

## ENHANCED INTEGRAL ORIFICE ASSEMBLIES PROVIDE HIGH ACCURATE SMALL LINE MEASUREMENT

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### ABSTRACT

*By combining integrated electronics with integral orifice technology, these flowmeters are capable of measuring three process variables in one device: DP, static pressure, temperature, and then dynamically compensating mass flow rate. With built in flow computers for dynamic compensation, integrated flowmeters eliminate the errors commonly found in non-dynamic compensated flow measurement. This design eliminates tubing, valves, adapter unions, transmitter mounting, excessive welding and leak points, therefore reducing installation time.*

*Traditional meters measure a single process variable, where multivariable transmitters simultaneously measures all process variables necessary for calculating either pressure and temperature compensated gas flow or temperature compensated liquid flow. When calibrated in a factory laboratory, the mass flow rate accuracy over an 8 to 1 flow turndown is 0.75% of reading for liquids and 0.85% of reading for gas or steam.*

*Integral orifice flowmeters enhanced functionality gives the end user a greater degree of control over plant operations, as well as competitive advantages and economic benefits. With one device instead of three, installation is easier and maintenance costs are lower. In addition, because you have reduced the penetrations in your process line, you are better able to meet stringent environmental regulations. These enhanced DP flow products have revolutionized the industry and started a new era in DP based measurement.*

### INTRODUCTION

Differential pressure (DP) based measurement is the oldest 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;
- energy savings; and
- one instrument provides a measurement solution for a variety of applications.

DP flow measurement has been reinvented through the integration of the primary element and the multivariable transmitter. This combination of software, electronics and primary element allows the end-user to save on installation costs and improve the reliability and capability of the process. These enhanced differential pressure flowmeters have revolutionized the industry and started a new era in DP based measurement.

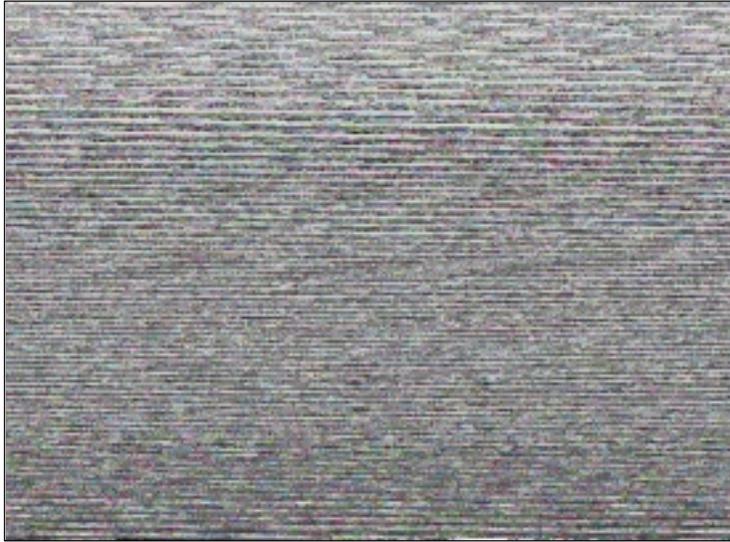


Figure 1. Enhanced integral orifice flowmeters are pre-assembled with a pressure transmitter, manifold and RTD to address a wide range of process applications.

Enhanced integral Orifice flow meters are capable of measuring DP, static pressure and temperature with one device, and then dynamically calculating mass flow rate. With built in flow computers for dynamic compensation, integrated flowmeters eliminate the errors commonly found in traditional DP flow measurement. The result can be better than a mass flow rate accuracy of  $\pm 0.85$  percent for liquids, gases and steam over an 8:1 flow turndown.

When compared with traditional DP flow or vortex mass flow measurement, integrated integral orifice flow meters outperform and offer significant cost reducing benefits.

## SINGLE SOURCE RESPONSIBILITY

Traditionally the primary element, referred to as the flow sensor, and the secondary element, or transmitter, have been purchased separately to measure DP flow. This process requires additional engineering and procurement time since each element would have to be sized and specified individually for each application.

More often than not, the cost of the transmitter and primary element is only a fraction of the total cost of the flow measurement system. Depending on the primary element specified, additional cost for flanges, mounting hardware, isolation valves and plumbing is needed to complete the system.

Integrated integral orifice flow meters use integral manifolds to allow direct mounting of the DP or multivariable transmitter to the sensing element. This eliminates the need for impulse tubing or connectors, reducing plumbing costs. Coupling the integral orifice with a smart multivariable transmitter has proven to be the most cost-effective mass flow measurement solution.

The integration of the electronics package and the sensing element is all that is required to sense DP, temperature and pressure. This reduces specification time, as one instrument replaces the four typically required for traditional compensated mass flow measurement.

Integrated DP flow meters offer single-source system responsibility, where one purchase order will provide all the hardware required for a mass flow measurement. Units are preassembled and configured for each specific application.

## MULTIVARIABLE TRANSMITTERS

Multivariable transmitters combine differential pressure, static pressure and temperature measurements with an integral flow computer to dynamically and continuously calculate all of the DP flow coefficients for fully compensated mass flow. *Full Dynamic Compensation* is when all the DP flow coefficients (discharge coefficient, gas expansion factor, thermal expansion factor, velocity of approach factor) in the full DP mass flow equation are continuously calculated and updated using real time measurements of differential pressure, static pressure and temperature. With real time dynamic calculations, multivariable transmitters can improve the performance of DP flow of an integral orifice  $\pm 0.75\%$  of mass flow rate over an 8:1 usable flow range.

Traditionally, a static compensation method has been used to calculate DP based measurement. This involved using a simplified mass flow equation that employed a single constant to represent the variable for discharge coefficient, gas expansion factor, velocity of approach factor and thermal expansion. In fact, only the units conversion factor is constant. The other terms, discharge coefficient, velocity of approach factor, and gas expansion factor, are functions of the process variables. The simplified flow equation cannot compensate for changes in these terms, resulting in unrecorded errors in the calculated flow rate.

$$Q_m = K \sqrt{\frac{DP \times P}{T}}$$

For gas measurements, the ideal gas law has typically been used for determining compressibility or density. This simplification method is generally used because the full compensation method is difficult and time consuming to configure.

The problem with simplification is that significant errors can occur in the mass flow measurement. This simplification also leads to the perception that DP based flow measurements are inaccurate with low rangeability. Multivariable transmitters that are capable of measuring differential pressure, static pressure and temperature with real time dynamic calculation of each of the mass flow equation coefficients provide users with more accurate DP measurement over a wider flow range than has been achieved in the past. Liquid applications also benefit from dynamic compensation with increased flow rangeability due to real time calculation of the discharge coefficient.

Compensating flow is the process of combining the dynamic fluid condition value with the flow signal to calculate the true flow rate. Multivariable transmitters present a unique solution. Multivariable transmitters measure differential pressure, pressure and temperature continuously to dynamically calculate flow coefficients several times per second over the entire process operating range. Enhanced DP flowmeters compensate for changes not only in density, but also in the other terms considered constant in typical mass flow compensation.

Another compensation method being employed is a modified form of the mass flow equation. This method uses the measured variables to compensate for changes in the value of flow coefficients calculated at reference conditions. However, this method is not true dynamic compensation. Significant errors can still be introduced into the mass flow calculation if all of the differential based mass flow coefficients, as well as density or compressibility, are not calculated continuously and updated real time.

Multivariable transmitters also provide an ideal solution to replace existing uncompensated volumetric DP flow measurement to pressure and temperature compensated mass flow. This permits cost-effective plant optimization without changing existing piping, delivering real time information to perform mass and heat balances across process units or even the entire plant.

## INTEGRAL ORIFICE TECHNOLOGY

An integral orifice is a highly accurate small-bore orifice flowmeter that requires minimal installation and maintenance. It is suitable for measurement of any clean gas, liquid, or vapor. Available for line sizes from ½ inch (12.7mm) to 1 1/2 inches (38.1mm). Integral orifice assemblies provide a

significant advantage over traditional orifice plates. The special flange and bolting structure ensures the bore is secured and centered directly in the pipe for accurate flow measurement. Measurement accuracy is significantly affected by errors in placement of the orifice opening to the center of the pipe. Significant deviation from the center can result in a difference between the calibrated factory flow coefficient used and the actual installed characteristics. These problems are eliminated an integral orifice. As an example, a 3% deviation in placement of the orifice opening from the pipe center can result in a 0.25 to 1.5% error depending on the beta value.

Integral orifices offer significant benefits such as:

- Self-centering orifice plate design.
- High accuracy and performance.
- Reduced installation costs.
- Reduced potential leak points.
- High Reliability.
- Available with special factory calibration.
- NACE MRO1-75 (90) compliant.

Integral Orifice flowmeters can be remotely installed or mounted directly to the sensor by means of either a 3- or 5-valve manifold. Integrating the primary and the transmitter provides the advantage of minimizing potential leak points. The electronics and sensor element may be fully integrated eliminating fittings, tubing, valves, manifolds, adapters, and mounting brackets to reduce potential leak points and installation time. Upwards of 28 potential leak paths can be eliminated with direct mounting. Direct mounting can be used in all fluids except where the temperature exceeds 500 F (260 C)

Permissible fabrication tolerances for piping below two inches (50.8 mm) based on ASTM A-530 can be significant. Pipe inner diameter variances can be up to seven percent as shown in Table 1.

Table 1 - Permissible variations in pipe diameters for seamless, welded and alloy pipe per ASTM A-530.

Pipe Line Size	ID Min	ID Max	% Error Min	% Error Max
½ inch	0.591	0.665	-4.98	6.91
1 inch	1.018	1.098	-2.96	4.67
1 ½ inch	1.579	1.661	-1.93	3.17

Using an incorrect piping diameter in the DP flow equation for the integral orifice plate can significantly effect the calculated flow. As an example, an error of 4% in the pipe diameter can result in an error of 1% in flow rate. Determining the inner pipe diameter of existing piping maybe be difficult and relying on standards can produce a wide variance. The pipe tolerance issue is eliminated when using our precision built upstream and downstream piping sections. Each piping section is precision bored and honed to the nearest 0.001 inch and essentially removes the error associated with incorrect pipe diameter measurements.

## AFFORDABLE PERFORMANCE

The integrated design of integral orifice flowmeter allows for a higher accuracy over a wider flow turndown than that offered by traditional DP technology. Using the multivariable electronics of the transmitter, the primary's flow coefficient is constantly changing with respect to operating pressure, temperature, density, thermal expansion and gas expansion. These variables are corrected as the flow properties change.

In gas flow measurement, the density of the gas changes as pressure and temperature change. This change in density can affect the accuracy of the measured flow rate if uncompensated.

There are two cases when an uncompensated density change will not affect the flow measurement. First, when a mass flow measurement is made with a direct mass meter or when only getting an actual volumetric measurement. Since most gas measurements are mass in mass units, not

volumetric, and are not measured with a direct mass flowmeter, the majority of gas measurements will be affected by changes in density.

A simple rule of thumb can be used to calculate how much the density of a gas will change due to changes in pressure and temperature. Gas density can be calculated using the Real Gas Law.

$$\rho = \frac{MW_{gas} P}{ZR_o T}$$

Since gas density is a function of absolute pressure and absolute temperature, the changes in density is proportional to the change in pressure and temperature. Therefore, a one-percent change in absolute pressure causes a one-percent change in density.

For example:

1. Gas flow measurement at 75 psig line pressure that varies by 3 psi.

$$\Delta\rho_{pressure} = \frac{\pm 3 psia}{(75 + 14.7) psia} = \pm 3.34\%$$

2. The same Gas flow measurement at 20°C and varies by 5°C.

$$\Delta\rho_{temperature} = \frac{\pm 5K}{(20 + 273.15)K} = \pm 1.71\%$$

The total change in density due to changes in pressure and temperature is  $\pm 3.8\%$  (root sum of the squares). The maximum density is at maximum pressure and minimum temperature and vice versa.

How much this affects the flow measurement is dependent on the type of meter. Velocity type meters have a 1:1 relationship between flow error and density change. DP flowmeters have a 1/2:1 relationship between flow error and density change. In the above example, for velocity meters, the flow error due to density variation is  $\pm 3.8\%$ . For a DP flowmeter, the error due to density is only  $\pm 1.9\%$ . A DP flow meter is half as sensitive to density variation as a velocity meter.

To eliminate these errors, line pressure and temperature should be measured to compensate the flow rate. Multivariable transmitters measure pressure and temperature to dynamically compensate for density changes.

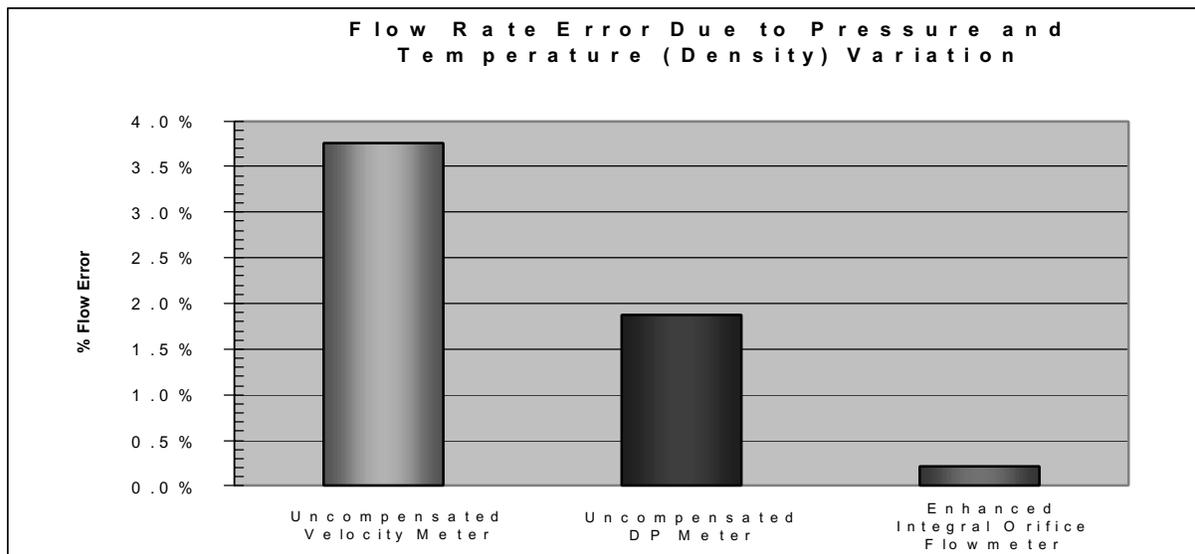


Figure 2. Flow rate error due to pressure and temperature variation

## INCREASE RANGEABILITY

One of the most common myths of DP flow is that the rangeability of DP flow technology is typically 3:1. This misperception is usually promoted by competing technologies that claim “high” rangeability of 20:1 or better. Rangeability is usually defined as the ratio of the maximum to minimum flow. There are two definitions of “maximum flow” which are commonly used in specifying the rangeability of the flowmeter. It is important to understand the difference between the two methods of defining the maximum flow because it can be the difference between a flowmeter that can measure the flow range of interest and one that cannot.

The first way to define “maximum flow” is the maximum flow rate that the flowmeter can measure. This is how most flowmeters specify rangeability in product literature. The other way is to define “maximum flow” as the maximum flow rate that occurs in a particular application. This is how most DP flow meters are specified. DP rangeability is always referred to from application maximum flow.

The distinction is critical because the specified meter maximum is often two to three times application maximum. In liquid application, vortex, coriolis, magnetic and ultrasonic flowmeters are designed to measure maximum flow rates of 20 to 30 feet per second. The optimum economic flowing velocity for liquids is about five to six feet per second, and they rarely flow over ten feet per second. This means that a flow meter with a 20 or 30:1 flow rangeability from meter maximum typically measures less than an 10:1 flow range in most actual processes. For gas applications, meter maximum flows are also much higher than typical process flows.

To achieve the advertised meter maximum flow and rangeability in a typical application, pipe size must be reduced at the meter. This increases installation costs and permanent pressure loss, which may not be acceptable. For this reason, flowmeter rangeability should be considered from application maximum, not the meter’s maximum specified flow rate.

It is also important to understand how the max to min flow ratio relates to percent of flow range. The figure below shows the relationship between rangeability and percent of maximum flow. Notice that 10:1 rangeability will measure down to 10% of maximum flow. A meter with 20:1 rangeability will measure down to 5% of maximum flow, only 5% more of the flow range. Since a meter with a high rangeability can significantly increase cost, care should be taken to specify no more rangeability than actually required for an application. With a properly selected averaging pitot tube and a multivariable transmitter, you can still achieve accurate mass flow measurement over an 8:1 flow turndown.

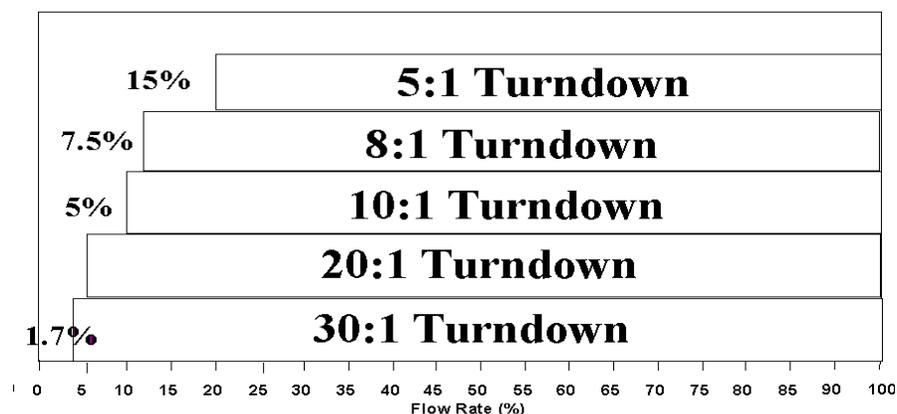


Figure 3. Comparison of Flow Turndown

## REDUCED INSTALLATION COST

Combining the primary and secondary element into an integrated integral orifice flowmeter offers the lowest installation cost of any flowmeter technology. When compared to a traditional orifice plate and

vortex installation, enhanced integral orifice flowmeters save installation and hardware costs while offering superior accuracy and turndown.

Cost savings from fully integrated flowmeters are realized in a number of areas, including selection, configuration, assembly and installation. Specifying a DP mass flow measurement point has traditionally involved selecting differential, gage and temperature transmitters, as well as a primary element, impulse lines, mounting hardware, RTD or thermocouple, thermowell, electrical wiring and conduit, and a flow computer.

Incorporating all components into a single unit considerably reduces installation costs. Integrated integral orifice flowmeters eliminate the need for fittings, tubing, valves, manifolds, adapters, and mounting brackets, which in turn reduces welding and installation time. In addition, the process line need only be tapped once to accurately measure temperature, pressure and differential pressure.

Installation time alone can be reduced up to 90 percent over traditional compensated mass flow. When compared with traditional orifice or vortex installations, integrated integral orifice flowmeters save installation and hardware costs while offering superior accuracy and turndown. Integration also allows for reduced chances of mechanical breakdown. No moving parts and easy access for diagnostics translates to reduced overall maintenance costs.

## SUMMARY

In reinventing DP flow measurement, integrated integral orifice flowmeters provide lower installation costs, lower operating costs and higher reliability than traditional DP flow measurement.

Differential pressure transmitters have been used to measure flow in process industries for many decades. Recently, a number of other technologies have emerged to compete with DP flow technology. Even with the variety of choices available, DP based flow metering continues as the primary choice in most flow applications.

The integration of the integral orifice primary element and secondary transmitter creates a new category of flowmeter measurement: multivariable integral orifice flowmeters. Users will no longer have to buy a DP transmitter and then search for a primary element supplier. Instead, the DP transmitter will come with the primary element already in place. This will provide a single integrated solution. Users will have a single supplier to call for all their flow measurement needs.

While multivariable electronics improve the performance characteristics of orifice plates, the use of integral orifice primary element offers significant advantages over traditional orifice plates. The special flange and bolting structure ensures the bore is secured and centered directly in the pipe for accurate flow measurement. Measurement accuracy is significantly affected by errors in placement of the orifice opening to the center of the pipe. Significant deviation from the center can result in a difference between the calibrated factory flow coefficient used and the actual installed characteristics. These problems are eliminated an integral orifice.

## REFERENCES

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