ADVANCED DIAGNOSTIC MEASUREMENT AND VERIFICATION WITH CORIOLIS MASS FLOWMETERS

Class # 2490.1

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Introduction

Electronic instruments have become increasingly intelligent. In the recent past, a sensor only transferred the measured process parameters to the Distributed Control System (DCS) in plant process applications, today sensors can measure multiple process variables, transmit internal data, and even provide information regarding their status. Digital communication, over fieldbus networks, enables the devices to provide all kinds of data, singly from each measurement point at a time. Today's data management systems have greater power to not just collect the process data and verify whether the system is within or outside acceptable limits but can also determine the reliability of the device information, it's condition and whether it is in need of maintenance.

Electronic instrumentation with data automation equipment has now found increased application into oil and gas field applications, replacing mechanical measurement and recording devices, and minimizing personnel needs at remote gathering points.

Coriolis mass flowmeters are replacing volumetric technologies. Coriolis mass flowmeters comply with the recommended standards described in the American Petroleum Institute Manual of Petroleum Measurement Standards and those of the American Gas Association. They comply with the operational requirements described by the Alberta Energy and Utilities Board and satisfy the requirements of Measurement Canada. In the United States, Coriolis mass flowmeters are often being used in oil and gas field applications. Although not specifically identified, they satisfy the requirements described in the Code of Federal Regulations that are enforced by the Bureau of Land Management and Mineral Management Services.

Today, Coriolis mass flowmeters enable the allocation meter user a more robust and flexible measurement technology.

Coriolis Mass Flowmeters

Commercial Coriolis meters for liquid and gas flow measurement were first developed in the late 1970's. First applied in chemical applications, these early devices evolved into the rugged, reliable, precise multivariable instruments used in many applications across many industries including liquid hydrocarbons.

As a flow measuring technology, Coriolis meters have unique measurement principle with fundamental benefits:

1. The direct measurement of mass flow rate and liquid density
2. The computed measurement of gross volume
3. Wide turndown and range of flow measurement
4. Accuracy and repeatability which exceeds the allocation metering standards
5. NIST traceable calibrations and laboratory accreditation to ISO-17025 for customer produced meters
6. In-situ verification tools
7. Detect long term sensor and transmitter linearity, repeatability or drift
8. Advanced diagnostics program detection of long term and transient process effects
9. Recognition of gas breakout or slug flow events
10. Immunity from process changes related to viscosity or density
11. Robust design
12. Extended MTBF versus mechanical meter technologies

The direct measurement of mass rate

Coriolis flow meters operate on the principle of the Coriolis Effect. It measures the mass flow rate directly. The Coriolis flow sensor is constructed of one or two balanced metal tube(s). (Figure 1) An electronic transmitter maintains the amplitude of the tube oscillation at a minimally applied excitation current which keeps the tube(s) in motion with an electro-mechanical system (exciter), mounted in the center of the tubes. A mass flow dependent Coriolis force occurs when a moving mass is subjected to an oscillation perpendicular to the direction of flow. When a mass of gas or liquid passes through the flow sensor, the Coriolis force is induced by the oscillatory motion.

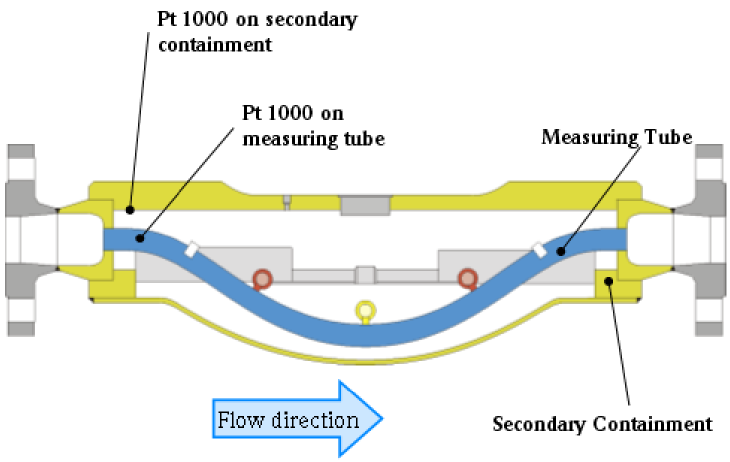

Figure 1

The Coriolis reaction force experienced by the traveling gas or liquid mass is transferred to the measurement tube(s) and induces a change of motion. Two motion sensors (electro-dynamic sensors) detect this change, essentially a twisting of the tube(s). Mass flow is determined by the phase offset or difference between the inlet and outlet measurement signals derived at the electro-dynamic sensors. (Figure 2) As the mass flow rate increases, the phase offset measured by the electro-dynamic sensors will increase proportionally.

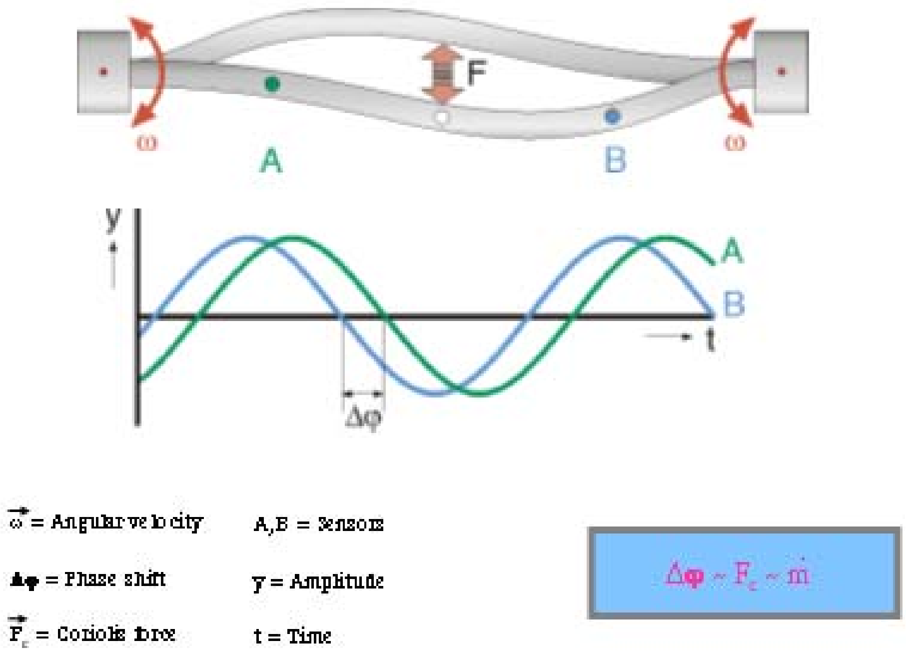

Figure 2

No additional correction for temperature or density is required to achieve a direct measurement of mass flow rate in a Coriolis flowmeter.

<u>The direct measurement of the fluid density</u>

The Coriolis flowmeter is also used to determine the liquid density. The flow tube(s) vibrates at a resonant frequency which corresponds to the sensing tube(s) material and the density of the fluid in the tube(s). When the liquid density changes, then the resonant frequency also changes. To counter the effects of density changes due to changing temperature, a Pt-1000 RTD (resistance temperature device) are mounted on the flow tube to measure the process fluid temperature. During the flow meter calibration process, the resonant frequency of each sensor is determined on air and water. This becomes an important “thumbprint”, unique to each sensor produced. For more exacting density measurement requirements, various liquids with know densities are used and temperatures are varied to provide a more precise density calibration. The process density can be corrected to a reference temperature (e.g. °API at 60° F).

<u>The measurement of gross volume</u>

Volumetric flowmeters do not measure mass directly nor density, or temperature. The addition of a flow computer and temperature element is required to correct for density changes due to the liquid temperature to achieve the resulting net volume measurement. Variation in flowing condition, such as velocity profile distortion and swirl, will influence the accuracy of the “gross” volume measurement. These additional measurement elements and computational assumptions will contribute to increasing the overall uncertainty of the measurement.

Coriolis mass flowmeters are unaffected by velocity profile. Since the Coriolis flowmeter produces a direct measurement of mass flow rate, product density and temperature, the accurately computed measurement of “gross volume” flow rate is also possible.

Outputs of measured variables and sensor diagnostics

The Coriolis transmitter powers the flow sensor, converts the measurements into required application specific units and provides useable output. Several output configurations are provided by Coriolis flowmeter technology. These include a factored pulse output (maximum 10,000 Hertz), an analog current output (4-20 milliamp) and a digital output (MODBUS RS-485). The flowmeter measured variables and sensor diagnostics may are instantaneously transmitted to the host DCS or PLC. Proving requirements are satisfied with the factored pulse output. The flow computer of the prover uses the pulse output to establish a meter factor (MF) during the proving process.

Wide flow range and immunity from process changes

Coriolis flowmeters have a wide operating range and can be applied in laminar, transitional, and turbulent flow regimes without degradation of flow accuracy, linearity and repeatability. Coriolis flowmeters are commonly applied into applications with turndown ratios from the flowmeter full scale of up to 100 to one, depending on the user performance requirements.

While viscosity changes will reduce the measuring range of volumetric meters and may affect the linearity of the measurement, Coriolis mass flowmeters measure the mass flow rate regardless of changing liquid viscosity.

Coriolis flowmeters measure density. Variation which occurs in the process liquid is actively accounted for in the "gross volume" calculation.

When the process liquid and ambient conditions differ, external temperature influences can be accounted for by measuring the temperature of the secondary containment housing with Pt-1000 resistance temperature detectors (RTD).

High reliability

Today, Coriolis flowmeters are selected for their highly accurate and repeatable measurement, long term stability, and resistance to wear. The broad acceptance into industrial and field applications has enabled detailed evaluation of Coriolis technology. The calculation of Mean Time Between Failure (MTBF) relates to the safety of the device when placed into operation. MTBF is a common relevant safety factor. Coriolis flowmeters have one of the highest MTBF for electronic instrumentation – greater than 43 years –exceeding the life span and expectancy of mechanical volumetric flow measurement technologies.

In-situ verification

Even with the robust design and long expected life of operation, over time, electronic flowmeters could suffer from drift or wear in operation as a result of process influences. Often, these changes were deemed "undetected" faults. A traceable method of in-situ electronic verification can isolate 'out of tolerance' trends and predictably identify pending flowmeter failures. A calibrated electronic device, FieldCheck, traceable to a reference standard through International Standards Organization - 17025 (ISO) methods, is used to perform in-situ verification. The verification is initiated based upon operator experience, at a proactive interval, or in response to an accuracy alarm. (Figure 3)

Linearity, repeatability, and deviation limit tests are performed during the electronic verification. A completed verification will indicate a pass, fail, or not tested condition for each Coriolis flowmeter system. The electronic verification performs tests of both the sensor and transmitter components. A verification test report can be produced for electronic archiving or printing a report. The verification reports are unalterable by the user, ensuring confidence in their result.

No such method of in-situ verification is known to exist for other mechanical flowmeter technologies.

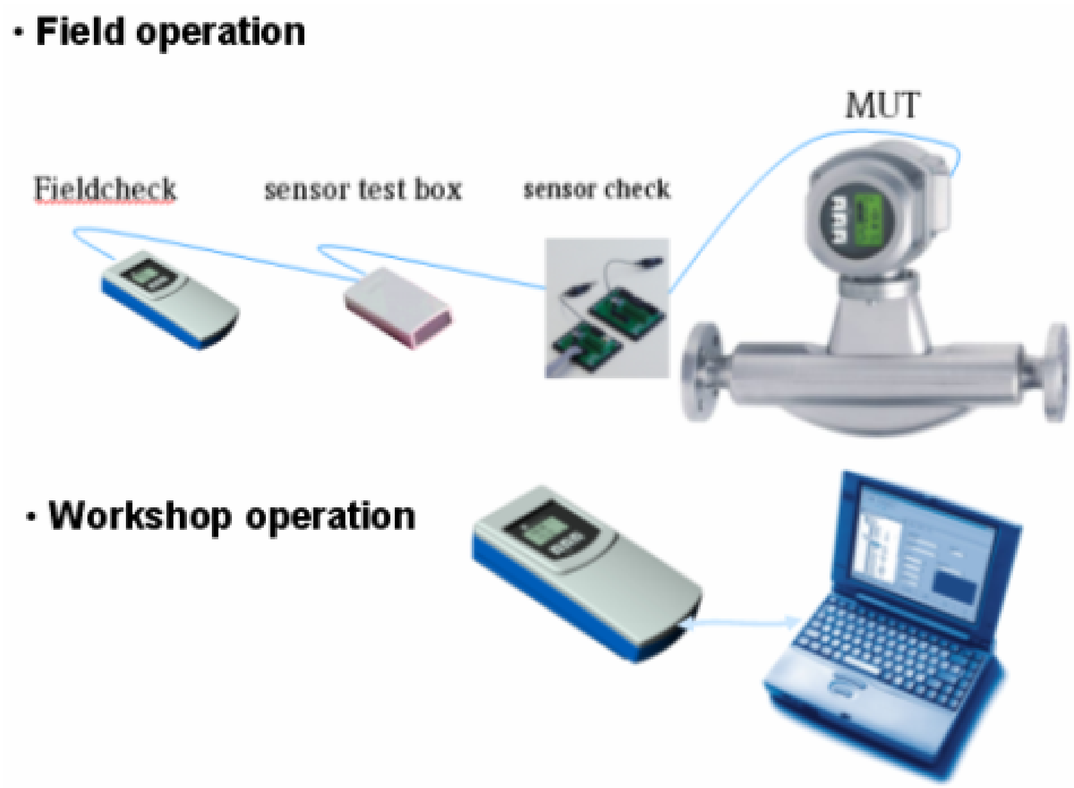

Figure 3

Advanced Diagnostics

The long term, continuous monitoring and detection of process effects should be considered for any flow measurement device. Coriolis flowmeters detect the conditions which compromise measurement stability, induce drift, or add measurement error. The Coriolis microprocessor based transmitters provide standard measurement capabilities as described above and also advanced diagnostics functions.

Advanced Diagnostics can identified process related effects in <50 mSec priority, reporting by MODBUS, an alarm output, or a failsafe driven output. Process effects can be categorized as long term or transient events. Identification of process related effects most likely to affect measurement accuracy and repeatability include:

Corrosion effects from process chemistry	Long Term
Erosion effects from suspended solid abrasion	Long Term
Solids settling or accumulating	Transient
Coating effects from fluid adhesion	Transient or Long Term
Gas breakout or slug flow conditions in liquids	Transient

When Advanced Diagnostics programming is implemented adverse conditions can be identified when they occur. A unique signature or "thumbprint" is created during this commissioning process. With a constant, known flowing process condition and with uniformly constant density, the detection of a resonant frequency change over time may be indicative of density drift. Sustained asymmetrical tube deviation may identify corrosion. Steady, rising damping of the tube vibration may be indicative of coating or solids accumulation. Rapid changes in drive current excitation or sensing tube frequency may pinpoint gas breakout. Limits are set by field service personnel based on previous manufacturer service experience. These limits are configured for automatic detection.

Advanced diagnostic implementation can ensure detection when process events occur.

Calibration traceability

Since Coriolis flowmeters directly measure mass flow rate, a gravimetric mass flow calibration method is the ideal method to calibrate Coriolis flowmeters. Mass, a fundamental unit, is directly traceable to the international kilogram artifact reference standard at the National Institute of Standards and Technology (NIST) in Gaithersburg Maryland. Volume is a derived unit (length cubed). Volume measures are typically calibrated gravimetrically with the volume then calculated based on the known density of water. Provers are calibrated with volume measures. The uncertainty increases with each additional process in the traceability chain to the national artifact standard.

Many manufacturers have laboratories compliant to the guidelines described in the International Standards Organization, ISO – 17025 with NIST traceability. While there are several methods of calibration used to calibrate Coriolis mass flowmeters, each having different levels of uncertainty, the most reliable calibration procedure, which provides the lowest uncertainty, is a direct gravimetric calibration method with traceability to the National Institute of Standards Technology. The direct gravimetric calibration rig is operational closest to the primary reference standard. This method is recognized in ISO 4185 and also the American Society of Mechanical Engineers MFC-9M (1988).

The gravimetric calibration method is not practical in field proving applications where volumetric provers or master meters are used in accordance to established procedures described in the American Petroleum Institute, Manual of Petroleum Measurement Standards, Chapter 4 - Proving. A factory calibration establishes the accuracy of the device. A field proving establishes repeatable performance.

Coriolis accuracy and repeatability exceed the allocation metering standards

Mass flowmeters are referenced in the Canadian Draft Weights and Measures Act and in NIST Handbook 44. Coriolis mass flowmeters have been type evaluated by both Measurement Canada and the National Type Evaluation Program (NTEP) and found to comply with requirements for use in legal trade service. Coriolis meters meet the required tolerance of better than +/- 0.20% measurement of mass or volumetric quantities. To achieve the volumetric tolerance, the density measurement accuracy must be less than or equal to 0.0005 Specific Gravity Units (SGU). The repeatability of the Coriolis meter is better than 0.05% for both mass and volume flow measurement.

Accuracy and repeatability for allocation measurement requirements are easily exceeded by Coriolis flowmeter technology.

Compliance to requirements

The Alberta Energy Utilities Board, Bureau of Land Management and Mineral Management Services all note requirements for meters to comply with the American Petroleum Institute (API) Manual for Petroleum Measurement Standards (MPMS) and American Gas Association (AGA) standards. Coriolis mass flowmeters are recognized use in liquid hydrocarbon custody transfer applications in the API MPMS Chapter 5 – Metering, Section 6 – Measurement of Liquid Hydrocarbons by Coriolis Meters, First Edition October 2002. The use of Coriolis mass flowmeters is recognized in natural gas custody transfer applications in the AGA Report Number 11, Measurement of Natural Gas by Coriolis Meter, 2003.

Trends in oil and gas applications with Coriolis mass flowmeters

Coriolis mass flowmeter are replacing high maintenance mechanical flow meters.

Coriolis mass flowmeters are not affected by flow pulsation or pressure surges. They are less susceptible to process condition changes and effects. They are used over a wide range of flow rate, density, viscosity, temperature and pressure without the need for a linearization meter factors. Coriolis mass flowmeters may provide outputs for density or temperature and fault/notification status. MODBUS digital communication is also available directly from the Coriolis mass flowmeters electronic transmitter.

With the implementation of in-situ verification and advanced diagnostics techniques, the Coriolis mass flowmeter used as royalty meters may enable extended proving periods beyond the 42 days typically required of royalty meters. The Coriolis mass flowmeter meter factor repeatability over time will first be demonstrated before extending the proving periods. Using a Coriolis mass flowmeter as a master meter will additionally reduce the proving time and the cost.

Conclusion

Coriolis mass flow technology affords users significant advantages in allocation metering service of liquid hydrocarbons. This technology provides more process measurement variables, higher accuracy, lower uncertainty, long term stability and extended life in service. Coriolis meters offer valued improvement over mechanical flowmeters. Broad based acceptance of Coriolis meters exists today as seen with recognition from national and international standards organizations. Recent refinements in the Coriolis flowmeter functionality adds value which will advance use into difficult applications that need exceptional dependable performance.

References:

American National Standard Institute / National Conference of Standards Laboratories, ANSI / NCSL Z540-1, Calibration Laboratories and Measuring and Test Equipment - General Requirements (1994)

American Petroleum Institute, Manual of Petroleum Measurement Standards, Chapter 5 – Meters, Section 6 – Measurement of Liquid Hydrocarbons by Coriolis Meters, First Edition October 2002

American Gas Association, Chapter 5 – Meters, Section 6 – Measurement of Liquid Hydrocarbons by Coriolis Meters, First Edition October 2002

American Society of Mechanical Engineers MFC-9M (1988) Measurement of Liquid Flow in Closed Conduits by Weighing Method

International Standards Organization / International Electrotechnical Commission, ISO/IEC -17025 General requirements for the competence of testing and calibration laboratories (2005)

International Standards Organization, ISO 4185 Measurement of liquid flow in closed conduits -- Weighing method (1980)

International Standards Organization / International Electrotechnical Commission, ISO/IEC Guide 25 Accreditation of Information Technology and Telecommunications testing laboratories for software and protocol testing services (1995)

National Institute on Standards and Technology, Handbook 44, Specifications Tolerances and Other Technical Requirements, Section 3.31 Mass Flow Meters.

Organizations:

American National Standard Institute, 1819 L Street, NW, Washington, DC 20036, Tel: 1.202.293.8020

American Petroleum Institute, 1220 L St NW, Washington, DC 20005, (202) 682-8000

American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990, 800-843-2763

International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland, Telephone +41 22 749 01 11

Mineral Management Services, 1849 C Street NW, Washington, D.C., 20240

Bureau of Land Management, 1849 C Street NW, Rm. 5665, Washington D.C. 20240