluid can be used to characterise pressure drop. In fact, it is difficult to predict pressure drop characteristics on low Reynolds numbers or high Reynolds numbers with water. Micro Motion uses mineral oil with viscosities between 30 and 90 cP and air at approximately 0.01 cp when additional characterization is required. These fluids are difficult to use because oil is difficult to handle for environmental reasons and air does not generate much pressure loss due to its low density. Note that if other fluids are used, viscosity is a critical parameter to understand. A Brookfield rheometer is used to measure the viscosity of liquids. Care should be taken to ensure any fluids other than water are Newtonian in nature.

Example

Use the data from Figures 5 & 6:

$$D = 0.647\,in = (0.01643m)$$

$$\dot{m} = 903\,\frac{lb}{min}$$

$$\rho = 998.4\,\frac{kg}{m3}$$

$$\mu = 0.9\,cP$$

$$\Delta P = 29.2\,psi = 201{,}300\,Pa = 201{,}300\,\frac{N}{m^2}$$

Tube velocity is calculated by (remembering that there are two tubes):

$$V = \frac{\dot{m}}{\rho A} = \frac{6.84}{[998.4][0.01643^2 \frac{\pi}{4} 2]} = 16.16\,m/s$$

Reynolds number is then:

$$Re = \frac{(998.4)(0.01643)(16.16)}{(0.0009)} = 294{,}500$$

Rearrange equation [4] to calculate fL/d:

$$\frac{fL}{d} = \frac{dP{\times}2}{\rho{\times}V^2} = \frac{2(201300)}{(998.4)(16.16)^2} = 1.54$$

Summary

Most Coriolis manufacturers have traditionally taken pressure measurements without attention to flow profile or pipeline pressure loss. If an upstream disturbance causes the flow to swirl, a pressure measurement at a single point may be inaccurate. Micro Motion recognizes that accurate pressure loss calculations are critical to Coriolis users. This test program considers the data integrity of both a multipoint flow profile and assymetry mitigation to provide a precise and thorough evaluation of pressure loss across a meter. For this test program, all meters were tested with ASME 16.5 CL150 flanges. Pressure drop values may deviate for differing process connection types on the same meter.

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