TRENDS IN FLOWMETER DESIGN

By *Jesse Yoder*

Anyone who observes the flowmeter market today can see very quickly that the demand for some types of flowmeters is growing faster than the demand for other types. For example, the use of Coriolis and ultrasonic flowmeters is increasing at a much faster rate than the use of positive displacement or variable-area meters. The reason for this trend is due in large part to the advent of newer technologies, including advancements in computer processing capability.

Published articles have proposed a distinction between the growing technologies and the flat or declining technologies by classifying them into two categories — new-technology flowmeters and traditional-technology flowmeters. This article restates the distinction between new-technology and traditional-technology flowmeters. It then explains the paradigm case method for flowmeter selection, as it applies to new-technology flowmeters.

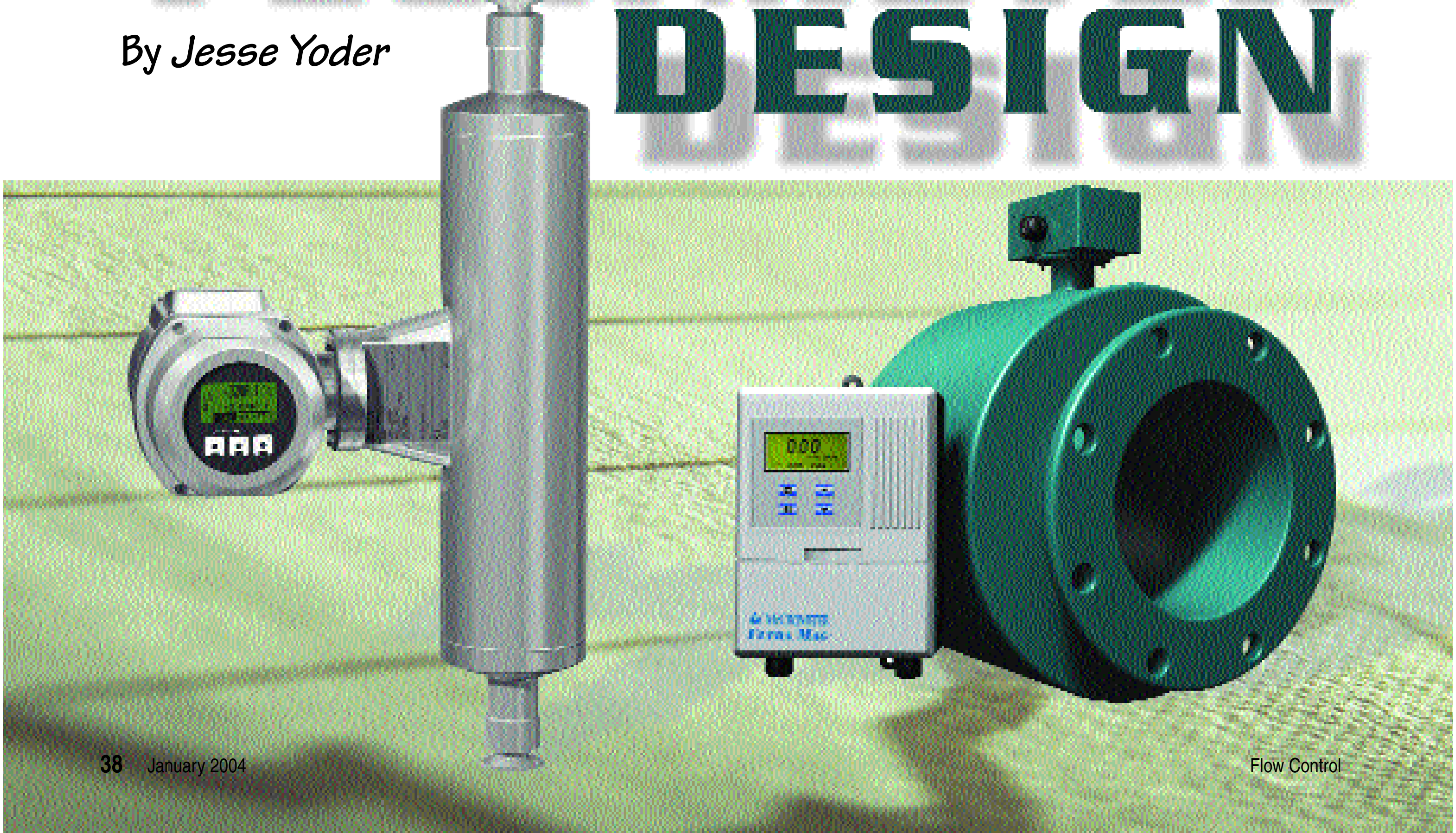
New-Technology Flowmeters

Most new-technology flowmeters came into industrial use in the 1960s and 1970s, while differential pressure flowmeters (traditional technology) were used in the early 1900s. Each new-technology flowmeter is based on a different physical principle and constitutes a unique approach to flow measurement.

New-technology flowmeters have the following characteristics:

1. They were developed after 1950.
2. They incorporate technological advances that overcome problems inherent in earlier flowmeters.
3. They attract more development attention from major flowmeter suppliers than traditional-technology meters.
4. They perform at a higher level than traditional-technology meters.

Included in this category are Coriolis, magnetic, ultrasonic, vortex, and multivariable differential pressure (DP) meters. All of these flowmeters have been introduced since 1950. Magnetic flowmeters first came onto



the market in 1952, while Tokimec (then Tokyo Keiki) introduced ultrasonic meters in Japan in 1963. Eastech brought out vortex meters in 1969, and Yokogawa developed its vortex meter at about the same time. Micro Motion introduced Coriolis flowmeters in 1977. Bristol Babcock brought multivariable DP flowmeters onto the market in 1992.

Flowmeters that incorporate older technologies are "traditional-technology" flowmeters. These include single variable DP, positive displacement, turbine, open channel, thermal, and variable-area flowmeters. As a group, these flowmeters have been in use longer than new-technology meters. Generally speaking, they have higher maintenance requirements than new-technology flowmeters. And even though suppliers continue to introduce new traditional-technology flowmeters, they are not typically the focus of new product development.

The history of turbine flowmeters goes back to the mid-1800s, while DP meters came into use in the early 1900s. Many of the problems inherent in DP flow measurement have to do with the primary elements used together with a DP transmitter. For example, orifice plates can be knocked out of position by impurities in the flowstream, and they are subject to wear. Positive displacement and turbine meters have moving parts that are subject to wear. The accuracy levels of open channel, thermal, and variable area flowmeters are substantially lower than that of new-technology flowmeters.

Coriolis Flowmeters

Coriolis flowmeters are made up of one or more vibrating tubes, usually bent. The fluid to be measured travels through the vibrating tubes. The fluid accelerates as it approaches the point of maximum vibration and decelerates as it leaves this point. As a result, the tubes take on a twisting motion. The amount of twisting motion is directly proportional to mass flow. Position detectors are used to sense the positions of the vibrating tubes. Most Coriolis flowmeter tubes are bent, and many different designs are available. However, some suppliers have also introduced straight-tube Coriolis meters.

Straight-tube flowmeters operate on the same principle as bent-tube meters. Fluid inertia causes the fluid in the first half of the meter to accelerate, while the fluid decelerates in the second half of the meter. The inertia of the fluid generates a Coriolis force that slightly distorts the measuring tube. The amount of this distortion is proportional to mass flow. Sensors are used to detect the amount of distortion. Temperature is constantly measured because the oscillatory properties of the tube vary with temperature. This makes it possible to make any necessary adjustments in the measurement.

It is often said that Coriolis flowmeters measure mass flow "directly," unlike other flowmeters that calculate mass flow by using an inferred density value. Multiplying the cross-sectional area of a pipe by the fluid's average velocity yields volumetric flow (Q). Mass flow is obtained by multiplying volumetric flow (Q) by fluid density. Some multivariable flowmeters measure the temperature and pressure of the fluid and use these values to infer the density of the fluid. It is then possible to calculate mass flow.

Coriolis meters can be used to measure flow of both liquids and gases. While these meters are highly accurate, they are limited in terms of the pipe sizes they can efficiently be used on. Over 90 percent of Coriolis flowmeters are used in pipe sizes of two inches or less. While they can be used in pipes up to and including six inches in diameter, the meters become expensive and unwieldy in the larger pipe sizes.

Paradigm Case Applications for 'New-Technology' Flowmeters

While a number of different methods of flowmeter selection have been devised, the most effective approach incorporates a step-by-step method that begins by matching the applications involved with the paradigm case applications for various flowmeters. The selection process should also apply application, performance, cost, and supplier criteria in order to select a flowmeter. A statement of the paradigm case method follows.

1. Every flowmeter is based on a principle that draws a correlation between flow and some specified set of conditions. This principle determines the paradigm case application for this particular type of flowmeter. The first step is to select those types of flowmeters whose paradigm case applications are most like your own.

2. Make a list of application criteria that relate to the flow measurement you wish to make. These conditions may include fluid type (liquid, gas, steam slurry), measurement type (volumetric or mass), pipe size, process temperature and pressure, fluid condition (clean or dirty), fluid density, flow profile considerations, fluid viscosity, range, Reynolds number constraints, and other. From the type of flowmeters selected in Step One, select those that meet these application criteria.

3. Make a list of performance criteria that apply to the flowmeter you wish to select. These include accuracy, reliability, range, repeatability, and others. From the flowmeters selected in Step Two, select those that meet your performance criteria.

4. Make a list a list of cost criteria that apply to your flowmeter selection. These include purchase price, installation cost, cost of ownership, maintenance cost, and others. From the flowmeters selected in Step Three, choose those that meet your cost criteria.

5. Make a list of supplier criteria that govern your selection of a flowmeter supplier. These include flowmeter type, service requirements, company location, training, responsiveness, internal requirements, and others. From the flowmeter types selected in Step Four, select the suppliers of those flowmeters who meet your supplier criteria.

6. For the final step, review the flowmeters selected in Step Four and the suppliers selected in Step Five. Review the application, performance, and cost conditions for the flowmeter types that remain, and select the one that best meets these conditions. Now, select the best supplier for this type of flowmeter from the suppliers specified in Step Five. You now have selected the best supplier for the flowmeter type that best meets your criteria.

It is possible that an application may fit the paradigm case for more than one flowmeter type. In this case, steps two through four are especially important in determining which type of meter to use. In some cases, however, new-technology flowmeters are complementary rather than competing. For example, Coriolis flowmeters work best in pipe sizes of two inches and less, while ultrasonic flowmeters typically work best in pipe sizes of six inches and up. This is especially true for natural gas applications. So pipe size can sometimes dictate whether to use a Coriolis or ultrasonic flowmeter. And if an application involves hydrocarbons, gas, or steam, magnetic flowmeters should not be selected.

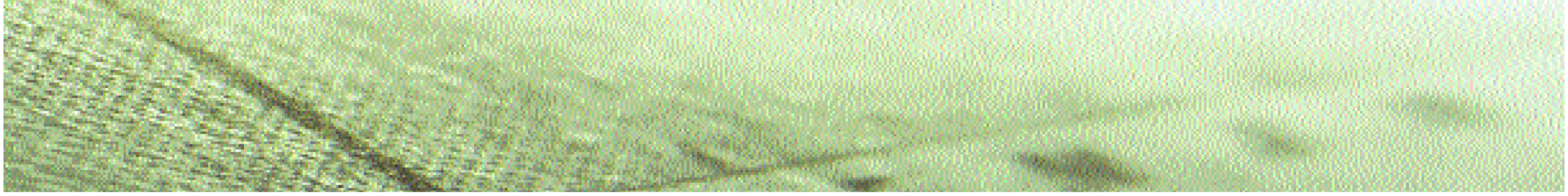
Reliability and accuracy are the two highest rated performance criteria by flowmeter users. Coriolis meters have the highest accuracy, followed by ultrasonic and magnetic meters. While Coriolis flowmeters typically have a higher purchase price, many users are now distinguishing between initial cost and cost of ownership. A flowmeter that offers reduced maintenance costs may be a better value than one with a lower purchase price that requires significant maintenance.

In many cases, users may choose to replace like with like when selecting a flowmeter to buy. They may do this for several reasons. Some users build up a stockpile of parts. It can be expensive to train staff on the use of a new flowmeter. And selecting a different flowmeter type may mean changing suppliers. Differential pressure flowmeters have a large installed base, and will continue to maintain significant market share over the next few years.

Multivariable flowmeters are an important growing trend in the flowmeter market. Multivariable flowmeters are flowmeters that measure more than one process variable. For example, multivariable flowmeters may measure temperature and/or pressure in addition to flow. Both multivariable magnetic and vortex flowmeters have been developed, and more types are likely in the future.

Multivariable transmitters are one way for suppliers of DP flowmeters to hold onto market share in the face of the growing trend towards new-technology flowmeters. Users can replace a DP transmitter with a multivariable transmitter, while leaving the primary element in place. Multivariable DP transmitters also measure more than one process variable, but may not measure flow. For example, some multivariable transmitters measure pressure (DP and/or P) and temperature, and output the results to a flow computer for the flow calculation. Other DP transmitters contain the computer power onboard to make a volumetric and/or mass flow calculation.

Multivariable flowmeters are considered to be new-technology flowmeters. However, magnetic and vortex meters are already new-technology flowmeters, so this mainly applies to multivariable DP flowmeters. A multivariable DP flowmeter is a multivariable DP transmitter that has the onboard capability of computing flowrate and is attached to a primary element. A DP transmitter that is not attached to a primary element is simply a transmitter and is not yet a flowmeter. Some companies are offering a multivariable transmitter connected to a primary element such as an orifice plate or an Annubar. This is an important new trend in the flowmeter market.



Coriolis flowmeters have a relatively high initial cost, although both Micro Motion and Endress & Hauser have introduced Coriolis meters with prices in the $3,000 range. While these lower-cost meters do not have the same accuracy level as the higher-priced meters, they represent an important breakthrough in terms of price. The higher cost of Coriolis flowmeters is offset by normally low maintenance costs. These meters can be used to measure the flow of some fluids with varying densities that cannot be measured by other flowmeters.

Type of Flowmeter	Paradigm Case Conditions	Comment
Coriolis	Clean liquids and gases flowing sufficiently fast through pipes two inches or less in diameter.	Measure mass flow directly; some provide density measurement
Magnetic	Conductive liquids flowing through full pipes that do not contain materials that could damage the liner or coat the electrodes.	Do not work with gas or steam
Ultrasonic: Transit Time	Clean, swirl-free liquids and gases of known profile	High accuracy may require the use of a multipath meter
Vortex	Clean, low viscosity, swirl-free, medium to high-speed fluids.	Work for liquids, gas, and steam

Table 1. *The principles of operation for new-technology and DP flowmeters.*

Paradigm Case Application: Coriolis Flowmeters

The paradigm case application for Coriolis flowmeters is with clean liquids and gases flowing fast enough to operate the meter and flowing through pipes of two inches or less in diameter. While three, four, and even six-inch meters are available, conditions are not ideal for meters of these sizes due to the required size of the meter. Some low-pressure gases do not have sufficient density to operate the meter.

Coriolis meters have the advantage that they can be used to measure different types of fluids, including fluids that have different density values. They can be used to measure the flow of dirty liquids and slurries. However, it is advisable to measure these fluids at relatively low flowrates to reduce the possibility of meter wear.

Magnetic Flowmeters

Magnetic flowmeters use Faraday's Law of Electromagnetic Induction. This principle states that a voltage is generated in a conductive medium when it passes through a magnetic field. This voltage is directly proportional to the velocity of the conductive medium, the density of the magnetic field, and the length of the conductor. These three values are multiplied together in Faraday's Law, along with a constant, to yield the magnitude of the voltage.

Magnetic flowmeters use coils that are generally mounted outside of a pipe, although some models have the coils mounted inside the pipe wall. As current passes through these coils, a magnetic filed is generated inside the pipe. As conductive fluid passes through the pipe, a voltage is generated and detected by electrodes that are mounted on either side of the pipe. The flowmeter uses this voltage value to calculate flowrate.

Magnetic flowmeters can be sued to measure the flow of conductive liquids and slurries, including black liquor and paper pulp slurries. Their main limitation is that they cannot be used to measure hydrocarbons, which are nonconductive. As a result, they are not widely used in the petroleum industry. Magmeters, as they are often called, create little to no pressure drop, and are highly accurate. While their initial purchase price is relatively high, most magmeters are priced lower than equivalent Coriolis meters.

Flowmeter	Type Technology
Coriolis	Fluid is passed through a vibrating tube; this causes the tube to twist. Mass flow is proportional to the amount of twisting by the tube
Magnetic	Creates a magnetic field within a pipe, typically using electrical coils. As electrically conductive fluid moves through the pipe, it generates a voltage. Flowrate is proportional to amount of voltage, which is detected by electrodes
Ultrasonic: Single Path Transit Time	Measures the time it takes for an ultrasonic pulse or wave to travel from one side of a pipe to the other. This time is proportional to flowrate.
Ultrasonic: Multipath Transit Time	Uses multiple ultrasonic paths to calculate flowrate; typical paths are two to six.
Ultrasonic: Doppler	Calculates flowrate based on the shift in frequency observed when ultrasonic waves bounce off particles in the flowstream
Vortex	A bluff body is placed in a flowstream; as flow passes this bluff body, vortices are generated. The flowmeter counts the number of vortices, and flowrate is proportional to the frequency of vortices generated.

Table 2. *A summary of paradigm case applications for different types of new-technology flowmeters.*

Flowmeter	Type Technology
DP-Orifice Plate	A flat metal plate with an opening in it; a DP transmitter measures pressure drop and calculates flow rate
DP-Venturi Tube	A flow tube with a tapered inlet and a diverging exit; a DP transmitter measures pressure drop and calculates flowrate
DP-Pitot Tube	An L-shaped tube inserted into a flowstream that measures impact and static pressure; the opening of the L-shaped tube faces directly into the flowstream. The difference between impact and static pressure is proportional to flowrate.
DP-Averaging Pitot Tube	A Pitot Tube having multiple ports to measure impact and static pressure at different points. Flowrate is calculated by DP transmitter based on average of difference in pressure readings at different points.
DP Flow Nozzle	A flow tube with a smooth entry and sharp exit; flowrate is calculated based on difference between upstream and downstream pressure

Paradigm Case Application: Magnetic Flowmeters

The paradigm case application for magnetic flowmeters is for conductive liquid flowing through a full pipe that does not contain materials that damage the liner or coat the electrodes. The most important limitation on magnetic flowmeters is that they do not work with nonconductive fluids. Since gases and steams are nonconductive, magmeters cannot be used to measure them. The pipe has to be full of liquid, since magmeters compute flowrate based on velocity times area. Liner damage and electrode coating can affect the accuracy of magnetic flowmeters.

Ultrasonic Flowmeters

Tokyo Keiki (now Tokimec) first introduced ultrasonic flowmeters for industrial use in Japan in 1963. Transit time and Doppler are the two main types of ultrasonic flowmeter. Transit time meters have both a sending transducer and a receiving transducer. The sending transducer sends an ultrasonic signal from one side of a pipe to the other. A signal is then sent in the reverse direction. When an ultrasonic signal travels with the flow, it travels faster than when it travels against the flow. The flowmeter measures both transit times. The difference between the two transit times (across the pipe and back again) is proportional to flowrate. Transit time flowmeters are mainly used for clean liquids.

Like transit time flowmeters, Doppler meters send an ultrasonic signal across a pipe. However, the signal is reflected off moving particles in the flowstream, instead of being sent to a receiver on the other side. The moving particles are traveling at the same speed as the flow. As the signal passes through the stream, its frequency shifts in proportion to the average velocity of the fluid. A receiver detects the reflected signal and measures its frequency. The meter calculates flow by comparing the generated and detected frequencies.

Type of Flowmeter	Applications They Excel In	Disadvantages
Differential Pressure	Clean liquids, steams, and gases with low to medium accuracy	Pressure drop; Orifice plates subject to wear
Positive Displacement	Low flows and viscous flows	Moving parts subject to wear
Turbine	Steady, high speed flows	Bearings subject to wear; Limited ability to handle impurities
Open Channel	Rivers, streams, partially filled large pipes	Medium accuracy
Thermal	Very low flows	Low to medium accuracy
Variable Area	Visual flow indication	Low accuracy; Many without transmitters
This table is excerpted from *The World Market for Flowmeters* report published by Flow Research, Inc. in February 2003.		

Table 3. *Applications in which traditional-technology flowmeters excel.*

Doppler ultrasonic flowmeters require the presence of impurities in the flowstream so the signal can bounce off them. Hence, they are used with dirty liquids and slurries.

Ultrasonic flowmeters are used to measure the flow of both liquids and gases. In June 1998, the American Gas Association (AGA) published *AGA-9*, a report that laid out criteria for the use of ultrasonic flowmeters for custody transfer of natural gas. The publication of this report gave a major boost to the ultrasonic flowmeter market in the oil production and transportation industry. Only multipath meters are approved for custody transfer use.

Multipath ultrasonic flowmeters use more than one pair of sending and receiving transducers to determine flowrate. Most multipath flowmeters use four to six different paths or ultrasonic signals to determine flowrate, although dual-path meters can also be considered multipath. The transducers alternate sending and receiving a signal over the same path length. Flowrate is determined by averaging the values given by the different paths, yielding greater accuracy than single-path meters.

Paradigm Case Application: Ultrasonic Flowmeters

The paradigm case application for transit time ultrasonic flowmeters is clean, swirl-free liquids and gases of a known profile. If high accuracy is required, it may be necessary to use a multipath flowmeter. Having clean fluid is the most important constraint on ultrasonic flowmeters, although transit time meters today can handle some impurities. A single-path ultrasonic meter bases its flowrate calculation on a single path through the pipe, making it susceptible to aberrations in flow profile. Multipath meters use multiple paths to make the flowrate calculation, and hence are more accurate. Ultrasonic flowmeters can handle both liquids and gases, and they can be affected by swirl.

The most effective selection approach incorporates a step-by-step method that begins by matching the applications with the paradigm case for various flowmeters.

Ultrasonic flowmeters are available in both clamp-on and inline models. The paradigm case application for ultrasonic flowmeters requires taking both pipe characteristics and fluid characteristics into account.

Vortex Flowmeters

Vortex flowmeters make use of a principle called the von Karman effect. According to this principle, the presence of an obstruction in the flowstream causes the fluid to generate alternating vortices. In a vortex meter, this obstruction is called a bluff body. It consists of a piece of material with a broad, flat front that is mounted at right angles to the surface of the flowstream. Flow velocity is proportional to the frequency of the vortices. Flowrate is determined by multiplying flow velocity times the area of the pipe.

In some cases, straightening vanes or a specified length of straight pipe upstream are required to eliminate swirl and distorted flow patterns. Under low-flow conditions, vortices are formed irregularly, so low-flow conditions present a problem for vortex meters. Vortex meter accuracy is from medium to high, depending on manufacturer and model. Vortex meters are among the most versatile of meters and can be used to measure liquid, gas, and steam flows.

Paradigm Case Application: Vortex Flowmeters

Paradigm case applications for vortex flowmeters are clean, low-viscosity, swirl-free fluids flowing at medium-to-high speed. Ideal conditions include medium-to-high flow, because the formation of vortices is irregular at low flowrates. The stream should be swirl-free, since swirls can interfere with the accuracy of the reading. Any erosion, corrosion, or deposits that change the shape of the fluff body can shift flowmeter calibration, so ideal conditions include clean liquids. Vortex meters also work best with low-viscosity fluids, since vortex formation in high-viscosity fluids may be undependable. FC

The flowmeter images featured in this article were provide by Endress + Hauser, Fuji Electric, McCrometer, and Sparling Instruments.

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