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## ENGINEERING GUIDE TO Flow Measurement





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# Wireless flow measurement

Power remains the essential challenge; here are ways to meet it.

By Ian Verhappen

**F**low measurement techniques continue to grow and evolve with new methods such as multipath ultrasonic, magnetic and Coriolis increasing at the expense of more traditional technologies such as orifice, weir and other differential pressure (DP)-based techniques. The increased use of these new technologies is partly a result of the increased capability of microprocessors and sensors to enable measurements not possible without enhancements in these areas. Another reason for their adoption is that, in most cases, they also provide higher accuracy and rangeability than DP technologies. But most of these flow measurement techniques tend to require more energy than DP flowmeters, and hence aren't well suited for deployment as wireless devices.

A colleague on one of the international standards teams I belong to indicated at a recent meeting, during a conversation on wireless and batteries, that their company has only been able to find one source for a battery suitable for their wireless transmitters to meet a 10-year service life. This is, of course, with periodic recharging. Other rechargeable batteries tend to have 'memory' and other problems resulting in operating life of closer to five years.

A bigger concern with using wireless for flow measurement is the dynamics of the process itself. The majority of flow loops, especially for liquids (incompressible fluids) have very short process response times, often in the order of seconds, unlike temperature and level, which tend to be much longer (arguably measurable in minutes). Therefore, if using a

wireless sensor for flow control, you'll need a rapid update rate for the transmitter at a minimum, which of course leads to short battery life, and consequently make the economics for cable look better.

Of course, it would help if it were possible to develop the perpetual motion machine and scavenge some energy from different flowmeters to maintain or charge the batteries. For example, if the frequency-shedding bar of a vortex meter, or paddle/turbine in those forms of meters, or pulsations in a positive-displacement meter could drive some form of coil while not affecting the measurement proper, this would eliminate the energy concern for each of these forms of meter.

One way to address the response time issue is to increase the capability of the flow device by adding the ability to perform as a single-loop or self-contained flow controller. Then the control loop only requires transmission of the output to the final control element and remote HMI when such a change is required, which isn't likely to be every sensing or update cycle (assuming the control system can accept some degree of dead band on the signal). If the dead band isn't acceptable, then having the transmitter update the control system for historian and measurement purposes every cycle and the output directly to the device

“as needed” is a much more complex situation of managing different update rates from one device depending on data type.

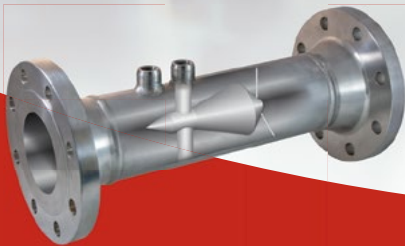
An alternative to every-cycle updates that may be acceptable is using a totalization option for the update rate to the control system, which risks losing raw data granularity. With all these features, the transmitter is getting closer to the Open Process Automation (OPA) forum's vision of a device control node (DCN), and closer to a SCADA RTU field controller being monitored and controlled (i.e., changing setpoint) remotely from the central control station. SCADA typically includes wireless but again, with longer update cycles and the need for intelligence at the field end.

As the above discourse indicates, monitoring versus controlling has a significant impact on system design. The apparently simple choice of monitor versus control or custody transfer affects not only the type of sensor required, but as we can see, how that device interacts with the control system and other devices within the control system. Though true for more than flow measurement, the impact is more pronounced with fast control loops such as flow, regardless of how innovative we try to be to overcome the basic principles and reason for which the system is being installed. ∞



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# Going with the Flow

## Choosing the Right Flow Sensor for Various Applications

By Greg McMillan, Stan Weiner

**Greg:** Flow measurements offer opportunities for feed-forward, identification of valve backlash and stick-slip, on-line metrics and diagnostics, rejection of pressure disturbance, linearization, modeling and tracking down disturbances as outlined in “Secondary Flow Loops Offer a Primary Advantage.” Flow is by far the most manipulated process input for controlling process variables, optimizing process efficiency and setting throughput.

**Stan:** To get insights on what flow sensor works best in various applications we continue our interview with Ram Ramachandran the principal engineer at Systems Research Int'l. Inc. Differential head measurements using differential pressure [DP] transmitters tend to have the lowest accuracy and rangeability due to the square root relationship; the highest noise due to sensitivity to velocity profile, and the highest maintenance cost due to impulse lines. If the velocity profile and density are constant (no opening and closing of valves or changes in composition), the repeatability is good. While the hardware cost may be low, the lifecycle cost is high from installation and winterization of impulse lines and maintenance to prevent line plugging, and to keep a constant phase and fluid composition in the lines. Furthermore, the increased process variability is a hidden cost. Most people don't realize density affects even the volumetric flow through the Bernoulli equation. Then there is the poor turndown leading to loss of flexible manufacturing to minimize inventories, and match fluctuating energy costs and market demands. I stopped using them [differential head measurements] in the 1980s. Why are differential head meters used?

**Ram:** Many of these installations are legacy systems, still with us in large chemical plants and refineries in the United States. For high temperatures and large pipe lines in mature continuous processes (e.g., refining, chemical intermediates and pigments and dye manufacturing) with infrequent and relatively limited production rate changes, the differential head meters have been traditionally used. Elbow flowmeters with purged taps have been used when the process fluid is too hazardous, too corrosive or erosive, or pressure drop can't be tolerated, and the accuracy required is only 5%. For much better accuracy and rangeability and less noise and sensitivity to piping configuration, Venturi tubes can be used with a minimal permanent pressure drop. Flow nozzles are a lower cost solution to Venturi tubes, particularly for large lines. The lowest cost flow sensor is an averaging pitot tube. Some manufacturers offer a retractable design.

**Greg:** If a wireless DP transmitter is used with an averaging pitot tube, the flow measurement is portable, enabling the exploring and prototyping of process control improvements, diagnostics and metrics. The rangeability can be extended to 10:1 if a second low-range transmitter is added, and measurement noise is incredibly low from strict attention to piping straight run requirements. These meters can justify a more permanent and accurate installation.

**Stan:** What can you do to achieve greater accuracy, rangeability and maintainability in large lines?

**Ram:** Turbine meters can provide incredible accuracy (e.g. 0.05%) and rangeability (e.g. 50:1). Bearing life is a problem for non-self-lubricating liquids, such as anhydrous ammonia. EMI has a sleeve bearing design that enables use in steam and gases. Insertion turbine meters and vortex meters are used for large pipelines. Vortex meters are the lower maintenance alternative, but at the expense of 5x deterioration in accuracy (e.g. 0.25%) and rangeability (e.g. 10:1) and greater straight run requirements. Repeatability stops at low flow. Improvements in bluff body and sensor design and temperature compensation have greatly increased vortex meter performance since their introduction. However, the meter coefficient is still a function of kinematic viscosity.

**Greg:** Where is volumetric displacement used for flow measurement?

**Ram:** The oil and gas industry uses the technology of pulsating disc flowmeters for their huge pipe lines. The measurement of reciprocating pump stroke is used for toxic and lethal fluid flow measurement. Rotating disc flowmeters are used for natural gas and water flow measurement. Since these tend to read low as they age, there is an initiative to replace these with non-mechanical meters for large users.



### TOP 10 REASONS NOT TO USE FLOW MEASUREMENTS

- |   |  |  |
|---|--|--|
| <p>10. Minimizing project costs are more important than minimizing operating costs.</p> <p>9. Adaptive control will take care of everything.</p> <p>8. I don't really want to know what the control valve is doing.</p> | <p>7. I want to do an academic paper on valve flow models.</p> <p>6. I love process mysteries.</p> <p>5. I don't want to disturb disturbances.</p> <p>4. Operators say they don't change feed rates.</p> | <p>3. Feed-forward control is too complicated.</p> <p>2. Online process metrics might show our mistakes.</p> <p>1. We know the flows from the process flow diagram</p> |
|---|--|--|

**Stan:** Magmeters offer quite a performance advantage at low flows since their accuracy is a percentage of rate rather than a percentage of full scale like most other flowmeters. Magmeters also have a very short straight run requirement and can measure reverse flow. What do you see as some of the application considerations?

**Ram:** The main consideration is materials of construction and fluid conductivity. While newer meters have special low-conductivity capability, still some amount of water must be present. Oil companies will not entertain the possible use of magmeters due to previous failures.

There have been some spectacular failures of soft liners (e.g. Teflon) collapsing from a vacuum condition from condensation after steam cleaning or from tearing away from the wall due to poor liner installation. Thompson Equipment perfected the art of lining magmeters and is the choice for many manufacturers. For hot, dilute HCL glas-lined magmeters are used. Electrodes are available in a wide variety of corrosion-resistant materials, including gold and platinum.

AC magmeters had some initial problems when first introduced, but now predominate because of lower drift and less of an effect of solids. For huge changes in conductivity, a DC magmeter may be used.

**Greg:** My personal favorite is the Coriolis meter because it has no drift or installation effects (other than vibration), incredible accuracy (e.g. 0.02%) and rangeability (e.g. 100:1) independent of composition and velocity profile, low noise, no calibration or maintenance, plus an extremely accurate density measurement that can offer an inferential measurement of concentration or percent gas or solids. Coriolis is the only true mass flow measurement. For liquid reactant feed measurement and ratio control, Coriolis meters are essential. Why isn't a Coriolis meter used?

**Ram:** The meter is expensive, particularly in large pipe sizes. The largest size is pres-

ently about 16 inches, but at quite a price. For slurries there must be no accumulation of solids. Straight-tube Coriolis meters are used to prevent erosion at a price of a 5x reduction in accuracy (e.g. 0.1%).

**Stan:** What about the measurement of flow in ducts?

**Ram:** Thermal gas flowmeters are predominantly used to measure refinery waste gas flow consisting of mostly ethane and methane. It is also common in material and energy balance controls in large furnaces by measuring air duct flow. Many of the emission reports to regulatory authorities are indirectly computed for total emission, based on plant throughput wherein air/gas flow measurements become critical besides direct composition analysis of stacks.

**Greg:** Thermal gas flowmeters depend on the thermal conductivity being constant. They are extensively used for measuring air, oxygen and carbon dioxide flow to bioreactors. For bench top and pilot-plant scale bioreactors, these flowmeters are integrated with a internal flow element and PID controller to become a mass flow controller (MFC) that gets its flow set-point from the bioreactor control system. The tuning of these MFCs can be made fast enough to insure speed as a secondary loop is 5x faster than the primary dissolved oxygen or pH loop. What are some low-cost alternatives?

**Ram:** Fluidic Components Inc.'s flowmeters that measure the heat loss have a better accuracy and rangeability than thermal mass flowmeters, particularly if the stream has moisture. Two heaters are used to prevent condensation.

**Stan:** What is done for the flow measurement of solids?

**Ram:** The most accurate measurement of conveyor flow is by gravimetric feeders that are separate, specially designed sections of conveyors on load cells to measure speed and weight. Linear voltage differential transmitters (LVDT) offer an economical and fairly repeatable solution. Ultrasonic sensors are also used. Radiation sensors are more accurate than LVDT or ultrasonic, but require wipe testing every three years and permitting for maintenance by a radiation officer.

Flow out of a hopper is measured by a rotary valve in the hopper discharge. Measuring hoppers may be used at several points in a fluidized solids process, such as spar in hydrofluoric acid (HF) manufacturing. The same technique is used for cement kilns and bagging operations.

**Greg:** Flow can be computed from the rate of change in weight by load cells or level by radar as described last month. Centrifugal

pump speed with temperature measurements for viscosity and pressure measurements for rise compensation have been used for computing polymer flow. A valve-flow model for equal percentage trim and a large valve to system drop ratio can extend the turndown of differential head and vortex meters, but should not be viewed as a replacement for flow measurements due to effects of shaft windup, backlash, stiction, composition and geometry.

**Stan:** How do you measure extremely low flow rates?

**Ram:** Coriolis meters as small as 1/8 in. are available. For even lower flows, capillary flowmeters with a DP measurement are used, keeping the system in temperature-controlled baths. Very small flow with high accuracy and resolution is achieved by using special turbine meters in pilot plants to measure 1 cc to 5 cc an hour or smaller.

**Greg:** Bench top bioreactors use peristaltic pumps for feeding seed cultures, amino acids, nutrients, reagents and glucose. The speed provides a volumetric flow measurement. If the choices seem too confusing, here is list of excuses to write the whole thing off.

Greg McMillan, Stan Weiner are frequent contributors to Control.

# Bidirectional Flow Measurement

The Right Flowmeter Is a Balance Between Technical Needs and Cost-Efficiency

By Ruchika Kalyani

**F**low measurement plays a critical role in chemical and petrochemical, oil and gas plants. Criticality of flow measurement in the plants has become a major component in overall economic success or failure of given processes. Accurate flow measurements ensure the safety of the process and profits in plants. Better measurement can only be achieved by selecting the best/most suitable flow technology for each flow application. Sometimes, the accuracy required by the end users is the most significant factor for the specific application. The challenge is to find out the value of the product stream being measured, thus providing the most cost-effective and reliable solution to the end users.

Instrument engineers should convince the end user to not install a flowmeter that is more expensive than the yearly value of the stream and the potential loss of money caused by inaccuracies.

A diverse range of flowmeters along with the turndown factors is available for various flow applications, such as regular flow control (steam, gas, utilities, etc), process flow rates, fiscal or custody-transfer metering, and others. Most of these applications will be unidirectional, but some will be bidirectional.

The measurement of unidirectional flow rate is possible with all types of flow technologies, but the bidirectional flow measurement capability is required to measure the flow

rates within the same flow loop in opposite directions. This sometimes creates difficult situations, challenges, process interruptions and/or measurement inaccuracies that can significantly affect the production and profitability of the plant.

We will further discuss the selection of the appropriate metering for bidirectional situations and applications, limitations, advantages and disadvantages, maintenance and installation cost.

## **BIDIRECTIONAL FLOW MEASUREMENT**

Bidirectional flow lines are not very common in refineries and petrochemical plants, but if they are needed, they are always difficult. For bidirectional flow, the piping scheme uses the same line to accomplish delivery and/or control functions for flows moving in opposite directions (forward or reverse flow), depending upon the process conditions and objectives.

Examples of bidirectional flow are

- Raw water feed to two or more water treatment plants,
- Bidirectional steam lines supplying steam from one unit to another unit in the plant,
- Utility and circulating pumping of dielectric fluid into underground electrical cables in order to dissipate heat generated by high-voltage power lines,
- Gas injected or withdrawn from the gas storage field or reservoir, purging and

- blanketing of nitrogen in plants,
- Chilled water plant decoupling headers.

## **BIDIRECTIONAL FLOW MEASUREMENT USING VOLUMETRIC FLOWMETER OPTIONS**

The selection process of bidirectional flow metering is dependent on application requirements, process demand, end-user accuracy requirements and physical design constraints of the flowmeter itself. Various flowmeters are available with bidirectional flow capabilities, such as the DP transmitter with an orifice, the Venturi or wedge element, the Coriolis, ultrasonic, vortex, pitot, turbine and the magnetic flowmeter.

Instances where a bidirectional flow measurement is required include

- Possibility of having two different flow rates in either direction, due to the process and design conditions, and both flows need to be measured,
- Reverse-flow accuracy is required by end user or by the process.
- The need to measure reverse flow in the process.
- Bidirectional Flow Measurement Using Dual DP Transmitter Options

For bidirectional flow measurement between two process units in a process plant, two steam units linked to each other; i.e., at the time of deficiency of steam in one unit, the other unit will supply the required steam to the deficient unit and vice versa.

If reverse and forward flow rates are identical in both directions and precise accuracy is not required, then dual transmitters, one for each flow direction, are the best solutions for measuring the steam flows in/out of the plant. Two DP transmitters with an orifice plate, along with temperature compensation can be used for the bidirectional flow. In this case, a non-beveled, square-edge type orifice plate should be used, and the two edges of the orifice should comply with specifications for the upstream edge mentioned in ISO 5167 standard. It also is necessary to ensure of the full “upstream” straight lengths on both sides of flow instrument. This must be clearly communicated to the piping design team during design reviews, and before construction begins.

With this combination, do not expect high accuracy and turndown. This combination will provide the lowest installed cost with acceptable accuracy, as it is easy to maintain and replace. Also, this dual transmitter combination option will be ideal in cases where the transmitter will experience reverse flow once every four or five years for a four- or five- day period.

### **BIDIRECTIONAL FLOW MEASUREMENT WITH SINGLE DP TRANSMITTER OPTION**

A single DP flow transmitter coupled to a primary element option, such as the special orifice plate mentioned above, can also be adopted for cheap reverse-flow measure-

ment. This arrangement will cut down the installing expense of another (second) DP transmitter, orifice plate, additional hardware, meter installation requirements and the complexity of signal switching. The square root function is complicated with the single- transmitter option, as reconfiguration of the transmitter signal (4-12 mA and 12-20 mA) requires additional function blocks and, subsequently, corresponding function blocks or logic at the distributed control system (DCS) side.

In cases where it is only a matter of knowing the reverse flow direction and accuracy is not important, then existing the DP set without configuration can be used. At zero flow 4mA is shown, and an output less than 4 mA can be used to alarm for reverse flow even when the square root function is on.

With newer, smarter flowmeter techniques, transmitters are equipped with a feature that allows reconfiguration of the DP transmitter range; i.e., split-range output signal (4-20 mA) to system side (DCS, PLC). The bidirectional function (i.e. square root functions) can be directly applied to the transmitter by either just by installing special bidirectionality software from the flowmeter vendor at the control system side, or by using the inbuilt capability of the flowmeter to be used in both forward and reverse flow directions.

With equal or unequal flow rates, flow direction will be indicated as the output

value (4-12mA = REVERSE and 12 -20 mA FORWARD). With equal flows, zero flow point is established based on DP range of forward and reverse flow, and for unequal flow rates, zero flow point will be a calculated value.

### **BIDIRECTIONAL FLOW MEASUREMENT WITH VORTEX FLOWMETERS**

The other option of two vortex flowmeters can also be used for steam bidirectional flow if higher accuracy is required than can be achieved using the orifice solution, but this application is limited to smaller line sizes, as vortex meters are more economical up to 4-in. (100 mm) pipe size. Beyond this size, orifice plates are more economical. In addition, the selection of a vortex-shedding flowmeter may increase the maintenance and installation cost.

Wherever higher accuracy is required, vortex flowmeters are not a good option, as vortices shed by both bluff bodies propagate really far beyond the pipe and may affect the other meters' readings. Another drawback is that the straight pipe run distance required between two vortex meters is unpredictable. For example, in the case of no obstructions, the meter required the run of 10 D to 15 D (diameters), and if there is a control valve in either direction, the meter may require the higher run of 25 D to 30 D, or even more. In comparison to the options of dual transmitters for bidirectional flow

measurement between the two process units, DP flow measurement may be the most cost-effective solution.

### **BIDIRECTIONAL FLOW MEASUREMENT WITH TURBINE AND MAGNETIC FLOWMETERS**

Bidirectional flow measurement is always a challenge when there are changes in process parameters, such as viscosity, conductivity, etc. It is always worth keeping these specific situations in mind while selecting any flowmeter technology but with bidirectional flowmeter applications, it is very important. DP type meters are usually not really well-suited to handle these process parameter variations.

An example is utility pumping and circulating plants pumping dielectric fluid into underground electrical cables in order to dissipate heat generated by high-voltage power lines.

This application requires flow rate monitoring upstream and downstream, as it involves dielectric fluid, therefore it requires viscosity compensation as the temperature of the dielectric fluid changes. In this application, turbine flowmeters can provide the solution for bidirectional flow measurement with moderate accuracy. Drawbacks associated with this technology include a poor response of the flowmeter at low flows due to bearing friction; lack of suitability for high-viscosity fluids because the high friction of

the fluid causes excessive losses; and the requirement for regular maintenance and calibration to maintain its accuracy.

The magnetic flowmeter can also be used for bidirectional flow measurement. It has the advantages of no pressure drop, linear output, short inlet/outlet pipe runs (5 diameters upstream of the electrode plane and 2 diameters downstream), and good turndown. Magnetic flowmeters are relatively expensive, and are mainly limited to conductive fluid applications such as acids, bases, slurries as well as water. A pre-requisite for this type of flowmeter is that the fluid is electrically conductive with an absolute minimum conductivity of 2-5  $\mu$  Siemens.

## **BIDIRECTIONAL GAS FLOW MEASUREMENT USING ULTRASONIC FLOWMETERS**

At gas storage fields or natural gas reservoirs, accurate gas flow measurements are required for tasks such as injection and withdrawal of gas from these reservoirs. Reservoirs are used as buffers between suppliers and consumers. In order to maintain the balance for the entire reservoir, it is necessary to monitor bidirectional flow at the wellhead.

For this purpose conventional DP flowmeters with an orifice are far from a suitable solution as they lack accuracy and reliability. Orifice plates are subject to wear and tear. Secondly, regular inspections and maintenance are required. While measur-

ing the dirty gas, the pressure taps of the orifice plates are particularly exposed to clogging due to the solid particles which may be present in the dirty gas. These will definitely distort the accuracy of measurement. In these specific cases, an ultrasonic flowmeter may be a far better solution, since this type of flowmeter has no pressure drop, no flow blockage, no moving parts, is suitable for high-volume bidirectional flow and also for low-flow measurements where other types of flowmeters do not provide the required results.

The advantage of using the clamp-on gas flowmeter transducer on the outside of the pipe doesn't require any pipe work or any kind of process interruption. With this type of flowmeter even a little moisture content present in the gas cannot significantly affect the measurement.

The reliability, negligible maintenance with highest accuracy and long term cost of ownership are the major benefits of this technology.

## **BIDIRECTIONAL FLOW MEASUREMENT WITH CORIOLIS MASS FLOWMETERS**

In the process industries, the Coriolis technology has set the standard for the flow and density measurements. This technology is used for various applications, such as mass balance, monitoring of fluid density and custody transfer, but also to reduce

maintenance, and for bidirectional flow measurements.

In refineries, there are bidirectional applications, such as import and export of product, product transfer to storage and to petrochemical plants, and where the accurate measurement is more important than cost. Coriolis mass flowmeters can be used for accurate and reliable measurements of all streams in and out of the plant. This is critical for accounting and profitability. End users should take into account that inaccurate measurements sometimes may cause them to give away more product than they are being paid for. This can result in a significant loss of profit.

Compared to the traditional use of volumetric flow technology for bidirectional measurements, the use of Coriolis mass flowmeters eliminates various well-known drawbacks of volumetric technologies, such as the requirement for significant upstream and downstream straight piping length and the reduction of potential errors that occur in compensation for temperature, pressure, viscosity or specific gravity. The Coriolis mass flowmeter technology does not require that compensation.

Coriolis meters measure mass flow. They do have their own inaccuracies, but these tend to be low relative to other types of flowmeters. The turndown of Coriolis meters is high compared to other types of flowmeters. An-

other advantage is that no recalibration is required when switching fluids or for changing process conditions.

## **PURCHASE PRICE V/S COST OF OWNERSHIP**

It is very important for the control system engineer to evaluate the accuracy required for specific application before selecting any of bidirectional flowmeter technologies, as more accurate and precise flow measurement often results in higher cost of the flowmeter.

The control system engineer must understand that price is always the consideration. However, there are some important distinctions to be made in terms of price. A flowmeter can have a low purchase price, but can be very expensive to maintain. Alternatively, a flowmeter can have a high purchase price, but will require very little maintenance. In these cases, the lower purchase price may not be the best bargain. Other components of price include the cost of installation, the cost of associated software, the cost of training people to use the flowmeter, the cost of maintaining the meter, and the cost of maintaining an inventory of any needed replacement parts. All these costs should be taken into account when deciding what flowmeter to buy. This should be the one reason for many users to look beyond purchase price when considering flowmeter cost.

Ruchika Kalyani is a control system engineer at Fluor Daniel India Pvt Ltd.

# Flaring flows and sources

Why and how to use ultrasonic flowmeters for this demanding application.

by Fawaz AlSahan

**A**ccurate flare flow metering is important to account for production and energy loss, closing the gaps in the plant mass balance, and in reducing emissions and protecting the environment.

Existing industry regulations and standards provide helpful guidelines by defining the

acceptable accuracy limits for flare flowmeters. The challenge has always been how to reveal the flowmeter inaccuracy, and minimize errors in flare flow measurement. We've found practical tools to properly select, configure, install, test and maintain flowmeters in flare applications, and how to determine the flaring source using the

## USING CLAMP-ON ULTRASONIC FLOWMETERS FOR FLARE

Clamp-on ultrasonic flowmeters can't measure a low-pressure flared gas in a metallic pipe because the flared gas has lower acoustic impedance than metallic pipes. This causes the acoustic signal to travel in the pipe and not to the second transducer across the pipe.

To address this limitation, there are two solutions. One option is to increase the flared gas pressure, which is difficult to accomplish. The other is to install a clamp-on flowmeter on a nonmetallic pipe. This will lower the acoustic impedance of the pipe, and increase the possibility of acoustic signals traveling across the pipe and measuring the flow. Using a nonmetallic pipe in the flare header is also a challenging option, and will require a very comprehensive assessment before implementation.

**TABLE I: ERRORS RELATED TO USING A FIXED COMPOSITION\***

	Actual volume	Standard volume	Mass
<b>Case 1—Propane increased</b>			
Differential pressure meter	34%	34%	25%
Thermal flowmeter	2-15%	2-15%	35-45%
Velocity meter (optical, ultrasonic, vortex)	0%	0%	0%
<b>Case 2—Hydrogen added</b>			
Differential pressure meter	31%	31%	45%
Thermal flowmeter	100-300%	100-300%	300-700%
Velocity meter (optical, ultrasonic, vortex)	0%	0%	112%
<b>Case 3—CO<sub>2</sub> increased</b>			
Differential pressure meter	9%	9%	8%
Thermal flowmeter	2-5%	2-5%	15-20%
Velocity meter (optical, ultrasonic, vortex)	0%	0%	15%

\* The approximate measurement error under constant flow conditions when using a fixed composition of 1% CO<sub>2</sub>, 0.9% H<sub>2</sub>S, 97% methane, 1% ethane and 0.1% propane and the flare composition changes to:  
Case 1: 0.53% CO<sub>2</sub>, 0.47% H<sub>2</sub>S, 51.08% methane, 0.53% ethane, 47.39% propane  
Case 2: 0.4% CO<sub>2</sub>, 0.36% H<sub>2</sub>S, 38.8% methane, 0.4% ethane, 0.04% propane, 60% hydrogen  
Case 3: 12% CO<sub>2</sub>, 0.8% H<sub>2</sub>S, 86.22% methane, 0.89% ethane, 0.09% propane  
Source: API MPMS 14.10

built-in features provided by these flowmeter technologies.

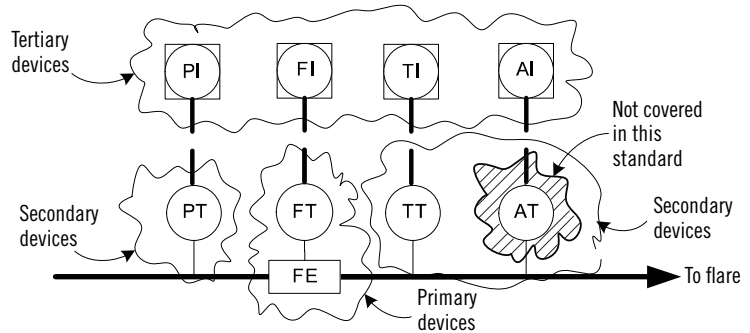
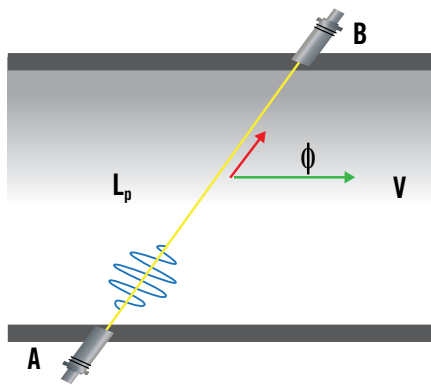
Each of the different flowmeters used for flare applications has limitations. For example, differential pressure (DP) flowmeters such as orifice plates and pitot tubes are sensitive to fouling and composition changes, and will require frequent calibration. Conventional thermal flowmeters are also sensitive to fouling, liquid and composition changes, and will require frequent calibration unless they have automatic composition measurement and correction. Vortex flowmeters also have limitations in

sensitivity to fouling and liquid, maximum flow capacity and maintenance difficulties.

An experiment (Table I) was carried out to demonstrate the possible errors in flare flow measurement using different types of flowmeters with different gas compositions. Because of the accuracies demonstrated in Table I and the above considerations, this article focuses on the use of ultrasonic flowmeters for flare applications.

## **FLARE FLOWMETER CHALLENGES**

Flare applications introduce many



## ULTRASONIC ESSENTIALS

**Figure 1: Ultrasonic flowmeters determine the flow velocity by measuring the difference in the travel time ( $t_{ab} - t_{ba}$ ) for a pulse moving from one transducer at one side of the pipe to another one at the other side ( $t_{ab}$ ) and vice versa ( $t_{ba}$ ). Secondary instruments for pressure and temperature are required to calculate the volumetric flow at standard conditions. Source: API MPMS 14.10, ISO 17089-2**

challenges on flow measurement and flowmeters, the major ones being:

- Flare can have a very low flow (0.01 m/sec) and a low pressure drop across the meter (typically 0.5 psig) is required.
- The flow can be non-axial and asymmetric. Laminar-turbulent transition flow introduces inaccuracy, and stratification (by sun or wind) can happen and affect the flow profile. Pulsating flow is also possible as the gas entry to the flare header is not continuous.
- High flow may cause low signal-to-noise ratio and probably liquid carry-over. High  $\text{CO}_2$ ,  $\text{H}_2\text{S}$ ,  $\text{N}_2$  and  $\text{H}_2$  can cause attenuation to the signal.
- Flare flow has a large turndown (2,000-4,000:1) and the gas composition is variable.
- Primary flow elements have uncertainties due to electronics drift, metrological (pipe

diameter, alignment) and process buildup.

Secondary instruments (temperature and pressure) have uncertainty due to electronics drift, mounting location and process buildup.

- The application might require a dual-path ultrasonic flowmeter (i.e., two sets of transducers) to either improve accuracy, cover very low flow conditions, or reduce the straight piping requirement.

## ULTRASONIC PRINCIPLE OF OPERATION

Ultrasonic flowmeters (UFM) can be either insertion or cross-pipe. Both types are installed as single- or dual-path. These flowmeters (Figure 1) determine the flow velocity and speed of sound by measuring the difference in the travel time ( $t_{ab} - t_{ba}$ ) for a pulse moving from one transducer at one side of the pipe to another one at

the other side ( $t_{ab}$ ) and vice versa ( $t_{ba}$ ). The transducers are inserted through the pipe wall, either by hot tapping or as an inline flowmeter (installed on a spool pipe). The flowmeter calculates the flared gas velocity ( $V$ ), volumetric flow at operating conditions ( $Q_{act}$ ) and volumetric flow at standard conditions ( $Q_{std}$ ).

Sound velocity ( $C$ ) is also calculated by this flowmeter. The value of sound velocity is used to estimate the molecular weight (MW) of the flare gas mixture. A mathematical or graphical correlation is experimentally extracted by testing many gas mixtures and defining their sound velocity and MW relationship. MW measurement helps in calculating the density and therefore the mass flow. Secondary instruments for pressure and temperature are required to calculate the volumetric flow at standard conditions. The setup of these secondary instruments is shown in Figure 1 or as advised by the flowmeter's manufacturer.

Referring to Figure 1, the main equations are:

- $V = [L / (2\cos\theta)] \times [1/t_{ab} - 1/t_{ba}]$
- $C = [L/2] \times [1/t_{ab} + 1/t_{ba}]$
- $Q_{act} = V \times \text{pipe area}$
- $Q_{std} = Q_{act} \times P/P_s \times T_s/T$

Where:

$V$ : flow velocity

$C$ : sound velocity

$Q_{act}$ : volumetric flow at actual flow conditions

$Q_{std}$ : volumetric flow at standard flow conditions

$L$ : distance between transducers

$t_{ab}$ : time for signal travel from transducer a to transducer b (and vice versa for  $t_{ba}$ )

$T, P$ : operating temperature, pressure

$T_s, P_s$ : standard temperature, pressure

## SPECIFICATION AND TESTING

ISO 17089-2 and BS 7965 define the required flowmeter uncertainty in flare application to be  $\leq 10\%$  for the flow above a certain minimum limit. This uncertainty can increase by 5% due to flowmeter installation effects. The flare flowmeter needs to be tested at the factory or at a third-party calibration shop. The main testing requirements are:

- Air is usually the testing media. A Reynolds number is used to account for differences in densities (between air and flared gas composition).
- Expansion of the flowmeter shall be considered in high velocity.
- Testing shall cover 0.03 m/s to the maximum design velocity. The flowmeter shall be tested at velocities 0.03, 0.15, 0.30, 0.61, 1.5, 3.0, 6.1, 15, 30 and 15 m/s increments up to the maximum operating velocity.
- The flowmeter shall be tested with the same pipe size and upstream/downstream straight piping.
- Pressure transmitter accuracy shall be maximum  $\pm 0.67$  kpa.

- Temperature transmitter accuracy shall be maximum  $\pm 2$  °C.
- The testing facility shall be traceable to NIST or equivalent national or international standard, and shall be accredited by ISO/IEC 17025.
- The factory and testing facility shall provide all the testing data and records of the installation, configuration and diagnostics data at the test bench.
- The manufacturer shall provide the flowmeter uncertainty and the installation effects.
- Testing shall be done at a low pressure and at ramping up and down.
- Transducers shall be retractable to allow online removal for testing and replacement.
- Recommended piping straight run is generally 20 diameters (20D) upstream and 10D downstream. This requirement can be relaxed based on the specific flowmeter installation and manufacturer recommendations, which must be verified.
- The end user shall consider accessibility for flowmeter maintenance and gas manual or automatic sampling.
- Pressure and temperature sensor mounting locations shall follow the flowmeter manufacturer's recommendations.
- Vibration shall be avoided by selecting the right location for the flowmeter and its associated panel.
- Any control valve with noise attenuation or fittings up or downstream shall be checked, as this can produce interference with the transducer pulses.
- The installation shall avoid liquid accumulation.
- Rapid pressurization or depressurization when removing or installing transducers shall be avoided.
- Manufacturer shall provide the accuracy impact when replacing any part or software of the flowmeter system.
- The hardware serial numbers, firmware and testing shall be submitted by the vendor.

## **INSTALLATION AND COMMISSIONING**

Requirements stated in API MPMS 14.10 and 22.3, ISO 17089-2 and BS 7965 will help users reach an accurate flare flow measurement. The major points to follow are:

- Manufacturer or manufacturer-certified entity shall be responsible to install and commission the flare flowmeter and all secondary instruments. This will eliminate critical problems, like transducer misalignment.
- The end user shall decide early on the installation approach (i.e., hot tapping, cold tapping or a complete spool piece). Definitely, the last option is the best option as it will eliminate all installation errors.

- All data and software configuration in electronics are saved as a backup. After commissioning, management of change (MOC) is required.

## FIELD VERIFICATION

To verify the reading of an installed ultrasonic flare flowmeter, there are many techniques. The steps and tools below can be used:

- The flowmeter manufacturer shall be requested to provide a written procedure for functionality testing and verification, inspection intervals and dimensional verification. Also, uncertainties and speed of sound calculations shall be provided.
- Wall thickness, inclination angle of transducers, length of acoustic path, the pipe internal diameter and pipe cleanliness shall be verified.
- Installed meter specifications and current operating conditions shall be checked to match the flowmeter's specification sheets and drawings.
- The installed flowmeter configuration and serial number shall be verified with the manufacturer requirements.
- Straight piping and installation of the meter, pressure and temperature transmitters shall be verified.
- Wiring shall be inspected for signs of moisture or physical damage.
- Performance of the flowmeter using the same transducers model and the same installation setup at a calibration shop can be checked. This is to verify the accuracy of the installed flowmeter, considering the same straight piping and mounting of the current field installation.
- The ultrasonic flowmeter reading can be verified using a secondary device such as:
  1. A second insertion flowmeter (such as a pitot tube).
  2. Optical method (laser doppler anemometer tracer), which requires a steady velocity.
  3. Tracer dilution technique: injecting a gas (like SF<sub>6</sub> or helium) and measuring the flow rate increase using a secondary flowmeter.
  4. Radioactive tracer: introducing a gaseous radioactive tracer and inserting two detectors to detect the passage (based on transit time). BS-5857-2 can be referenced for details.
- The transducers and the electronics can be verified using a zero flow box. This will provide zero calibration of transducers, and will also check speed of sound measurement for air compared to the estimated value (performed by the manufacturer software). Also, zero testing can be done for the electronics and cabling using dummy transducers and checking the signals.
- Absolute speed of sound (C) comparison, like injecting N<sub>2</sub> and determining C.
- Verification of the ultrasonic flowmeter can be also done by taking a sample of the flared gas and measuring SOS, and then comparing the measured value to the flowmeter estimated SOS. Difference shall be less than 0.25%.

- Another verification tool is comparing C and the velocity reading of one path, and comparing it to the second path. This is only applicable for dual path measurement (i.e., when two sets of transducers are installed).
- Flaring volume could be estimated by conducting mass balance or using process simulation, and the result can be compared to the flowmeter reading.
- Computational fluid dynamics (CFD). This is a modeling and verification technique, which is a cost-effective solution and helps to reveal installation errors. Also, it provides a correction for the flow profile and the missing straight piping run. The flow is modelled in 3-D coordinates considering turbulence and wall roughness. Manufacturers of flare flowmeters or some flow calibration labs can provide this service.

## ONLINE PERFORMANCE MONITORING

Ultrasonic flowmeters have the advantage of providing online diagnostics. Diagnostics can be used to check the health, performance and the accuracy of the flowmeter without the need to remove and physically check, calibrate or replace any part. Once the flowmeter is proven to be correctly selected, installed and commissioned, diagnostic parameters can be collected and used as a baseline for future online performance monitoring.

### DETERMINING FLARING SOURCE

Observing flared gas and not being able to determine which operating flare branch it's coming from is very frustrating for operating facilities. In many circumstances, the source of the flared gas is a leaking valve. However, identifying which valve and from which operating unit is difficult and time consuming.

An ultrasonic flowmeter offers a solution to this problem because the most valuable advantage of the technology is the sound velocity measurement. There's a determined sound velocity value for every type of gas and for every mixture of gases. Knowing the sound velocity will determine the molecular weight and composition of the flared gas. Knowing the composition will help the operating facility identify the potential sources of flaring. This is a unique feature of ultrasonic flowmeters.

The flare flowmeter manufacturer shall be requested to provide detailed diagnostics parameters along with their acceptable limits. Having these diagnostics parameters in the local display and also reflected in the remote workstation (i.e. distributed control system) is crucial for online performance monitoring. The main diagnostics parameters to be displayed and monitored are:

- System diagnostics: Transducers and electronics functionality check, flow

profile. This diagnostic parameter helps with the recalibration decision.

- Speed of sound (C): The measured C and the actual C can be compared to check the health of the flowmeter. Actual C is calculated using a gas sample and the flowmeter manufacturer software. Also, compare the initial flowmeter C reading and the current C.
- Signal strength/quality indicator: Signal-to-noise ratio (SNR) indicates the quality of ultrasonic signals. Distribution of SNR among transducers might indicate a source of a problem such as noise.
- Automatic gain control (AGC) level: As meter performance deteriorates, AGC level increases and a fault happens.
- Flow profile: A change in flow profile indicates viscosity changes and/or changes to pipe wall roughness.
- Axial velocity through the flowmeter.
- Meter performance: The ratio of transducers good pulses received to rejected pulses received. As the flow rate increases, meter performance decreases. Performance also decreases with a decrease in pressure.
- Temperature: Can indicate stratification in the gas flow.

Following the above steps will assist end users in evaluating their installed flare flowmeters and could also result in modifying or even replacing existing flowmeters to fix the system performance and installation errors. ∞

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# Getting to Know Insertion Flowmeters

Insertion Flowmeters Come in Many Varieties, but They All Share Similar Characteristics and Problems

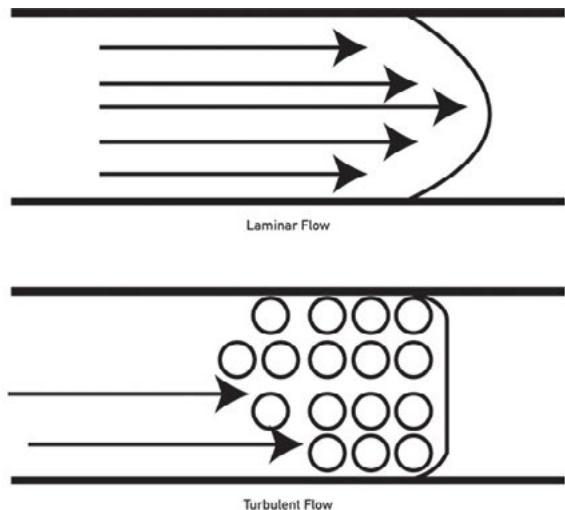
By Walt Boyes

**Y**ou can get flowmeters in insertion versions that are paddlewheel, propeller, turbine, magnetic, vortex and differential pressure sensors. Insertion flowmeters are popular in many industries, because they appear to be easy to install, inexpensive and come in technology variations that mimic full-pipe meters.

But with no exceptions, insertion flowmeters are not the same as their full-pipe counterparts. In fact, there is some evidence for David W. Spitzer's claim in his book *Industrial Flow Measurement* that insertion flowmeters are a type all of their own.

## HOW DOES THIS WORK?

In Figure 1, you see turbulent flow and laminar flow. These are based on the concept of the Reynolds number, which is a dimen-



### FULLY DEVELOPED FLOW

Figure 1. Turbulent flow from 4500+ Rn. Laminar flow from 0 to 2500 Rn.

sionless number relating to the ratio of viscous to inertial forces in the pipe. Laminar flow where the flow profile is straight and smooth occurs at Reynolds numbers of less than about 2500. Turbulent flow, where

there are eddies, vortices and swirls in the pipe, occurs above 4500 Reynolds numbers. Transitional flow, which is neither fully laminar nor fully turbulent, occurs between about 2500 and 4500 Reynolds numbers. Laminar flow profiles are usually visualized as being bullet-nosed, while turbulent flow profiles are seen as plug flows.

Without getting too far into the math, flow studies have shown that in a pipe with a fully developed flow regime, either fully turbulent or fully laminar, the average velocity in the line can be found at a point somewhere between 1/8 and 1/10 of the way in from the side wall, depending on the flow study you read.

## **INSERTION PADDLEWHEELS, PROPELLERS AND TURBINES**

There are three very similar types of insertion flowmeter that use a rotor that spins with the velocity of the fluid.

The first is a paddlewheel, because the rotor is parallel to the centerline of the pipe, just like a paddlewheel steamer. Paddlewheels range from very inexpensive to expensive, and are designed to be disposable. The least expensive ones use polymer bearings, which go out of round and cause the rotor to wobble before the rotor shaft cuts through a bearing and goes downstream.

The best use jeweled bearings and ceramic shafts so that they have much more longevity and less drag.

The spinning of the rotor is sensed by either a magnetic pickup that generates a sine wave the frequency of which is proportional to velocity, or a Hall effect sensor that generates a proportional square wave.

The advantage of the magnetic pickup is that it generates the sine wave without additional power. The advantage of the Hall effect sensor is that it does not cause “stiction” (the momentary friction stop when the rotor sees the magnetic pickup’s magnet). Hall effect sensors generally are able to read lower flow rates and are more accurate at lower flow rates as well.

Paddlewheel flow sensors are designed to be easily inserted into a small hole cut into the pipe using a custom fitting. Some paddlewheel sensors can be inserted into the pipe using a hot tap assembly, which allows the sensor to be inserted and retracted without shutting down the flow or relieving the pressure in the pipe.

Propeller meters use a prop shaped very much like an outboard motor’s propeller and are generally connected to a mechanical or electromechanical totalizer with a

cable very much like a speedometer cable. In fact, there is a legend that one very large manufacturer of propeller meters made a very inexpensive lifetime buy of Ford Pinto speedometer cables and used them for years. Some more modern propeller meters use embedded magnets and either magnetic pickups or Hall effect sensors. Like paddlewheels, propeller meters have a pulse output that is proportional to the average velocity in the pipe. Because propeller meter rotors are large and located at the centerline of the pipe, they are likely to be quite accurate, and even insertion propeller meters have been certified for billing purposes for decades.

Propeller meters, because their prop is significantly larger than a paddlewheel, are inserted using a flange that mounts into the upright member of a tee fitting.

Turbine meters come in both electronic and electromechanical styles, but the only insertion turbine flowmeters are electronic. They, like paddlewheels, use either a mag pickup or a Hall effect sensor to produce an output pulse that is proportional to the velocity of the fluid. Like paddlewheels, they must be inserted to the “average velocity point” that exists somewhere between 1/8 and 1/10 of the inside diameter away from the pipe wall.

Most insertion turbine meters have very small rotors, so they can be inserted through a small diameter fitting or through a small diameter hot tap assembly. Sometimes, especially in the municipal water industry, this is called a “corporation cock assembly,” but it is essentially the same thing—a way of inserting a probe through a valve and still maintaining the pressure in the pipe without leaks. At least one vendor uses a larger turbine rotor and claims significantly better accuracy, especially at low flow rates. Your mileage may vary.

Propeller meters are almost always used for water service, either in potable water systems or in irrigation systems.

Paddlewheels and insertion turbines can be used in a variety of applications, with materials of construction varying based on the requirements of the applications, such as acids, bases, and hot or cold fluids.

Electronic paddlewheels and turbines can be set up to be bidirectional using quadrature detectors, which enable the signal to indicate either forward or reverse flow as well as flow rate. These are often used in HVAC applications where chill water and hot water flow through the same lines depending on the season.

The signal from the paddlewheel or turbine or electronic propeller meter is sent to a transmitter, which uses the pulse (or frequency) output to display flow rate and increment a totalizer (usually electronic). These transmitters generally have a pulse output, an analog output (usually 4-20 mADC), and often have one or two programmable relay contact closure outputs. These can be used as flow alarms, as diagnostic alarms or as a rudimentary dead-band controller.

## **INSERTION DP FLOWMETERS**

The most commonly used flow sensor in the world continues to be the differential pressure transmitter connected to a primary device such as an orifice plate or Venturi tube. In its insertion incarnation, the differential pressure sensor is connected to a pitot tube inserted in the flow stream, and just as a pitot tube measures velocity on the outside hull of an aircraft, the pitot tube measures the velocity in the fluid flowing in the pipe.

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