It’s no surprise that gas applications are a definite growth zone for Coriolis flowmeters. While they have been around since the 1980s, their use has primarily been with liquids. However, they offer double containment, and with improvements over the years in sensitivity and enhanced immunity to noise, they are much more suited for measuring a variety of gases.

If you turn to page 40, you’ll find the most recent results from natural gas metering research illustrating the financial significance of measurement bias errors as it relates to Coriolis flowmeters (and turbine also, in the beginning of the article). Written by three highly respected researchers from the Gas Technology Institute (GTI) — Marybeth G. Nored, Dr. Darin L. George, Terrence A. Grimley and Edgar B. Bowles, Jr. — the report takes a look at very recent research conducted at the GTI Metering Research Facility (MRF), located at Southwest Research Institute in San Antonio, TX.

They’ve been conducting research and development to help the natural gas industry since the late 80s to advance the state of the art in measurement.

The feature fleshes it all out, but one interesting item to note was that they were looking at off the shelf meters. And, after compensating for line pressure induced bias, they found that the water-calibrated meters were functioning within their measurement uncertainty level when applied to the gas flow measurements.

Coriolis meters in general, for liquid and gas measurement, have much going for them, foremost of which has been a high level of accuracy, good rangeability, no need for flow conditioning and the ability to provide output for density, volumetric flow and temperature. They operate well for a host of applications. Also, they have developed a good reputation for reliability. When uptime is important, this becomes a lifetime cost variable.

One of the knocks against them has always been price. However, like all maturing technology, prices have been coming down. They have for a while, in fact. Moreover, as user comfort levels increase, prices lower, selection widens and the technology improves, you can look to see these meters come more into play as general-purpose meters. This could cut into the magmeter market, and even with the significant technological improvements made to DP flowmeters, there will likely continue to be inroads into this market, as well. Others think vortex, PD and turbine meters will be, in selected apps, supplanted by Coriolis meters.

A recent study from the Arc Advisory Group (Dedham, MA) highlights this trend and predicts there will be a $381 million-dollar market for Coriolis meters this year, up about $10 million from 2001. They further predict a market jump of $139 million by 2006, but I would be wary of these outside predictions, as life has a way of interfering with them. Nevertheless, as mentioned above, there are solid reasons why Coriolis meters may find their way into more and more of your process applications.

One hundred and sixty-seven years after he discovered the force ultimately named for him, French mathematician, Gustave Coriolis, I think, would be rather intrigued by it all.
Recent results from natural gas metering research illustrate the financial significance of measurement bias errors as it relates to turbine and Coriolis flowmeters.

By M.G. Nored; Dr. D. L. George; T. A. Grimley and E. B. Bowles, Jr.

Introduction

Since 1987, the Gas Technology Institute (GTI) has funded a research and development program on behalf of the United States natural gas industry to help advance the state of the art of natural gas measurement. This program helps improve existing measurement technologies and assists with the development and acceptance of new, more cost-effective technologies. Following is a description of some recent GTI research work on turbine and Coriolis flowmeters used for pressurized gas applications. This research was conducted at the GTI Metering Research Facility (MRF) located at Southwest Research Institute in San Antonio, TX.

Turbine Flowmeter Research

Turbine meters are often used for high-pressure gas applications because of their measurement precision and repeatability. The current U.S. natural gas industry standard for turbine flowmeters is the American Gas Association (AGA) Report No. 7, Measurement of Gas by Turbine Meters, which was last revised in 1996. There have been several advances in turbine meter technology since the last revision of AGA-7.

For instance, dual-rotor meters have gained broad industry acceptance and high-capacity or extended-range meters were recently introduced to compete with ultrasonic flowmeters. Dual-rotor meters are a significant advancement because a secondary rotor is used to verify the flow rate measured by a primary rotor. Thus, dual-rotor meters feature a self-checking capability that enhances reliability and assists with maintenance planning.

Furthermore, the pulse outputs from both rotors in some dual-rotor configurations can be combined mathematically to compensate for certain types of adverse operational effects, such as a distorted flow field at the meter inlet or excessive rotor bearing friction. The recently introduced high-capacity meters utilize a 30° rotor blade angle (compared to the conventional 45° blade angle) to achieve flow capacities at least 25 percent greater than conventional meters.

In recognition of the recent technological advances in turbine flow meters, the AGA Transmission Measurement Committee (TMC) initiated efforts in 2001 to update AGA-7. In support of this AGA effort, the GTI provided funding for independent performance assessments of both the conventional and the new
high-capacity turbine meter designs.

Past research has clearly demonstrated that there are operational and installation effects that can bias a flowmeter measurement. If left undetected, measurement biases can prove to be very costly. Fortunately, most biases can be avoided through thoughtful installation, operation and maintenance of a meter.

The following example illustrates the financial significance of measurement bias errors. Assume that a 6-inch diameter high-capacity turbine meter measures natural gas flowing through a transmission pipeline for a period of 12 months. Furthermore, assume that the gas is at a line pressure of 750 psig and a temperature of 70°F, and that the meter runs at capacity (i.e., 60,000 acfh) for the entire 12-month period. If the meter has a +0.5-percent bias (i.e., a flow rate over-registration) that goes undetected, the gas customer would be overcharged by slightly more than $400,000 for the 12-month period (assuming gas costs $3 per thousand standard cubic feet).

The GTI-funded research in support of the revision of AGA-7 focused on identifying and quantifying measurement biases that may result from operational or installation effects. AGA-7 references three different meter installation configurations: recommended, short-coupled and close-coupled. Flow tests of both conventional and high-capacity turbine meters were run at the GTI MRF to determine if any of these referenced installation configurations could produce a bias in the meter measurement. Tests were also run to determine if variations in pipeline pressure could result in measurement biases.

Figure 1 shows a turbine meter installed in the AGA-7 close coupled configuration under test at the GTI MRF Low Pressure Loop (LPL). In the GTI MRF research tests, each turbine meter installation was tested first with “well-conditioned” flow at the inlet to the meter run and then with a highly distorted flow at the inlet to the meter run. “Well-conditioned” flow refers to a flow field in which velocity profile asymmetry and swirl are eliminated and the velocity profile is a swirl-free, fully developed turbulent profile. Distortion of the flow field at the meter run inlet was achieved by placing the high perturbation piping configuration described in the International Standard ISO 9951 (Measurement of Gas Flow in Closed Conduits – Turbine Meters) immediately upstream (as shown in Figure 1). This upstream piping configuration produced both velocity profile asymmetry and swirl at the inlet to the meter run. To determine the magnitude of line pressure effects on meter performance, the turbine meters were tested at line pressures of 50 and 160 psig. The test medium for all tests was transmission-grade natural gas. The nominal gas temperature for all tests was 70°F. The AGA-7 recommended meter installation configuration with “well-conditioned” flow at the meter run inlet was used as the baseline test condition to which all other meter installation configurations and test conditions were compared.

Four commercially available turbine flowmeters (identified here as test meters A, C, D and E), including both single- and dual-rotor models, were tested at the GTI MRF Low Pressure Loop. The meters were all 6-inch diameter (ANSI 600 class) standard (35,000 acfh) and extended-range (60,000 acfh) models. To compare the meters equitably, the mechanical outputs from the main rotors of the dual-rotor meters were calibrated separately, and flow rates computed from the main rotor alone were compared to flow rates from single-rotor meters. For each combination of test meter, piping configuration and flow condition, six 90-second data sets were acquired consecutively to obtain average results and to assess the short-term repeatability of the meters.

**Figure 2** Installation effect for short-coupled turbine meter installation with “well-conditioned” flow.

**Figure 3** Comparison of “Meter A” calibration factors at different line pressures.

**Turbine Flowmeter Test Results**

The GTI MRF test results showed that for the range of conditions tested, all test meters produced total measurement uncertainties (i.e., combined bias and precision errors) of less than ±1 percent of reading. (Unless otherwise noted, the measurement uncertainty values reported herein are for two standard deviations.) For test gas flow rates of 9,000 acfh and above, the measurement bias attributed to any upstream piping installation effect was less than ±0.4 percent of reading, regardless of the upstream piping configuration and meter design. To illustrate, Figure 2 shows the performance of the four test meters using the AGA-7 short-coupled installation configuration with “well-conditioned” flow at the inlet to the meter run. With proper integral flow “conditioning” at
the meter inlet, the total measurement uncertainty can be reduced even further, on the order of ±0.25 percent of reading for both single-rotor and dual-rotor designs, regardless of the upstream piping configuration.

The GTI MRF tests also found that the turbine meters can experience measurement biases as a result of variations in the line pressure (at least from 50 to 160 psig). In the GTI MRF tests, the magnitude and direction of the meter bias caused by a line pressure shift was a strong function of the meter design and, therefore, could not be generalized. However, all test meters produced different calibration curves for the different line pressures tested. This result confirmed that line pressure changes (at least between 50 and 160 psig) can affect meter performance. Figure 3 illustrates the effect of line pressure variation on test Meter A.

The GTI MRF test results suggest that, if time and budget allow, a turbine meter should be calibrated using the installation piping configuration and operating pressure expected for field use. This approach will minimize the likelihood of costly measurement biases being incorporated into the meter calibration. The payback period for the cost of a meter calibration of this type can be quite short if a significant meter bias due to an installation or operational effect is avoided.

**Coriolis Flowmeter Research**

Coriolis flowmeters infer the mass flow rate of a fluid by measuring the phase shift in the frequency of a vibrating tube. The shift in frequency is proportional to the Coriolis force imparted on the tube by the flowing fluid. The frequency shift is also nominally proportional to the mass flow rate of the fluid through the tube. Both straight-tube and a variety of bent-tube designs are available. An example of a bent-tube design is shown in Figure 4.

Because of the mechanics involved in inducing and measuring the Coriolis force, this type of flowmeter has historically been used to meter liquids. However, recent advances in the technology now make it possible to measure high-pressure, high-volume gas flows. The latest advancements prompted the Transmission Measurement Committee of the AGA to consider developing a gas industry standard. In 2001, the AGA TMC first published an *Engineering Technical Note* on the subject, *Coriolis Flow Measurement for Natural Gas Applications*. This technical note defined the state of the art and outlined additional research needed before a gas industry standard could be completed. Also in 2001, the GTI provided funding to carry out most of the research plan recommended in the AGA *Technical Note*. This research work included (1) baseline performance testing of commercially available Coriolis meters to establish meter accuracy and repeatability limits over a broad range of operating conditions; (2) installation and operational effects testing to determine the influences of piping installation configurations and other operational effects, such as line pressure variations, on meter performance.

Five commercially-available Coriolis flowmeters in the 2-inch, 3-inch and 4-inch diameter line size were used for the tests. The test medium was transmission-grade natural gas. Nominally accurate flow tests at the GTI MRF were performed over a broad range of operating conditions. All test meters: single 90° elbow upstream undergoing installation effects tests were run on the 2-inch diameter meters. In the installation effects tests, the following piping elements were placed upstream of the test meters: single 90° elbow (both in-plane and 90° out-of-plane relative to the plane of the meter body); double 90° elbow combination (with the elbows both in-plane and 90° out-of-plane relative to one another); a standard concentric reducer (i.e., a 3-inch diameter by 2-inch diameter reducer) and a standard 2-inch diameter tee mounted in a “clean-out” configuration (i.e., with gas flow into the branch of the tee and out one end of the run). Both bent-tube and straight-tube (radial-mode) meter designs were included in the tests. For each combination of test meter, piping configuration and flow condition, six 90-second data sets were acquired consecutively to obtain average results and to assess the short-term repeatability of the meters. The test medium was transmission-grade natural gas. Nominal line pressures of 1,000, 500 and 180 psig were tested. Reverse flow tests and the installation effects tests were only run at a line pressure of 500 psig. The nominal gas temperature for all tests was 70°F.

Figure 5 shows a 2-inch diameter bent-tube Coriolis flowmeter with a single 90° elbow upstream undergoing flow tests at the GTI MRF High Pressure Loop.

**Coriolis Meter Test Results**

As a general observation, the Coriolis meters tested at the GTI MRF were all proprietary devices and, as such, exhibited unique operating characteristics. Some general conclusions can be drawn for these meters as a group. However, each meter design exhibited individual strengths and weaknesses compared to the others in the group.

**Robust Meter**

Accurate flow measurement is now available for high gas flow rates with Micro Motion’s CMF400 with MVD technology. The CMF400, 4˝ sensor, coupled with the company’s new MVD technology transmitter, provides gas accuracy of 0.35 percent and repeatability of 0.20 percent. It has the capability of measuring natural gas up to 110,000 scfm. The meter has a secondary containment standard and a pressure rating of 1,450 psi.

Micro Motion’s flowmeter is suited for such applications as natural gas feedlines, combustion control, ethylene transfer points and refinery fuel gas.
When considering the use of a Coriolis meter for pressured gas flow measurement, one should take into consideration the unique characteristics of the various proprietary meter designs to determine which is best suited for a particular application.

The GTI MRF baseline performance results found that the total measurement uncertainties for the group of meters tested were typically within ±0.5 percent of reading. Furthermore, the baseline test results suggested that the application of water flow calibrations for meters intended for high-pressure gas service shows promise. With appropriate corrections for the change in meter bias due to increased line pressure, the residual bias errors for the four water-calibrated meters were, for the most part, within the measurement uncertainty level of the MRF HPL when the water calibrations were applied to the gas flow measurements. However, the reader is cautioned that calibration data from a statistically significant sample of meters (calibrated both on water and high-pressure gas) are needed before any broad conclusion can be drawn with regard to the applicability of water calibrations for gas flow applications.

Repeated tests of the 2-inch diameter meters in the baseline meter configuration indicated that meter reproductibility levels were on the order of 0.15 to 0.25 percent of reading. This result is illustrated in Figure 6.

Meter calibrations performed with both forward and reverse flow demonstrated that there was no significant dependence of meter error on flow direction for the bent-tube meter designs. However, the only straight-tube (radial-mode) meter in the test group did show a directional meter bias of approximately 0.8 percent.

The meter “zero” (i.e., the meter flow registration with no flow through the meter) for the bent-tube designs was relatively insensitive to the static line pressure, while the “zero” of the straight-tube (radial-mode) meter showed a nonlinear dependence on pressure, varying more at line pressures below 500 psig.

The installation configuration effects tests found that the bent-tube meter designs were less sensitive to flow field disturbances created by the upstream piping configuration than was the straight-tube (radial-mode) meter design. The bent-tube designs showed insignificant changes in flow measurement error when subjected to a variety of upstream piping configurations. This result is illustrated in Figure 7. In contrast, the straight-tube (radial-mode) meter experienced a significant change (-1.5 to +4 percent of meter reading) in flow measurement error due to the upstream piping configuration effect.

**Conclusions**

As a general observation, the turbine and Coriolis flowmeters recently tested at the GTI Metering Research Facility were all proprietary devices and, as such, exhibited unique operating characteristics. Each meter design exhibited individual strengths and weaknesses compared to the others of that particular meter type. Both turbine meters and Coriolis meters have proven to be viable metering devices for pressurized gas flows. When considering the use of either a turbine meter or a Coriolis meter for pressurized gas flow measurement, one should take into consideration the unique characteristics of the available meter designs to determine which is best suited for a particular application. Significant and costly measurement biases associated with the meter installation configuration or the operating conditions, or both, can result if a meter station designer or operator is not fully aware of the operational limits of a particular meter design.

**References**


**About the Authors**

Ms. Marybeth G. Nored is a mechanical and environmental engineer with primary interest in fluid flow measurement. Before coming to the Southwest Research Institute, Ms. Nored worked as an environmental engineer at Applied Materials in Austin, TX. Ms. Nored was an intern with Texaco, where she worked in the field repairing pump equipment, recommending potential well sites and overseeing pressure transient tests. Since joining the Southwest Research Institute in 2001, Ms. Nored has assisted with a variety of natural gas metering research projects, including development of an energy flow rate meter, assessment of various natural gas sampling methods and research on orifice flowmeter installation and operational effects. Ms. Nored is currently pursuing her Masters of Science degree in mechanical engineering.

Dr. Darin L. George is a nuclear and mechanical engineer with primary interests in the measurement and control of liquid and multi-phase flows. His accomplishments include both computational and experimental engineering projects. Dr. George began his career as an engineer and reactor reload analyst at the U.S. government’s Savannah River Site, where he specified coolant flow hardware and determined physics parameters for isotope production. Later, at Sandia National Laboratories, Dr. George demonstrated the capability of an electrical-impedance tomography (EIT) method to determine quantitative phase distributions in a gas-liquid vertical flow. He also combined EIT with an established gamma-densitometry tomography method to successfully measure material distributions in a solid-gas-liquid vertical flow. Since joining the Southwest Research Institute staff in 2000, Dr. George has been primarily involved with orifice and turbine flowmeter research for natural gas applications. Dr. George is currently a member of the Multi-phase Flow Committee of the Fluids Engineering
Figure 6 Repeat baseline test results for a 2-inch diameter bent-tube Coriolis meter operating at 500 psig line pressure.

Figure 7 Test results for a 2-inch diameter bent-tube Coriolis meter operating at 500 psig line pressure with a 3” X 2” concentric reducer, or a double 90° elbow combination upstream.

Division of ASME, and is a registered professional engineer in South Carolina and Michigan.

Mr. Terrence A. Grimley is a mechanical engineer with experience in analytical, computational and experimental heat transfer, fluid mechanics and two-phase flow. He has been a member of the Southwest Research Institute staff for 16 years, with prior work experience at Trane. Since 1991, Mr. Grimley has been involved with the development of the Gas Technology Institute Metering Research Facility. His responsibilities have included construction and integration of key elements of the facility’s weigh tank proving system and data acquisition systems. Since 1995, Mr. Grimley has been manager of the ultrasonic flowmeter research program at the Metering Research Facility. Results from this research program have contributed to the development of the natural gas industry’s recommended practice for ultrasonic meters, AGA Report No. 9 — Measurement of Gas by Ultrasonic Meters. In 2000, Mr. Grimley began managing a new research initiative on Coriolis flowmeters for natural gas applications.

Mr. Edgar B. Bowles, Jr. is a mechanical engineer with primary interests in fluid dynamics and heat transfer. He has experience with both analytical and experimental engineering projects. During his 23 years at the Southwest Research Institute, Mr. Bowles has been involved with a variety of projects for the oil and gas industry. Since 1995, he has managed the Gas Technology Institute Metering Research Facility located at the Southwest Research Institute. This large-scale test facility was built in 1991 for the purpose of advancing the state of the art of natural gas flow measurement in the United States and abroad. Mr. Bowles is an active contributor to the development of industry standards for natural gas flow measurement. He is currently a member of the American Gas Association Transmission Measurement Committee; the American Petroleum Institute Committee on Gas Fluid Measurement and the Consultative Committee for Mass — Working Group Flow of the Comité International des Poids et Mesures of the Bureau International des Poids et Mesures. He is also on the organizing committees of the International School of Hydrocarbon Measurement and the American School of Gas Measurement Technology.

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