CONTROL
For the Process Industries

Flowmeter Shootout Part I: New Technologies

Start With Physical Principles, Then Consider Application, Performance, Cost, and Vendor Criteria to Choose Among Coriolis, Magnetic, Ultrasonic, and Vortex Meters

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This article is the first in a three-part series on flowmeter technologies and selection. Next month's installment will compare the more traditional technologies including open-channel, positive-displacement, thermal, turbine, and variable-area. In April, users reveal how they choose flowmeters.

One of the most interesting developments in the flowmeter market today is the battle between newer technologies and traditional flowmeters. New technologies include Coriolis, magnetic, ultrasonic, and vortex flowmeters (Figure 1). Traditional technologies include differential pressure (DP), turbine, and positive displacement (PD) meters. While there is a general trend towards new technologies and away from traditional meters, this change varies greatly by industry and application.

When users select flowmeters today, they are faced with a variety of choices. Not only are there many technologies available, there are also many different suppliers for each technology. When ordering replacement meters, users often replace like with like--this is one reason why DP flowmeters still have the largest installed base of any type. In other cases, users need to select meters for new plants or for new applications within existing plants. Users also sometimes replace one type of flowmeter with another. How should this selection be made?

This article addresses the issue of flowmeter selection by examining the underlying principles, advantages, and limitations of new technologies. It then presents a step-by-step method of flowmeter selection that takes these considerations into account, along with application, performance, cost, and supplier conditions. This is called a paradigm-case method for selecting flowmeters.

Because the first step in the paradigm-case method of selection involves selecting flowmeters whose paradigm case matches a particular application, the paradigm case is defined for each type of flowmeter. A paradigm-case application is one where the conditions are optimal for the operation of that type of flowmeter. The conditions are determined by the physical principle that underlies the flowmeter technology.

New-technology flowmeters are so called because they represent technologies that have been introduced fairly recently compared to DP flowmeters. Most of the new-technology flowmeters came into industrial use in the 1960s and 1970s, while the history of differential pressure flowmeters goes back to the early 1900s. Each new technology is based on a different physical principle, and represents a unique approach to flow measurement.

Coriolis Flowmeters

Coriolis flowmeters are named after the French mathematician Gustave Coriolis. In 1835, Coriolis showed that an inertial force must be taken into account when describing the motion of bodies in a rotating frame of reference. The earth is commonly used as an example of this Coriolis force. Because the earth is rotating, an object thrown from the North Pole to the equator will appear to deviate from its intended path.

Coriolis flowmeters are composed of one or more vibrating tubes. The fluid to be measured passes through the vibrating tubes, accelerates as it passes towards the point of maximum vibration, and decelerates as it leaves this point. The result is a twisting motion in the tubes. The degree of twisting motion is directly proportional to mass flow. Position detectors sense the positions of the tubes. While most Coriolis flowmeter tubes are bent and a variety of designs are available, some manufacturers have also introduced straight-tube Coriolis flowmeters.

It is often said that Coriolis measures mass flow directly. This method is contrasted with other flowmeters that calculate mass flow by using an inferred density value. Volumetric flow (Q) can be calculated by multiplying the cross-sectional area of a pipe times average fluid velocity. Mass flow can be determined by multiplying volumetric flow (Q) times the density of the fluid. Some multivariable flowmeters measure the pressure and temperature of the process fluid and use these values to infer fluid density. Mass flow can then be calculated.

Coriolis flowmeters are used on both liquid and gas. While they are highly accurate, they are generally limited in size to 6 in. or less. Coriolis flowmeters have a relatively high initial cost, although some models are now available in the $3,000 range. Maintenance costs are normally low. Coriolis meters can handle some fluids with varying densities that cannot be measured as accurately by other flowmeters.

The paradigm case application for Coriolis meters is with clean liquids and gases flowing sufficiently fast to operate the meter and flowing through pipes 6 in. or less in diameter. It is also important that a mass flow rather than a volumetric flow measurement is desired. The primary limitation on Coriolis meters is size, since they become very expensive and quite unwieldy in sizes larger than 6 in.

Some low-pressure gases do not have sufficient density to operate the flowmeter. One advantage of Coriolis meters is the same flowmeter can be used to measure different types of fluids, including fluids of different density. Coriolis meters can measure the mass flow of slurries and dirty liquids, but these fluids should generally be measured at relatively low flowrates to minimize meter wear.

Magnetic Flowmeters

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

Magnetic flowmeters use wire coils mounted on or outside of a pipe. Current through these coils generates a magnetic field inside the pipe section. As conductive liquid passes through the pipe, it generates a voltage detected by electrodes mounted on either side of the pipe. The magnetic flowmeter uses this voltage to compute flowrate.

Magnetic flowmeters are used to measure conductive liquids and slurries, including paper pulp slurries and black liquor. Their main limitation is they cannot measure electrically non-conductive fluids such as hydrocarbons, and hence are not widely used in the petroleum industry.

Magmeters, as they are often called, are highly accurate, and do not create a pressure drop. Their initial purchase cost is relatively high, though generally magmeters are priced lower than Coriolis meters.

The paradigm case application for magmeters is a conductive fluid that does not contain materials that damage the liner or coat the electrodes, flowing through a full pipe. The most obvious limitation on the use of magnetic flowmeters is that they only work with conductive fluids. Gases and steam are non-conductive, so magmeters cannot measure them. Because they compute flowrate based on velocity times area, accurate readings require that the pipe be full of fluid. In addition, the accuracy of magnetic flowmeters can be affected by electrode coating and by liner damage.

Ultrasonic Flowmeters

Ultrasonic flowmeters were first introduced for industrial use in 1963. There are two main types of ultrasonic flowmeters: transit-time and Doppler. Transit-time ultrasonic meters have both a sender and a receiver. They send an ultrasonic signal across a pipe and measure the time it takes for the signal to travel from one side of the pipe to the other. This time is proportional to flowrate. Transit-time ultrasonic flowmeters are mainly used for clean liquids.

Doppler ultrasonic flowmeters also send an ultrasonic signal across the pipe. However, instead of sending it to a receiver on the other side, the signal is reflected by particles traveling in the flowstream. These particles are traveling at the same speed as the flow. A receiver detects the reflected signal, which is shifted in frequency according to the average velocity of the particles and hence the flowstream. Doppler ultrasonic flowmeters are used with dirty liquids.

Ultrasonic flowmeters are used with both liquid and gas. One recent development is approval by the American Gas Assn. (AGA) in June 1998 of criteria for using them for custody transfer of natural gas. This approval gave a major boost to the ultrasonic market in the oil production and transportation industry. Only multipath flowmeters are approved for use in custody transfer. Multipath ultrasonic flowmeters use multiple pairs of sending and receiving transducers to determine flowrate. The transducers alternate in their function as sender and receiver over the same path length. Flowrate is determined by calculating an average of values given by the different paths. This provides greater accuracy than single-path meters.

The paradigm case application for transit time ultrasonic flowmeters is clean, swirl-free liquids and gases of known profile. In addition, high accuracy may require the use of a multipath meter. The most important constraint on ultrasonic flowmeters is that the fluid be clean, although today's transit-time meters can handle some impurities. A single-path ultrasonic meter calculates flowrate based on a single path thorough the pipe, making it quite susceptible to flow profile. Multipath flowmeters are more accurate since they use multiple paths (usually between four and six) to make the flow calculation.

Ultrasonic flowmeters are available in both in-line and clamp-on models. The paradigm case application for clamp-on models requires taking characteristics of the pipe into account, as well as fluid characteristics.

Vortex Flowmeters

Vortex flowmeters use a principle called the von Karman effect. According to this principle, flow around a bluff body will generate vortices on alternate sides of the body. In a vortex meter, the bluff body is a piece of material with a broad, flat front that extends vertically into the flowstream. Velocity of flow is proportional to the frequency of the vortices. Flowrate is calculated by multiplying the area of the pipe times the velocity of the flow.

In some cases, vortex meters require straightening vanes or straight upstream piping to eliminate distorted patterns and swirl. Low flowrates present a problem for vortex meters because they generate vortices irregularly under low-flow conditions. The accuracy of vortex meters is from medium to high, depending on model and manufacturer. In addition to liquid and gas flow measurement, vortex flowmeters are widely used to measure steam flow.

Paradigm case applications for vortex meters are clean, low-viscosity, swirl-free, medium to high-speed fluids. Because formation of vortices is irregular at low flowrates, ideal conditions for vortex flowmeters include medium to high flowrates. Since swirls can interfere with the accuracy of the reading, the stream should be swirl-free. Any corrosion, erosion, or deposits that affect the shape of the bluff body can shift the flowmeter calibration, so vortex meters work best with clean liquids. Vortex meters work best with low-viscosity fluids.

Selection Starts With the Paradigm Case

The operating principles of new-technology flowmeters are summarized in Table I. The main types of DP flowmeters are in included because users often must choose choosing between them and new-technology flowmeters.

The advantages and disadvantages of new technology flowmeters, along with some additional application criteria, are shown in Table II. The main types of DP flowmeter are also included in this table.

While various selection methods have been devised, this article presents a step-by-step method that begins matching the application involved with the paradigm cases for various types of flowmeters (Table III). It then advocates looking at application, performance, cost, and supplier criteria to select a flowmeter:

1. Every type of flowmeter is based on a physical principle that correlates flow with some set of conditions. This

principle determines the paradigm case application for this type of flowmeter. When selecting a flowmeter, begin by selecting the types of flowmeters whose paradigm case applications are close to your own.
2. Make a list of application criteria. These conditions may include type of fluid (liquid, steam, gas, slurry), type of measurement (volumetric or mass flow), pipe size, process pressure, process temperature, condition of fluid (clean or dirty), flow profile considerations, fluid viscosity, fluid density, Reynold's number constraints, rangeability, and others. From those types of flowmeters selected in step 1, select those that meet these application criteria.
3. Make a list of performance criteria. These include reliability, accuracy, repeatability, rangeability, and others. From those types of flowmeters selected in step 2, select the ones that meet these performance criteria.
4. Make a list of cost criteria. These include initial cost, cost of ownership, installation cost, maintenance cost, and others. From the types of flowmeters chosen in step 3, select the types that meet your cost conditions.
5. Make a list of supplier criteria. These include type of flowmeter, company location, service, responsiveness, training, internal requirements, and others. From the types of flowmeters listed in step 4, select the suppliers that meet your criteria.
6. For the final step, review the meters that are left as a result of step 4 and the suppliers listed as a result of step 5. Review the application, performance, and cost conditions for the remaining flowmeter types, and select the one that best meets all these conditions. Now select the best supplier for this flowmeter from those suppliers listed as a result of step 5.

In some cases, an application may appear to fit the paradigm for more than one technology, but this may be misleading. For example, ultrasonic flowmeters for natural gas applications generally work best in pipe sizes 6 in. and up, while Coriolis flowmeters work best on pipe sizes 6 in. and down. Even though there is some overlap in the 6 in. pipe size, Coriolis and ultrasonic are more complementary than competing technologies, at least when used for natural gas applications. And magnetic flowmeters do not work on hydrocarbons, gas, or steam.

Surveys of flowmeter users consistently show that reliability and accuracy are the two performance criteria rated highest in importance when selecting flowmeters. Among new technologies, Coriolis flowmeters provide the highest accuracy, followed by ultrasonic and magnetic meters. Many users are now distinguishing between purchase cost and cost of ownership. As a result, they may be willing to pay more for a flowmeter if it promises reduced maintenance costs down the line.

How are decisions actually made in a plant about what flowmeter to buy? In many cases, users choose to replace like with like. There are several reasons for this. Often inventories of parts and supplies are built up based on a particular type of flowmeter. It can be very expensive to train personnel to install, use, and maintain a new type of flowmeter. And changing flowmeter types sometimes means changing suppliers, which can be difficult.

These reasons help explain why differential-pressure flowmeters still have the largest installed base. The battle for the hearts and minds of users is largely between the suppliers of new-technology flowmeters and the suppliers of DP flowmeters. It is less a battle among the suppliers of new technology flowmeters, although new lower-cost Coriolis flowmeters may begin to impinge on the magmeter market.

Multivariable flowmeters represent one way DP suppliers are responding to the challenge of new technologies. Multivariable flowmeters usually measure pressure and temperature, in addition to flow. Multivariable vortex and multivariable magnetic flowmeters have also been developed, and it is likely that more types of multivariable flowmeters will be introduced in the future. This ongoing drama is definitely worth watching.

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