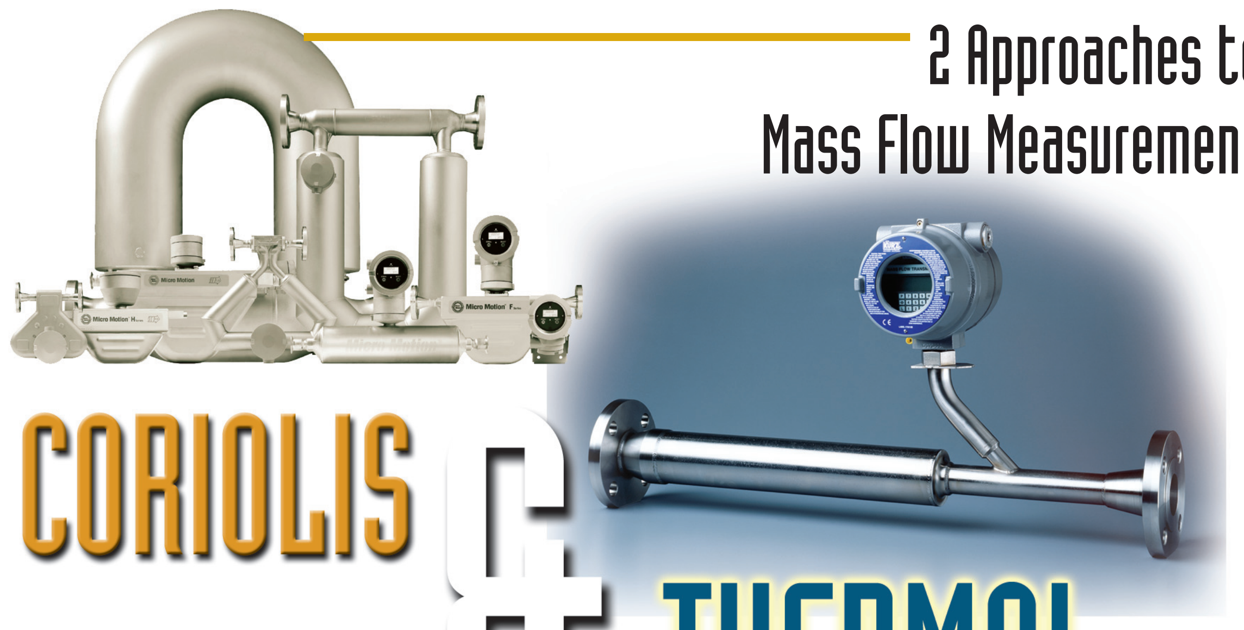

2 Approaches to Mass Flow Measurement

CORIOLIS & THERMAL

By Jesse Yoder

Photos courtesy of Micro Motion and Kurz Instruments.

Coriolis and thermal flowmeters have a lot of similarities. Both can be used to measure mass flow, each can measure liquid and gas flow, and both are relatively new technology. But how are they different? This article discusses the similarities and differences between Coriolis and thermal flowmeters, including mass flow controllers.

Coriolis Flowmeters

The French mathematician Gustave Coriolis formulated the principle that underlies Coriolis flowmeters. In 1835, Coriolis showed that an inertial force needs to be taken into account when the motion of bodies in a rotating frame of reference is described. Earth is often used as an example of the Coriolis force. A hypothetical object thrown from the North Pole to the equator appears to vary from its intended path, due to the planet's rotation.

Coriolis flowmeters contain one or more vibrating tubes. These tubes are usually bent, although straight-tube meters are also available. The fluid to be measured passes through the vibrating tubes. It accelerates as it flows toward the maximum vibration point, and slows down as it leaves that point. This causes the tubes to twist. The amount of twisting is directly proportional to mass flow. Position sensors detect tube positions.

While the roots of today's Coriolis flowmeters can be traced back to the 1950s, it was not until 1977 that Micro Motion (*www.micromotion.com*) introduced a commercially viable Coriolis flowmeter for industrial applications. Since that time, a number of other suppliers have entered the market, including Endress+Hauser (*www.endress.com*) and Krohne (*www.krohne-mar.com*).

Coriolis suppliers differentiate themselves in a number of ways. One is by the proprietary design of the bent tubes in their meters. Another is by the different types of straight-tube meters offered. Suppliers also compete by bringing out Coriolis flowmeters for particular industries and applications, such as food & beverage and pharmaceutical. Accuracy and other performance specifications also provide differentiation.

While Coriolis flowmeters are loved by many end-users, price is often an issue. Coriolis flowmeters are the most expensive meter made, in terms of average selling price. The cost of Coriolis flowmeters is typically between $5,000 and $6,000. Some suppliers have introduced low-cost Coriolis flowmeters in the $3,000 range. Performance specifications for the lower-cost flowmeters are not at the same level as those of the higher-priced meters.

Advantages & Limitations

Probably the single biggest advantage of Coriolis flowmeters is their high accuracy. Accuracy levels for many Coriolis flowmeters are in the 0.1 percent range. This makes them ideal for custody transfer and other applications where high accuracy is required. Users who want to measure mass flow rather than volumetric flow would naturally consider a Coriolis flowmeter. This could be the case when there are wide variations in the temperature and pressure of the fluid being measured.

Line size is the single biggest limitation of Coriolis flowmeters. While Coriolis flowmeters have been used in line sizes of six inches, the large majority are used in line sizes of two inches or less. This makes Coriolis flowmeters more complementary than competitive with ultrasonic flowmeters, which do best in line sizes of four inches and up. Coriolis flowmeters become unwieldy and expensive in line sizes above three inches.

Industry Approvals

Having approvals by industry associations is important for the growth of any type of flowmeter. Industry approvals have greatly helped the growth of ultrasonic, turbine, and differential pressure (DP) flowmeters. By contrast, a lack of industry approvals has held back the growth of vortex flowmeters. In the past several years, both the American Gas Association (AGA, *www.aga.org*) and the American Petroleum Institute (API, *www.api.org*) have issued reports on the use of Coriolis flowmeters for flow measurement. The AGA report is for gas flow measurement, and the API report is for the measurement of liquid hydrocarbons. Both reports will help the growth of the Coriolis flowmeter market, especially for custody-transfer applications.

Customer Loyalty

A recent survey of end-users by Flow Research (*www.flowresearch.com*) revealed some very satisfied users of Coriolis flowmeters. One commenter noted, "Coriolis [meters] are very reliable. We would like lower cost. Their features are excellent." The respondent's company is a global producer of coatings, glass, fiberglass, and chemicals. Another comment was, "We have had problems with primary elements and may change out to Coriolis." All told, the study showed

Coriolis for Natural Gas

Until recently, Coriolis meters have been primarily used for liquid rather than gas. The reason is because gases are less dense than liquids and are somewhat more difficult to measure. However, a number of suppliers are now touting Coriolis meters for gas flow measurement, and this is a growing focus area. One application in particular that Coriolis has come to excel in is in measuring compressed natural gas for alternative fuel vehicles. In this area, the primary competition for Coriolis is turbine meters.

Some of the advantages Coriolis holds in respect to gas measurement is the ability to reduce temperature, pressure, and compressibility compensation errors common to some volumetric meters. They also are resistant to flow profile and natural gas composition, which makes recalibration less of an issue than it is with other meter types.

Gas + Measurement = Thermal

Unlike Coriolis, which is a fairly new to the gas measurement process, thermal flowmeters are used almost exclusively to measure gas flow. Thermal flowmeters typically inject heat into the flow stream and then measure how quickly it dissipates. This value is proportional to mass flow. Two methods used are called constant current and constant temperature.

Thermal flowmeters grew out of the use of hot-wire anemometer for research applications. Thermal flowmeters excel at measuring gas at low flowrates. Measuring low flows is a difficult proposition for some meters, including vortex, which makes thermal meters a hot commodity for gas measurement. Accuracy levels are improving for thermal flowmeters as well, as suppliers introduce product improvements.

One application where thermal flowmeters are widely used is in the measurement of stack flows. Gas flow has to be measured in smoke stacks to conform to EPA reporting requirements. Insertion thermal flowmeters are used to measure the flow of sulfur dioxide, nitrogen oxide, and other industrial pollutants. Because of the large size of the stacks, insertion thermal meters that use multiple measuring points are a good fit for these applications. DP flowmeters with averaging pitot tubes and ultrasonic flowmeters are also commonly used.

there is a high degree of loyalty among Coriolis flowmeter users.

Thermal Flowmeters

The roots of thermal flowmeters go back to the hot-wire anemometers that were used for airflow measurement in the early 1900s. Hot-wire anemometers were used in velocity profile and turbulence research. They are very small and fragile and consist of a heated, thin wire element. Hot-wire anemometers have a quick response time, because they are so small and thin. However, their fragility makes them unsuitable for industrial environments.

Thermal flowmeters were first introduced for industrial applications in the 1970s. The story of how they came on the market is a fascinating one that involves Sierra Instruments (*www.sierrainstruments.com*), Fluid Components International (FCI, *www.fluidcomponents.com*), and Kurz Instruments (*www.kurz-instruments.com*). Sierra Instruments and Kurz used hot -wire anemometer technology as the basis of their thermal meter designs. FCI used a system of flow switches to develop its thermal meters. All three companies were pioneers in the development of thermal flowmeters, and all three companies still offer thermal flowmeters today. *(**EDITOR'S NOTE:** For more information on the history of thermal flowmeter technology, see "Thermal Flow Innovators," page 28, March 2004.)*

Thermal flowmeters use heat to facilitate flow measurements. Thermal flowmeters put heat into the flowstream and use one or more temperature sensors to measure how quickly this heat dissipates. Heat dissipation is measured in several different ways.

One method of measuring heat dissipation keeps a heated sensor at a constant temperature and measures how much current is needed to keep it at that temperature. Another method measures the temperature difference between the flowstream temperature and a heated sensor. What is common to both methods is the idea that higher speed flow results in increased cooling. Both methods measure the effects of this increased cooling, and compute mass flow based on this result.

Advantages & Limitations

Thermal flowmeters have fast response time, and they excel at measuring low flowrates. They also provide a direct means of measuring mass flow and can handle some difficult-to-measure flows. Insertion thermal flowmeters are used in continuous emissions monitoring (CEM) applications to help measure the amount of sulfur dioxide and nitrous oxide being released into the environment. Concentration measurements, along with flowrate measurements, are required.

One limitation of thermal flowmeters is that they are used almost entirely for gas flow measurement. Thermal flowmeters have difficulty in measuring liquid flows because of the slow response time involved in using the thermal principle on liquids. However, some companies have released thermal flowmeters for liquid flow measurement.

A second limitation is in their accuracy. Thermal flowmeters are not nearly as accurate as Coriolis meters, and typical accuracy levels are in the 1 percent to 3 percent range.

Mass Flow Controllers

Another type of thermal flowmeter is called a mass flow controller. Most mass flow controllers use thermal principles to determine mass flow, although some use a pressure-based measurement. Mass flow controllers contain an integrated control valve that is used to control the flow as well as measure it.

The mass flow controller market is far larger than the thermal flowmeter market. Most mass flow controllers are used in the semiconductor industry for measuring gas flow. However, a group of companies also sells mass flow controllers for industrial markets. The mass flow controller market is highly competitive, with a large number of suppliers. It is one of the most rapidly developing flowmeter markets. FC

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