Direct Mounting Allows Differential Pressure (DP) Based Flow Measurement Optimization

Gregory Robert Strom, Marketing Product Manager
Gregory Livelli, Manager of Worldwide Pressure Marketing

Rosemount, Inc.
5601 N 71st Street
Boulder, CO 80301

Keywords

Direct Mounting, Multivariable Compensation, Installed Accuracy

ABSTRACT

The accuracy of a differential pressure (DP) flow measurement point can be optimized by eliminating impulse lines, compensating for changing flow equation coefficients, and utilizing the most accurate DP measurement instrumentation available.

Plugging, leak points, and head uncertainty are direct consequences of complex impulse tubing arrangements used in traditional DP flow measurement installations. Cost and accuracy issues associated with installation at grade were once considered a necessity due to the reliability of traditional DP measurement devices. A new generation of DP measurement instrumentation has robust characteristics that allow for direct mounting to the primary element and elimination of traditional limitations.

Multivariable transmitters can be programmed to alleviate introduction of bias errors attributed to flow equation coefficient non-linearity. Accuracy dividends will be particularly noticeable at low flow rates, which correspond to lower Reynolds numbers.

The major contributor to inaccuracy in a DP flow measurement is the uncertainty of the DP measurement. The square root relationship between the flow rate and the DP induced across a primary element results in the inaccuracy at lower flow rates. Careful selection of instrumentation focusing on of the characteristics that most effect flow measurement can enhance system accuracy.

Direct mount DP flowmeter technology offers a greater degree of process control, provides competitive advantages, and generates economic benefits.

INTRODUCTION

The fundamental principles that form the basis of all DP flow measurement are outlined in Bernoulli's streamline energy equation. This equation defines the relationship between kinetic and potential energy in a flow stream. It allows the inference of volumetric flow rate based on the measurement of DP across a restriction.

DP based measurement has a history that reaches back to ancient times and has the largest installed base of any process flow technology. DP flow measurement continues to be the most often specified flow technology, not because of its tradition in flow measurement, but because of the value it offers. While new flow measurement technologies have emerged, which have strength in certain applications, the DP flowmeter remains a favorite for process flow applications for reasons such as:

- application flexibility
- excellent repeatability
- proven reliability
- direct process mounting
- easy to calibrate and troubleshoot
- worldwide industry standardization
- low installation costs
- meter interchangeability

Recent developments in DP flow measurement bring the primary element together with the secondary element. The combination of software, electronics and primary element allows the end-user to save on installation costs and improve reliability. Enhanced differential pressure flowmeters herald the beginning of a new era in DP based measurement.

IMPULSE TUBE ELIMINATION

The reliability of a flow measurement point can be directly correlated to the length of impulse tubing used. The differential pressure generated by a primary element must be effectively communicated to the sensing apparatus of a secondary element to allow accurate measurement. Following direct mounting practices can minimize errors due to plugging, process leaks, and inequalities in the hydrostatic head of impulse tubes while lowering the total installed cost of the measurement point.

Plugging

Plugging often occurs in steam application impulse tubing as a result of flashing. Flashing is the phenomena in which a fluid quickly changes from a liquid to a gaseous state. Precipitate, composed of suspended solids found in steam, can be deposited on the walls of an enclosure when flashing occurs. Consistent flashing can cause enough precipitate accumulation to plug the impulse tubing. A plugged impulse tube can not communicate the differential pressure generated by a primary element and will result in inaccurate measurement.

The potential for flashing in a given application is influenced by the manner in which the primary element is connected to the secondary element. Flashing is common in remote mount applications with long impulse tubes. Temperature oscillations along the length of the impulse tubes cause the fluid to change state continuously; forming layers of precipitate that ultimately result in plugged tubing. Direct mounting results in a fixed transition from the gaseous state to the liquid state. This eliminates the opportunity for flashing and the plugging commonly associated with it. The geometric and thermal transfer characteristics of direct mount assemblies result in the fixed transition.

Precipitate accumulation is another common cause of impulse tube blockage. Solids in a flow stream will have a tendency to accumulate at the lowest point in an impulse tube arrangement. Impulse tubing is often plumbed around and over obstacles resulting in many areas of low potential energy where solids can collect.   Direct mounting eliminates elbows and traps where solids could potentially accumulate, effectively eliminating the potential for precipitate blockage.

Leakage

Process leaks in impulse tubing result in erroneous DP readings and can have a significant effect on flow measurement accuracy. The potential for a leak in a DP flow measurement system is directly proportional to the number of connections in the system. The integration of the electronics and differential producer through direct mounting eliminates fittings, tubing, valves, manifolds, and adapters resulting in a significant reduction in potential leak points.

Hydrostatic Head Uncertainty

Variation in the hydrostatic head in impulse tubes can mask the DP generated by a primary element. These variations in hydrostatic head are the result of temperature variation and geometric inconsistencies in the impulse tubing.

Impulse tubes must be installed carefully and properly insulated from the environment to prevent serious accuracy issues. These issues become acute at flow rates that generate low differential pressure signals. Direct mounting ensures consistent impulse tube geometry and reduces the potential for temperature variation due to the close proximity of high and low side impulse tubes.

Lowered Total Installed Cost

Integrated flowmeters offer significant savings compared to traditional installation techniques. These innovative products consist of a primary element, a secondary element, and connection accessories. They are specified with a single model code. Typically, these products are pre-assembled, pre-calibrated, and leak tested by the supplier. Cost savings from fully integrated solutions are realized in a number of areas including specification, procurement, material, and installation.

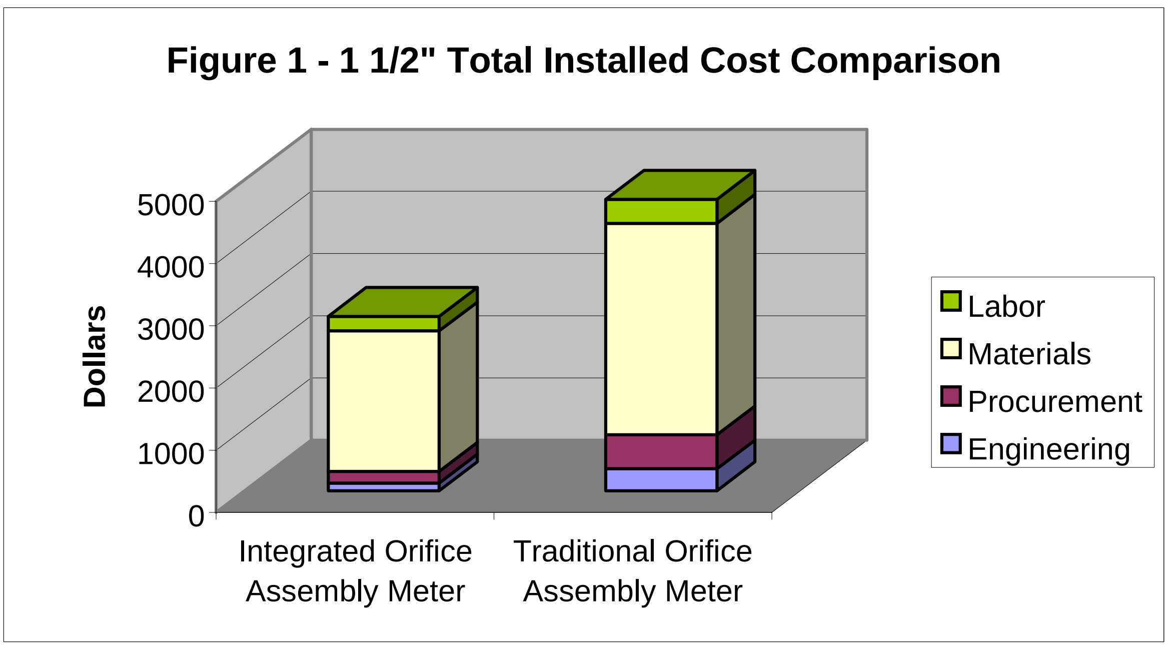
Engineering time spent selecting, specifying, sizing, and creating drawings for flow instrumentation can be significantly reduced through the use of integrated solutions. Traditional measurement requires the separate specification of differential, gage, and temperature transmitters, as well as a primary element, impulse lines, mounting hardware, RTD, thermowell, electrical wiring and conduit, and a flow computer. When using integrated meters, a single model code completely defines the primary element, secondary element, and connection accessories.

The procurement of measurement instruments is a significant cost that is commonly overlooked. Savings are realized during request for quote (RFQ) and purchase order (PO) generation due to the single model code. Receiving costs are also reduced due to the reduction in paperwork and model codes to check against product received.

Using integrated solutions can also reduce material costs. Suppliers will typically offer a price break on the discrete components of the system to ensure single source ordering. The cost of the transmitter and primary element often accounts for only a fraction of the total cost of the flow measurement system. Depending on the primary element selected, additional cost for flanges, mounting hardware, isolation valves, and plumbing are needed to complete the system.

The labor cost associated with the installation of an integrated meter can be significantly lower than that of a traditional installation. The transmitter, manifold, and primary element are received as and assembly. Impulse tubing, root valves, mounting brackets, and interconnections are all eliminated. Units are pre-configured for the application, an especially important fact in light of emerging multivariable technologies.

Figure 1 summarizes anticipated total installed cost savings. The integrated orifice assembly consists of a single model code that defines the pressure transmitter, isolation manifold, and primary element. The traditional orifice assembly meter consists of a pressure transmitter, orifice plate, flange union, three-valve manifold, mounting bracket, and impulse tubing. Procurement and engineering costs are based on discussions with engineering contractors. Materials and labor costs are based on Richardson's Process Plant Construction Estimating Standards, 1997 and Rosemount Inc. Price Lists.



MULTIVARIABLE COMPENSATION

A new generation of multivariable flow transmitters allows simultaneous measurement of differential pressure, static pressure, and temperature. Traditionally, DP flow has been calculated in a flow computer or DCS using a simplified mass flow equation. This practice does not produce the most accurate flow measurement possible due to the fact that it compensates for changes in fluid density only. State of the art examples of the new multivariable transmitters perform complex real time calculations to compensate for coefficient variation in the flow equation. The following flow equation is commonly used to perform fully compensated mass flow calculations:

$$Q_{mass} = NC_d EY_1 d^2 \sqrt{DP(\rho)}$$

Where: N = units conversion factor, C_d = discharge coefficient, E = velocity of approach factor, Y_1 = gas expansion factor, d^2 = bore of differential producer, DP = differential pressure, ρ = density

The only constant value in this equation is the units conversion factor. The other terms are functions of the process variables. A simplified flow equation cannot compensate for changes in these terms, resulting in unrecorded errors in the calculated flow rate. Compensating for changes in discharge coefficient, velocity of approach factor, gas expansion factor, differential producer bore, and density can minimize flow measurement uncertainty.

The discharge coefficient is the ratio of theoretical flow rate to actual flow rate. Many primary elements have discharge coefficients that vary depending on the velocity profile of the flow stream. The velocity profile of a flow stream is related to a unitless value called a Reynolds number. The Reynolds number can be calculated real time with a multivariable transmitter allowing dynamic discharge coefficient compensation. Discharge coefficients tend to change most dramatically at the low Reynolds numbers most often found in liquid applications. As a result, despite the incompressible nature of liquids, multivariable technology allows significant accuracy improvement over traditional methods.

As the area available to a fluid travelling through a pipe changes the velocity of the fluid must change. A primary element is essentially a tightly toleranced restriction associated with a large collection of empirical data that relates the differential pressure generated across it to fluid velocity. Process temperature can effect the restriction presented to the flow stream by the primary element. The velocity of approach factor compensates for geometric variation due to temperature effects.

When a compressible fluid flows past a primary element the velocity change is accompanied by a change in density. The gas expansion factor is applied to compensate for this change. The expansion factor also compensates for small changes in the internal energy of the fluid due to the temperature difference between the upstream and downstream ports of a primary element.

Process temperature variation causes thermal expansion and contraction in both the pipe and primary element. The change in geometry of the system has an impact on the blockage the primary element presents to the flow stream. Dynamic calculation of blockage eliminates any error that could be introduced by the changing geometry.

The main source of flow error in most gas or steam application is error due to changes in fluid density, caused by fluid pressure and/or temperature variation. This assumes, of course, that the application requires mass flow. The need for mass – rather than volumetric - flow can be inferred when a flowrate is expressed in mass (lb/hr) or “standard volumetric” units, such as *standard* cubic feet per minute (*s*cfm). In very rare cases, the user is actually concerned with volumetric flowrate, represented in volumetric units such as *actual* cubic feet per minute (acfm).

Multivariable technology improves measurement accuracy in liquids and gases by dynamically compensating for changes in flow equation coefficients. Performing compensation in the transmitter instead of the DCS saves valuable system resources and reduces the programming expertise required to configure a flow measurement point.

IMPORTANCE OF QUALITY INSTRUMENTATION

Accurate DP measurement is a prerequisite to accurate flow measurement. Many factors have an adverse impact on the installed accuracy of a measurement point including ambient temperature variation, high static pressures, and the frequency of calibration. All transmitters are not created equally in their resistance to error introduction from these factors. Reference accuracy, though important, is not the absolute measure of an instrument’s ability to make a measurement.

Even with a well-installed and well-maintained transmitter, real-world accuracy can be significantly worse than laboratory accuracy. The reason for this is that real-world transmitters are not installed and operated under laboratory conditions. Real-world effects may include:

Ambient Temperature Variation

In the vast majority of flow measurements, the transmitter can operate at a different ambient temperature than the temperature at which it was calibrated. In some outdoor applications, ambient temperatures can vary more than 50 °F from calibration temperature. These variations can have a significant effect on the accuracy of a measurement. This phenomenon is easily simulated on the bench. Simply blow warm air over a transmitter, and watch the change in output.

High Static Line Pressures

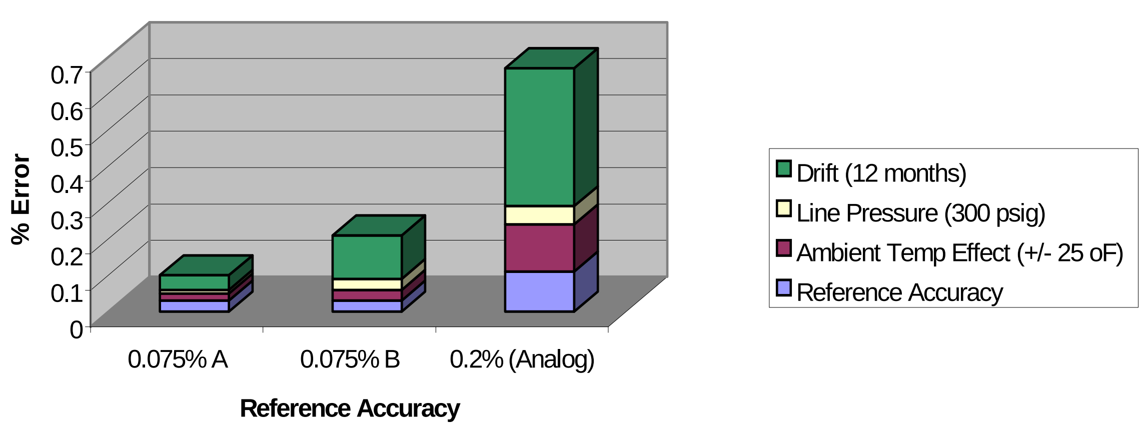
High static line pressure can significantly affect a differential pressure transmitter used to infer a flowrate. This can also be simulated on the bench. Apply a small differential pressure across a transmitter. When several hundred pounds of additional static pressure are added to *both* sides of the transmitter simulating operating conditions the output will shift.

Drift/Stability

The output of any analog component will vary over time. Smart transmitters are more stable than older, analog transmitters or transducers. Within regulatory or contractual restrictions, a more stable transmitter will allow the user to obtain equivalent accuracy and repeatability when calibrated less frequently. An inferior device will need to be calibrated more frequently to maintain acceptable performance.

Reputable suppliers publish specifications that allow users to calculate and predict the impact of "real-world" effects on installed flow accuracy and repeatability. The flow errors at 100% flow due to typical installed conditions are shown in Figure 2 for three different transmitters. Reference accuracy contributes a trivial component of total installed error. Two transmitters with identical reference accuracies can provide dramatically different installed performance. If a supplier does not publish specifications for real-world effects, this does not mean that their products are immune to these effects – usually, the reverse is true.

Figure 2 - Percent of Flow Error



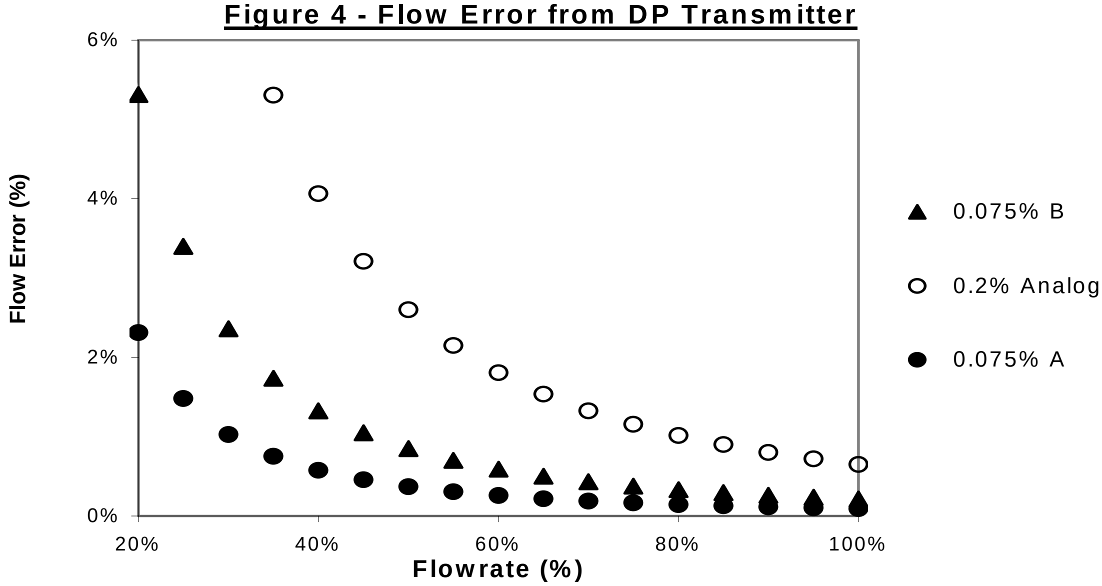
Figures 3 & 4 show the impact of these errors at low flowrates. Note that these errors apply to accuracy and repeatability, and are usually fixed over the DP range. Also, DP α flow^2 – since DP declines twice as fast as flow, small errors at 100% - and small differences in transmitter accuracy - are magnified at lower flowrates

Figure 3 – Flow Error from DP Transmitter

Flowrate (scfm)	DP	0.075% A	0.075% B	0.2% Analog
1000	100	0.09%	0.21%	0.65%
750	50	0.16%	0.38%	1.16%
500	25	0.37%	0.85%	2.60%
250	6.25	1.48%	3.40%	10.40%

Seemingly trivial improvements in transmitter accuracy yield significantly better flow accuracy and repeatability at normal flows – the effect can be dramatic at lower flows.

Figure 4 - Flow Error from DP Transmitter



Summary

Accurate flow measurements allow efficient process operation and are critical to the profitability of your business. Direct mounting practices, multivariable compensation, and quality instrumentation can all have a direct impact on your bottom line.

Bibliography

Flow Measurement Engineering Handbook, R. W. Miller, 1989

Handbook of Instrumentation and Controls, Howard P. Kallen, 1961

Enhanced Integral Orifice Assemblies Provide High Accurate Small Line Measurement, Gregory Livelli, 2000

Improving Flow Measurement by Real-Time Flow Calculation in Transmitters Having Multiple Process Variables, David E. Wiklund and Loren M. Englestad, 1995

Measurement Best Practices for Better Powerplant Safety, Availability, and Efficiency, Mark Menezes, Tony Norris, and Scott Mawhinney, 2000

Integrated Flowmeters Have Revolutionized Differential Pressure Based Measurement, Gregory Livelli, 1999

Richardson's Process Plant Construction Estimating Standards, 1997