Flowmeters: New technologies battle enhanced measurement workhorses

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Coriolis mass, ultrasonic, and vortex flowmeters are taking on multivariable flowmeters and pressure transmitters with improved sensors.

Flow measurement is one of the most important functions in modern industrial plants. Whether the application involves oil from a well, hydrocarbon in a refinery, or steam in a chemical plant, accurate flow measurement is essential to efficient and productive manufacturing operations.

This article discusses the operating principles of the different types of flowmeters currently available, as well as their advantages and disadvantages. It also identifies new flowmeter technologies that are replacing more traditional methods based on differential pressure (DP)-based measurement, and explains why this occurring.

(*Editor's note: An expanded version of this article that includes a discussion of a different way of viewing flow geometry appears on the* I&CS *Web Site. You'll find it in the "Online Articles" section at www.chilton.net/ics/articles.htm.*)

Types of flowmeters

Most flowmeters can be classified among the types listed in Table 1 (though you will undoubtedly run into other classification structures). The table lists flowmeter types, along with a brief description of the technology used by each type.

DP-based flowmeters measure the decrease in pressure that occurs when there is a restriction in the flow path. The type of DP-based flowmeter varies with the type of restriction—with the restriction being referred to as the primary element. The main types of primary elements are orifice plates, venturis, flow nozzles, and averaging Pitot tubes.

Table 1: Types of flowmeters and flowmeter technologies

Flowmeter type	Technology
DP-based	An obstruction is placed in the flow path, and the difference in pressure is measured before and after the obstruction. This pressure difference is used to calculate flow rate.
Magnetic	Flow rate is calculated by measuring the voltage generated by electrically conductive material as it moves through a magnetic field.
Coriolis mass	Fluid passes through a vibrating tube, causing the tube to twist; the amount of twisting is proportional to mass flow.
Thermal mass	Some thermal mass thermometers measure the rate of heat loss in a fluid when a heated wire thermistor is placed in the fluid; others measure temperature increase in a flowing stream when it passes over heated materials.
Open channel	Many use weirs or flumes and calculate flow rate based on liquid level; others use velocity, level, depth, or diameter information to calculate flow.
Positive displacement	Fluid is caught or drained into a cavity or area of known quantity, then drained out; flow rate is calculated by counting the number of times this action occurs.
Turbine	A rotor with propeller-like blades rotates as fluid passes over it; the fluid force turns the blades; flow rate is proportional to blade rotation speed.
Ultrasonic	Flow rate is calculated by measuring the time it takes an ultrasonic pulse in the form of a wave to travel a specified distance; main types are transit time and Doppler.
Vortex	A bluff body, also called a shedder bar, generates vortices; flow rate is determined by counting the number of vortices generated.

Magnetic flowmeters are used exclusively for conductive liquids or slurries, and are widely used in the food and beverage and pulp and paper industries. The sizes of magnetic flowmeters range from under one inch to nearly 100 inches.

Coriolis flowmeters measure mass flow directly by sensing the effect of flowing liquid on a vibrating tube. They are known mainly for their high accuracy, and are the most expensive flowmeter, in terms of initial price, within their size range. They range in size from under one inch to six inches. Besides mass flow, many Coriolis meters also provide a density measurement.

Thermal mass flowmeters are mainly used to measure the flow of clean gases with known heat capacities. They are largely used in the refining and chemical industries.

While most flowmeters measure flow in closed pipes, open-channel flowmeters are used to measure the flow of liquids in open channels and partially-full pipes. In many cases, open-channel flowmeters are the only type of measurement device available. They are widely used in the water and wastewater industry and process plants to measure the flow of effluent.

Positive displacement (PD) flowmeters are based on the idea of collecting fluid in a container of known size, then counting how many times the container can be filled with the fluid. PD meters are very accurate, and widely used in the oil and gas industry.

Turbine flowmeters rely on a rotor that spins in proportion to flow rate. They are widely used to measure both liquid and gas flow. The American Gas Association (AGA) has published a standard for use of turbine meters called AGA-7. The American Petroleum Institute (API) has also published standards for the use of turbine meters.

Ultrasonic flowmeters were first introduced commercially in 1963. In the early days of their use, they gained a bad reputation, mainly because they were being misapplied. Recent improvements have dramatically improved their accuracy, and have reversed this negative impression. Today, the worldwide ultrasonic flowmeter market is the fastest growing of all flowmeters, outpacing even the Coriolis meter market.

Vortex flowmeters were introduced in the early 1970s. They rely on the generation of vortices by a bluff body placed in the flow stream. Vortex meters are most widely used for steam measurement, but can also be used to measure liquid and gas. These instruments have higher accuracy than DP-based meters using an orifice plate, and their installation is relatively simple.

Flowmeter advantages and disadvantages

While reasons for selecting one flowmeter over another vary, users typically make their decisions based on the perceived advantages and disadvantages of the flowmeters they are considering. A complete list of advantages and disadvantages would take into account at least these criteria: accuracy, reliability, purchase price, installed cost, cost of ownership, ease of use, capability of measuring liquid, steam, and gas, rangeability, turndown, degree of smartness, repeatability, pressure drop, intrusiveness, Reynolds Number constraints, sizes available, maintenance, sensitivity to vibration, and upstream and downstream piping requirements *(Table 2)*.

Volumetric flow vs mass flow

Flow in a pipe is the actual volume of fluid that passes a given point in a specified unit of time. Volumetric flow (Q) can be calculated by multiplying the cross-sectional area of the pipe times average fluid velocity. Typical units of volumetric flow include gallons (or liters) per minute and cubic feet (or meters) per minute.

The flow of gases is normally measured in terms of mass per unit time. Mass flow (W) of a gas can be calculated by multiplying its density (ρ) times the volumetric flow. Typical units of mass flow include pounds (or kilograms) per minute and standard cubic feet (or meters) per minute.

While most liquids are nearly incompressible, densities of gases vary with operating temperature and pressure. Some flowmeters, such as Coriolis meters, measure mass flow directly. While volumetric flowmeters do not measure mass flow directly, mass flow can be computed from density and volumetric flow ($W = Q\rho$). Some volumetric meters infer density based on the measured pressure and/or temperature of the fluid, then use this density value together with volumetric flow to compute mass flow. This is called an inferred method of measuring mass flow.

New technologies displace workhorses

One of the most significant trends in today's flowmeter market is that new technologies, such as Coriolis mass, ultrasonic, and vortex, are displacing traditional DP flowmeters that use orifice plates and other primary elements. These newer technologies are also displacing turbine and positive displacement flowmeters.

The increasing need for highly-accurate measurements is the principal driving force behind the increased use of Coriolis mass flowmeters. Ultrasonic flowmeters are being used more because they are nonintrusive, have wide rangeability, and are substantially more accurate than they were ten years ago. Vortex flowmeters are used because they have low installed cost, low maintenance, and can measure steam, liquid, and gas. Thus, the perceived advantages of the new technology flowmeters are driving the flowmeter market.

While there is no doubt about the trend toward new technologies, the speed with which the large installed base of traditional technologies (e.g., orifice plate, turbine, and positive displacement meters) is being displaced is being limited by several factors. To begin with, users prefer to stick with a proven technology, and typically need a compelling reason to move to a new technology. As a result, they often choose the same type of flowmeter when selecting a replacement meter. Also, many users simply do not understand the newer technologies well enough to feel comfortable selecting them. And finally, the traditional technologies have a strong advantage in approvals from industry associations such as the AGA and the API. While this is changing, it is changing slowly.

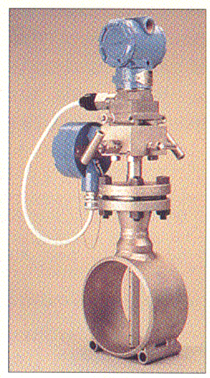
However, pressure transmitter suppliers are not standing idly by while their market shares in flow measurement lose ground to alternative technologies. They have responded in two ways: introducing multivariable flowmeters that provide a measurement of inferred mass flow, and accelerating the search for improved primary elements to use with pressure transmitters.

Multivariable flowmeters for inferred mass flow

Most volumetric flowmeters, such as DP-based flowmeters, sense a single process variable and calculate volumetric flow based

Table 2: Advantages and disadvantages of different types of flowmeters

Flowmeter type	Advantages	Disadvantages	Primary process industries	Liquid, steam, or gas
Differential pressure-based orifice plate	Low initial cost; familiar technology; easy to use	Subject to plugging; pressure drop; subject to wear	Chemical, oil & gas, refining, power	all
Magnetic	Accuracy; no pressure drop; bidirectional measurement; well-suited to measure flow in big pipes	Requires conductive fluids; electrodes subject to coating	Chemical, water & wastewater, pulp & paper, food & beverage	liquid
Coriolis mass	High accuracy; true mass flow measurement	Sensitive to vibrations; high initial cost; not suitable for big pipes	Chemical, food & beverage, refining, pulp & paper	all
Thermal mass	Low cost; capable of measuring low density fluids	Requires periodic cleaning; not highly accurate	Chemical, water & wastewater, power, refining	gas
Open channel	Many methods available; low installed cost; familiar technology	Weirs get clogged by debris; flumes are more expensive and less accurate than weirs	Water & wastewater, chemical, refining, pulp & paper	liquid
Positive displacement	Accuracy; wide rangeability	Subject to wear; limited use for large pipe sizes; requires clean flow	Oil & gas, refining, chemical, pulp & paper	liquid, gas
Turbine	Accuracy; widely proven and accepted technology	Moving parts subject to wear; high flow velocity can damage meter	Oil & gas, refining, chemical, water & wastewater	liquid, gas
Vortex	Accuracy; ease of installation; measures liquid, steam, and gas	Vibration can affect accuracy; lacks industry association approvals	Chemical, refining, power, food & beverage	all
Ultrasonic	Low maintenance; non-intrusive; well-suited to measure flow in big pipes; clamp-on models available	High initial cost; some models require clean fluids	Water & wastewater, chemical, refining, oil & gas	liquid, gas



(counter clockwise)
FIG. 1: Multivariable technology is not limited to differential pressure transmitters. Honeywell has introduced a multivariable version of its MagneW 3000 Plus magnetic flowmeter that uses a process temperature measurement and a density compensation calculation to calculate mass flow.

FIG. 2: Sierra Instruments recently introduced its Innova-Mass multivariable vortex flowmeter. This instrument measures mass flow, along with four other process variables.

FIG. 3: Fisher-Rosemount has integrated its Model 3095 MV transmitter with the Annubar to create the Mass ProBar—a system that computes mass flow from the differential pressure, static pressure, and temperature process values.

on this parameter. However, the past few years have seen the introduction of multivariable flowmeters that measure more than one process variable, and produce more than one output.

Among the multivariable flowmeters currently available are pressure transmitters that use differential pressure, static pressure, and process temperature measurements to calculate mass flow. Examples of these instruments include the Model 3095 MV from Fisher-Rosemount and the SMV 3000 from Honeywell. These multivariable pressure transmitters can do the same job as two pressure transmitters, a temperature transmitter, and a flow computer.

While transmitters such as these measure mass flow, the measurement is a calculated, or inferred, value rather than a direct measurement, as is achieved with Coriolis flowmeters. Calculated mass flow is less accurate than a direct measurement because of the inaccuracies in the variables involved in the calculation.

Multivariable technology is not limited to DP transmitters. Honeywell has introduced a multivariable version of its MagneW 3000 Plus magnetic flowmeter *(Fig. 1)*. This flowmeter uses a process temperature measurement and a density compensation calculation to calculate mass flow. And Sierra Instruments has recently introduced its Innova-Mass *(Fig. 2)*, a multivariable vortex meter that measures mass flow *(see* I&CS, *Oct. 1997, p 96)*.

Changes in the primary element market

In addition to introducing multivariable flowmeters, some pressure transmitter suppliers are taking a new look at the role of primary elements in the measurement of flow. Fisher-Rosemount has shown that it's serious about primary elements by purchasing Dieterich Standard, a primary elements supplier that sells the Annubar—an averaging Pitot tube. Fisher-Rosemount has integrated its Model 3095 MV transmitter with the Annubar to create the Mass ProBar *(Fig. 3)*, a system that computes mass flow from the differential pressure, static pressure, and temperature process values. What's unique about the Mass ProBar is that it's a DP flowmeter. By integrating a sensing element with a transmitter in a single unit, this system resembles most other flowmeters, and simplifies installation and calibration procedures.

The implications of this approach are significant. It provides a way for pressure transmitter suppliers to reduce the encroachment of other new technology flowmeters into DP-based flow measurement. Instead of switching out of DP-based flow measurement altogether, users can switch to a new primary element. At the same time, they can take the opportunity to upgrade to multivariable flowmeters.

Ongoing flow measurement development

Primary flow elements are important because they place a limitation on the accuracy of any flowmeter using them. Today,

The need for a new geometry of flow

One other area that may prove fruitful in providing a fresh perspective on flow measurement consists of taking a new look at the geometry of flow. One reason that flow measurement is so difficult conceptually is that volumetric flow requires a value for area, A, in the flow equation, $Q = Av$. Because most pipes are round, the calculation of area requires the use of π (pi), an irrational number that represents the ratio of the circumference to the diameter of a circle. The value r^2 in the formula for the area of a circle, πr^2, is the value of a square whose borders have the value of the radius of the circle. The formula πr^2 represents the number of squares corresponding to this radius that can be fit inside the circle. Yet, as everyone knows, it is impossible to fit a square peg into a round hole. It's no wonder, then, that there is no definite number of squares that will fit inside a circle.

When Rene Descartes invented the Cartesian coordinate system, he created a frame of reference consisting of two intersecting straight lines which has been used since his time to measure curved and circular areas. It took calculus, with the introduction of the concept of the limit of a function as it approaches infinity, to solve the problem of how to represent the area under a curve. Given the straight-line frame of reference assumed by calculus, it is no wonder that it took the use of the fundamentally incomprehensible notion of infinity to plug the geometric gap created by a straight-line frame of reference that is not suited to curved area. Anyone who has struggled to understand the concepts of calculus can appreciate that there might be a simpler way of doing things. Nonetheless, even the non-Euclidean geometries of the 19th century did not abandon the Cartesian coordinate system.

There is, in fact, a better way to analyze curved and circular area. Cartesian geometry essentially assumes the square inch as a primitive in analyzing the area of a circle or any other geometric figure that can be drawn on the Cartesian plane, leading to the fit of a square peg in a round hole. If a unit circle (a round inch) is assumed as a primitive instead of a unit square, it is possible to generate a geometry that has rational values for the area of a circle. Of course, squares would now have irrational values in this geometry. But possibly square and circular areas are incommensurable, and there is no way to convert from one to the other without using irrational numbers. If this is the case, we may need a new circular geometry that can provide rational values for circular area.

In a circular geometry, the Cartesian coordinate system is replaced by a series of unit circles that serve as the frame of reference for analyzing circular area. If such a geometry can be developed, it will greatly simplify the way in which flow is measured. The fundamental flow equation, $Q = Av$, will not change, but area will no longer have an irrational value. While many details remain to be worked out, this new circular geometry has the promise of bringing rationality to flow measurement.

users are attaching pressure transmitters with 0.5% accuracy or better to orifice plates that have 3% accuracy or greater. Even if an orifice plate has an initial accuracy of better than 3%, this accuracy typically degrades with use. Yet the accuracy of any flowmeter system is no better than the accuracy of its weakest element. As a result, highly accurate transmitters are sending digital signals to the controller that can be carried out to any desired degree of precision, but that carry the baggage of inaccurate sensing elements.

Attempts to find improved primary elements are part of a broader search for improvements in flow sensing. The search for the ultimate flow sensor, whether it's in the form of a primary element or some new type of sensor no one has yet conceived, is an ongoing goal of flow measurement research.

Whether or not anyone succeeds in finding an ultimate flow sensor, finding more accurate sensing techniques is the next logical step in generating more accurate flow measurements. Companies will continue to refine the sensors on existing magnetic, vortex, Coriolis, ultrasonic, and other flowmeters, while their R&D groups continue their efforts to invent previously untried ways to sense and measure flow.

About the author

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