PRACTICAL SELECTION AND USAGE OF CORIOLIS METERS FOR GAS MEASUREMENT

MARC BUTTLER
DIRECTOR, APPLICATION INNOVATION
EMERSON – MICRO MOTION

Introduction

Coriolis meters have been commercially produced and used widely across many industries and in many processes since 1977. Coriolis meters are capable of measuring liquids, slurries, and/or gases very precisely. Use of Coriolis meters for gas applications has become increasingly popular since 2003 when the first edition of the American Gas Association (AGA) Report No. 11/American Petroleum Institute Manual of Petroleum Measurement (API MPMS) Standards Chapter 14.9, *Measurement of Natural Gas by Coriolis Meter* was published. The second edition of AGA Report No. 11/API MPMS Chapter 14.9 was published in 2013 and expanded the guidelines for the use of Coriolis meters for natural gas measurement.

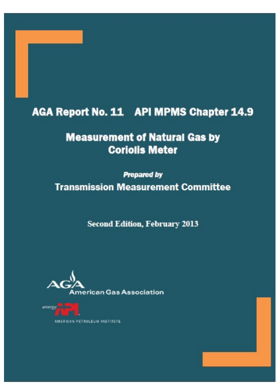

Figure 1. AGA Report No. 11 / API MPMS Ch. 14.9 Second Edition, 2013

Because Coriolis mass flow meters measure mass directly without the need for pressure and temperature compensation for fluid properties, they can significantly reduce installation complexity, potential leak points, potential maintenance issues, and improve overall accuracy compared to other metering technologies. Having the ability to measure the mass flow of any gas bi-directionally from -400 to +660 degrees Fahrenheit with little to no concern of error caused by flow profile disturbances, pulsations, or flow surges, Coriolis meters are becoming the preferred meter in many applications.

Without moving parts to wear, Coriolis meters are typically immune to flow factor shift as they age over years in service. Many Coriolis meter designs have implemented methods of meter verification to detect any unexpected damage that could impact flow accuracy which can be run online without disruption in flow and without having to visually inspect the flow element.

Overall, Coriolis meters greatly reduce the amount of measurement and maintenance concerns compared to other gas flow meter technologies. This paper will discuss the principle of operation, calibration, application, and maintenance of Coriolis meters used in gas measurement applications.

Principle of Operation

A Coriolis mass flow meter generally has one or two tubes (straight or bent) that are vibrated at their natural frequency (Figure 2). When there is no fluid flowing through the tube(s), the inlet and the outlet of the tube(s) are moving symmetrically (Figure 3). Sensing coils located on the inlet and outlet sections of the tube(s) oscillate and produce a sinusoidal electrical wave as the coil passes through a magnetic field (Figure 4).

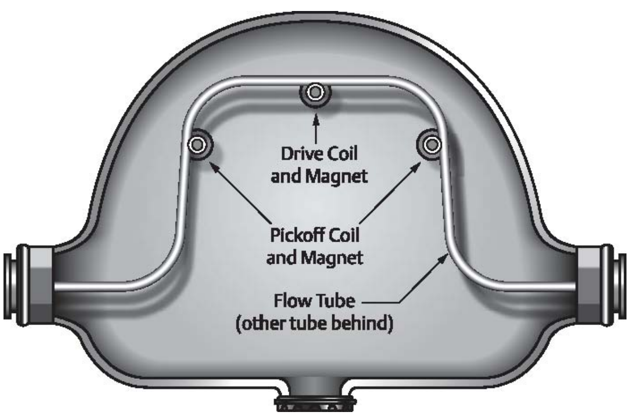

Figure 2. A typical curved tube Coriolis flow meter

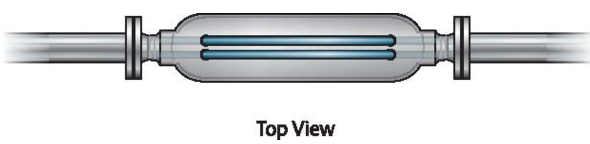

Figure 3. Coriolis flow meter tubes during no flow

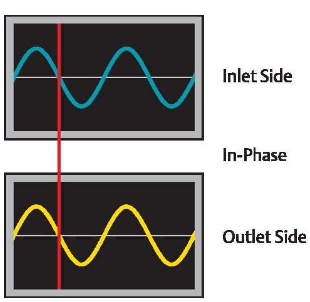

Figure 4. Inlet and outlet side of the tubes are in-phase during no flow

When there is flow through the tube(s), because of the Coriolis effect, the gas causes the tube(s) to twist (Figure 5). The inlet of the tube(s) and the outlet of the tube(s) will no longer be moving at the same time. The time difference between the inlet and the outlet of the tube(s) is proportional to the mass flow of the gas (Figure 6). This is true for compressible and non-compressible fluids. Therefore, a Coriolis meter can measure mass flow rate for a gas application without needing to compensate for changes in the density resulting from pressure and temperature changes. The Coriolis meter can measure the mass of a gas even if the composition is changing. Equations and methods for the conversion of mass to base volume are documented in AGA Report No. 11, *Measurement of Natural Gas by Coriolis Meter* and AGA Report No. 8, *Compressibility Factors for Natural Gas* and Other Hydrocarbon Gases Industry Standards.

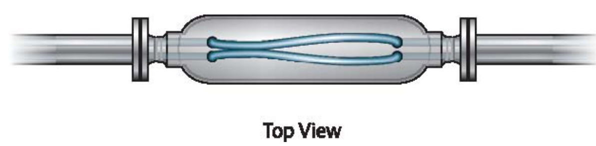

Figure 5. Coriolis flowmeter tubes during flow

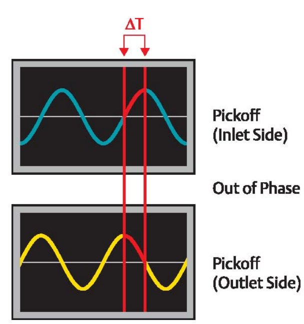

Figure 6. Inlet and outlet side of the tubes are out of phase during flow and the time shift is proportional to the mass flow rate

In addition to measuring the mass flow rate, a Coriolis meter can also measure the flowing density of liquids. The square of the vibration frequency of the flow tube(s) is inversely proportional to the density of the fluid in the tubes.

However, the "flowing" or "live" density measured by the Coriolis meter is typically not used for gas measurement because the resolution of the measurement for such a low density fluid as gas is not acceptable for measurement or calculation purposes. Although this prevents precise measurement of gas density and actual volume flow rate, density measurement in gas applications can be used as a diagnostic variable and the standard volume flow rate derived from the mass flow and base density of the gas is still very precise.

Industry Standards

Multiple industry standards have been written around the use of Coriolis flow meters including ISO 10790, OIML R137, and AGA Report No. 11. In North America, the AGA report is the most commonly used and will be the focus in this paper.

AGA Report No. 11 discusses the specification, calibration, installation, operation, maintenance, and verification of Coriolis flow meters and is limited to the measurement of single phase natural gas, RNG, and biogas.

The second edition of AGA Report No. 11 revised the content to align more with AGA Report No. 9 (for Ultrasonic meters), to increase the level of detail in the guidance, and to incorporate the use of diagnostics to verify a meter's performance into the document.

AGA Report No. 11 currently allows the use of meter diagnostics to verify the performance of the meter and to determine whether or not to perform a field or laboratory flow performance test.

Calibration

Due to the variability of manufacturing processes, all Coriolis meters require a flow calibration to adjust their performance to the accuracy limits inherent to their particular design. As a common practice, most Coriolis manufacturers capitalize on the economics and high stability of a water calibration to perform these calibrations. Some advanced Coriolis meter designs are immune to fluid phase, density, and viscosity; enabling water calibrations to transfer to all other fluids (i.e., gases, liquids, and slurries.)

Testing by numerous European and North American flow labs has confirmed the transferability of water calibration data on a Coriolis meter to gas applications. Most notably early testing sponsored by the Gas Research Institute in 2004 and documented in report GRI-04/172, which covers water to gas transferability and wet gas performance of Coriolis meters. Conclusions in the report state, "The single fluid calibration tests show that a water calibration of a Coriolis mass flow meter can be used for natural gas applications without loss of accuracy". See Figure 7 for example data.

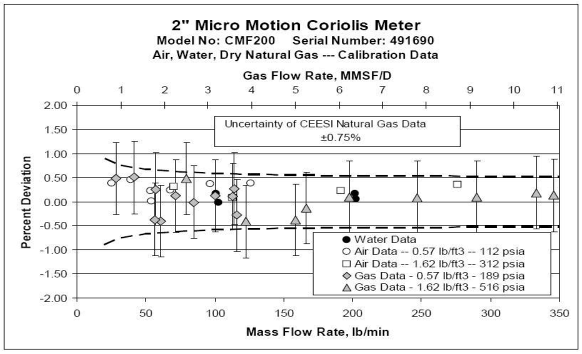

Figure 7. GRI 04/0172 Water, Air, and Gas Transferability Data

Although industry testing has shown that there may be no requirement for performing a gas calibration, some users make a practice of testing every meter at a gas lab. They typically do this to demonstrate traceability to a known laboratory and to be consistent with other technologies, like ultrasonic meters. In addition, some users have been using multi-point piecewise linear interpolation (PWL) to characterize the meter to match the laboratory over the user's normal flow range. Some manufacturers offer software in the transmitter (if specified) to facilitate this practice. The user should review industry recommended practices, standards, and regulatory requirements when establishing a calibration policy for Coriolis meters.

Maintenance Best Practices

Maintenance for Coriolis meters can include cleaning, zeroing, and changes to flow calibration factors. Manufacturers may have specific recommendations or guidelines about using diagnostic parameters or long-term monitoring of performance indicators. In general, Coriolis meters require very little maintenance, and the flow calibration factors do not drift over time. In the absence of erosion, corrosion, or physical damage to the tube(s), it is very unlikely that the flow calibration factor will shift.

As recommended by AGA Report No. 11, cleaning should be condition-based (dependent upon meter diagnostics, process conditions, and meter usage). One example of this is that monitoring density can indicate when a coating develops in the meter and would require cleaning. The coating will shift the zero of the meter, but if the meter is re-zeroed with the coating, testing has shown that the calibration will still be correct.

In addition, AGA Report No. 11 allows for the user to verify the meter in the field. The verification is a four-part process that includes:

- meter transmitter verification
- sensor verification
- temperature verification
- meter zero verification.

The transmitter verification consists of checking that all diagnostic indicators are in the normal state and checking that the configuration for the sensor parameters has not changed since the previous calibration. Sensor verification will vary by manufacturer but needs to check for a change in the measurement performance. This check may run continuously on demand, or on a periodic basis. Some manufacturers provide automated meter verification functionality that can be executed without interrupting the process or the measurement and may even provide scheduling functionality to run the verification at an established interval.

To verify the temperature measurement of the Coriolis meter, a temperature reference is installed in an upstream thermowell or placed against the upstream flow inlet and insulated. The reference temperature and the meter temperature reading should be compared and should match within the published uncertainty of the Coriolis temperature measurement device plus the uncertainty of the reference temperature device.

As a minimum, AGA Report No. 11 recommends checking the meter zero at flowing pressure and temperature within 4 weeks of installation, and quarterly during the first year of installation. Depending on the operating conditions, operator policy and the collected zero data, a frequency for checking the meter zero after the first year should be determined. Some manufacturers offer an automated zero verification method to facilitate this test.

The piping configuration of a Coriolis installation should consist of block valves upstream and downstream of the Coriolis meter with bleed valves to facilitate purging of the piping, zeroing of the meter, and maintenance procedures. A bypass should be installed around the meter if interruption of service is an issue.

The full meter verification results should be used to decide whether or not to perform a field flow performance test or laboratory flow test and the frequency of such tests. In some cases, flow testing may be required by certain agencies or contractual agreements, regardless of the verification results.

Application Selection

Coriolis meters are available in a wide variety of sizes up to approximately 12” (typical corresponding pipeline size of approximately 16”). For larger line sizes, multiple Coriolis meters in parallel may be used.

Most Coriolis meters can be used at temperatures ranging from -400°F to 400°F (-240°C to 204°C). For high temperature applications, specialty Coriolis meters are available up to 660°F (350°C).

Coriolis meters include temperature measurement to automatically compensate for the change in tube rigidity with temperature. However, flowing temperature is not needed to convert the mass flow measurement to base volume or energy.

The typical operating pressure for stainless steel Coriolis meters is up to 1480 psi (ANSI Class 600). Other materials of construction like nickel alloys, duplex materials, or even thick-walled stainless steel materials make higher pressure ratings possible up to 6000 psi (ANSI Class 2500) or higher.

While operating pressure is not necessary to convert the mass flow measurement to base volume or energy, it may be used to compensate for tube stiffness changes. As pressure increases in the Coriolis meter, the tube(s) stiffen. As the tube stiffness increases, the mass of the gas causes less deflection of the tube(s). This results in a negative bias in the mass flow reading. This effect is size and design dependent and is often negligible for small meters. The manufacturer should provide pressure compensation values for the specific Coriolis meter. In some cases, the pressure effect may be greater in magnitude than the normal sensor uncertainty.

For applications with significantly varying line pressure, a pressure transmitter can be connected to most transmitters to do live compensations. When the operating pressure is different from the calibration pressure, but remains fairly constant, a static pressure value can be entered into most transmitters for pressure compensation using a fixed value.

Although change in compressibility, density, viscosity, and Reynolds Number are a concern with almost all metering technologies, the inferred mass flow rate of a curved tube Coriolis meter is typically insensitive to error caused by these changes.

There are certain operational factors that should be considered when selecting a flow technology for a particular application including, but not limited to:

- surging flow conditions
- high gas velocities
- flow pulsations
- bi-directional capabilities
- flow perturbations that can distort the flow profile.

Surging flow conditions (commonly found in engine, boiler, and burner fuel gas applications) are the most common cause of damage in flow meters with mechanically moving parts like turbine, rotary, and positive displacement meters. However, Coriolis meters will physically limit (or choke) the flow according to the size of the meter and based on the operating natural gas density. Fast changes in rate or flow surges will not damage the Coriolis meter.

Likewise, high gas velocities are not typically a concern for most Coriolis meters and velocities up to 400 ft/sec are very common for natural gas applications through Coriolis meters. Many Coriolis meters can measure the natural gas up to the choke point (typically around 1400 ft/sec), but the measurement is typically noisier above 400 ft/sec. Some manufacturers will only size the meters up to 0.3 times the sonic velocity because most sizing programs cannot accurately predict pressure drop above that velocity due to changes in compressibility.

If the natural gas has any abrasive particles such as sand, welding slag, or other debris, filtration should be used upstream of the meter to prevent eroding the meter especially at high velocities. Other soft or fine contaminants like iron oxide, oil or dust will not cause damage to the tube(s) but may cause a tube imbalance if the contaminants build up inside the meter. These imbalances from dirty process fluids will impact the meter zero and will cause error at low flow rates but will have very little effect at high flow rates. Some type of zero verification may detect if there is any buildup in the meter and a new zero calibration can eliminate the error due to the buildup.

Flow pulsations may be present in some natural gas applications such as fuel gas lines to reciprocating engines, the inlet and outlet compression lines of reciprocating compressors, and the inlet and outlet lines of regulators. The presence of such pulsations can make flow measurement a challenge. For some metering technologies such as differential pressure, ultrasonic, rotary and turbine meters, pulsations will cause measurement error. For other technologies such as rotary and turbine meters, flow pulsations can cause permanent mechanical damage.

Coriolis meters have had design improvements over time that have made them maintain superior accuracy in the presence of flow pulsations. However, if the pulsation happens to occur at the same frequency as the operating frequency of the meter, there may be some interference that will cause measurement error. Most curved tube Coriolis meters operate at a resonant frequency of approximately 100 Hz which is not where normal gas pulsations are found. The resonant frequency will vary with meter design and operating fluid density.

The data shown in the Figure 8 shows some testing that was performed using various pulsation frequencies. As shown on the graph, the point with the most error coincides with the resonant frequency of the flow tube(s). Flow pulsations occurring near the resonant frequency of the meter is extremely rare for gas applications.

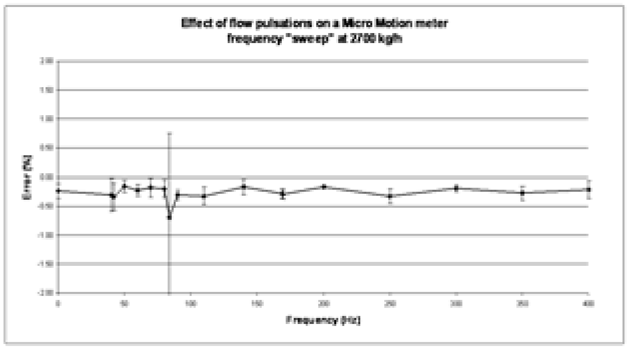

Figure 8. Effect of Flow Pulsation on Coriolis Meter

Another operational consideration when selecting a flow metering technology is whether there will be flow in one direction only or bi-directional flow. Applications like cavern storage may benefit from bi-directional flow capabilities. Coriolis meters work equally well in both forward and reverse directions and are commonly used for bi-directional flow.

Upstream and downstream piping should also be considered when selecting a flow metering technology. Most technologies require flow conditioning or straight runs for fully developed flow profile that matches laboratory conditions. Installation effects testing performed by Southwest Research Institute (SwRI) and sponsored by the Gas Research Institute (GRI) in 2002 confirmed bent tube Coriolis meters to be mostly immune, within the uncertainty of the flow lab, to upstream installation effects. The test results can be found in GRI Topical Report GRI-01/0222.

Other testing by third parties has been completed to study the effect of flow perturbations upstream and downstream of bent tube Coriolis meters. These tests have shown that flow conditioning or straight pipe runs are not required for most Coriolis meters.

Meter Sizing and Installation Considerations

When sizing and selecting Coriolis meters, it is important to consider the full range of operating conditions. As operating pressure decreases and operating temperature increases, the gas density will decrease and the mass of gas passing through the meter will be less at any given volumetric flow rate. As the gas density increases, the Coriolis meter turndown for a particular sensor will increase because the maximum flow through the sensor increases with increased gas density.

The best practice for selecting the appropriate size Coriolis meter is to choose the smallest sensor size that has acceptable pressure drop at the maximum flow rate. After choosing that sensor, it is important to verify that the accuracy at the minimum flow rate is acceptable.

The minimum flow rate for a particular sensor is determined by the “zero stability” number. Zero stability defines how low the meter can measure and still maintain accuracy. Although proper sizing is important, installation and proper meter zeroing is also important, especially at low flow conditions.

In case there is any liquid in the gas stream, the meter should be installed in such a way that the meter will always remain filled with gas and liquid will not collect in the meter. For curved tube meters, the best installation practice is to have the tubes up in a horizontal pipeline or mount the sensor in a vertical pipeline in the "flag" position. The meter will operate in any orientation as long as it remains filled with the process fluid.

Although meter designs have improved over time to reduce external influences, pipe stresses can cause measurement error. Good piping practices should be used to minimize stress on the meter. The piping should all be aligned, and the meter should never be used to make up for pipe misalignment. In addition, piping supports can be used upstream or downstream of the meter but should never be attached to the case of the sensor.

Typical Applications

Coriolis meters are used in a variety of liquid, gas, and slurry applications. Natural gas applications from the wellhead to the burner tip have been successfully measured using Coriolis meters. Coriolis meters are commonly found in line sizes of approximately 16" and smaller. While Coriolis meters can work in low pressure applications, more turndown is available as the pressure increases, so the "sweet spot" for natural gas is in 300 ANSI to 900 ANSI applications.

Coriolis meters are ideal for dirty, wet, or sour gas where other technologies may have maintenance or measurement issues. They are also ideal in pulsating flow applications or applications where flow surges may be possible.

One example application is for fuel control as shown in Figure 9. Some major suppliers of gas turbines have standardized on using multiple Coriolis meters to measure the natural gas burned in the combustion zones. They use Coriolis because of the high accuracy, turndown, immunity to vibration and tolerance of high flow rate of change. Coriolis meters are also easy to install with no need for straight piping or flow conditioning.

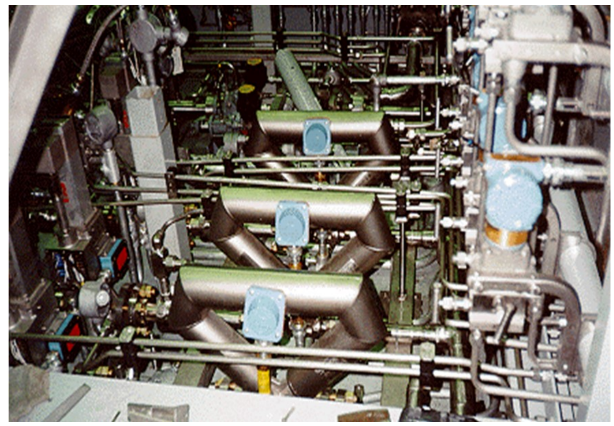

Figure 9. Coriolis Fuel Gas Measurement on a Gas Turbine

Coriolis meters are commonly used for fiscal custody transfer of natural gas. They are often chosen for their high accuracy, turndown, and long-term stability. In addition, with verification methods that can be done in-situ, they make ideal custody transfer meters. Since the first publication of AGA Report No. 11, this application has grown increasingly popular.

Another example application for Coriolis meters on natural gas can be highlighted by a success story in Hungary. A storage field uses 27 two-inch Coriolis meters for injection and withdrawal measurement of natural gas into a multilayer sandstone formation (see Figure 10). The formation has an aquifer flowing through it and multiple small wells are required to manage the water level in the sandstone with the injection and withdrawal of natural gas.

The application is especially challenging because it is bi-directional and the gas that is withdrawn from storage is typically saturated, has H_2S present, and can even have sand in the gas. After evaluation of other technologies, they found that only a Coriolis meter could provide the bi-directional measurement with long-term accuracy and wide turndowns that were required.

Figure 10. Natural Gas Storage Management Using Coriolis Meters

Coriolis meters have been used for many other applications for natural gas. Some of these applications are circled on the distribution system graphic shown in Figure 11. In addition, Coriolis meters are used for measurement of many other gas applications including supercritical ethylene which can be difficult to measure with other technologies due to the highly compressible and non-ideal behavior of supercritical fluids.

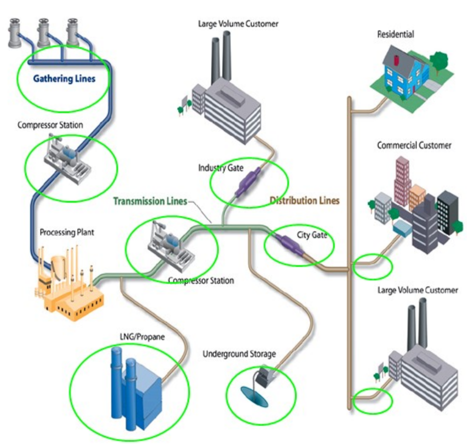

Figure 11. Common Locations for Coriolis Natural Gas Applications

Summary

With little to no maintenance, high accuracy, high turndown, and immunity to flow profile effects, Coriolis meters are often the ideal choice for natural gas measurement. Most countries have written standards around measurement of natural gas using Coriolis meters with the most notable standard being the joint publication by AGA and API of AGA Report No. 11 / API MPMS Chapter 14.9, *Measurement of Natural Gas by Coriolis Meter*.

Most of the earlier limitations of Coriolis for gas applications have been overcome with improved designs. Third party testing has demonstrated that most Coriolis meters can be calibrated on water and that calibration will directly transfer to gas applications. Additional testing has shown the technology to be virtually immune to flow profile, flow surges, and pulsation.

Users have adopted Coriolis meters for a variety of natural gas applications including custody transfer, fuel control, combustion control, storage management, and check metering. Coriolis meters are often used in conjunction with Ultrasonic meters where Ultrasonic are used on larger line sizes and Coriolis are used on small to medium line sizes (although the technologies often overlap in the 4-16” line range).

With the publication of the second edition of AGA Report No. 11, meter verification techniques have been recognized as a viable way to verify the performance of the Coriolis meter without removing the meter from the line to send it to a flow calibration facility which further enhances the benefits of using Coriolis technology.

Coriolis meters have improved significantly since their commercial introduction in 1977 making them a serious contender for low cost of ownership metering for natural gas applications.

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