CORIOLIS MASS FLOW METERS
FOR GAS AND LIQUID MEASUREMENT

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Introduction

The first flow meter utilizing the Coriolis force to measure mass flow was patented in 1978. Today, hundreds of thousands of Coriolis meters are in service in the hydrocarbon industry to measure mass, volume, and liquid density of a wide variety of fluids.

The American Petroleum Institute published Chapter 5.6 entitled "Measurement of Liquid Hydrocarbons by Coriolis Meters" in October 2002 and a second edition in 2021. The standard describes methods to achieve custody transfer levels of accuracy when a Coriolis meter is used to measure liquid hydrocarbons.

Coriolis meters have rapidly gained worldwide acceptance in gas phase applications with over 100,000 meters installed worldwide and most notably the publication of the second edition of AGA Report Number 11, **"**Measurement of Natural Gas by Coriolis Meter"**.**

Principle of Operation of Coriolis Meters

The Coriolis force was mathematically expressed in 1835 and referred to the deflection relative to the earth's surface of any object moving about the earth. This force is produced on a vibrating tube(s) as fluid moves through the Coriolis meter. When a fluid moves through the vibrating tube(s), the Coriolis force will cause the tube(s) to distort slightly. The degree of distortion is directly proportional to the mass flow rate of the fluid. Coriolis manufacturers use various proprietary techniques to monitor the magnitude of the distortion and process the measured signals into useable flow information. As mass flow rate through the vibrating tube(s) increases, the offset in position or distortion monitored between the upstream and downstream portions of the tube(s) will increase. The manufacturers flow calibration factor defines the relationship between the degree of distortion and the mass flow rate.

In addition to the Coriolis force, most meters can measure the frequency of vibration of the tube(s) which is proportional to the density of the fluid inside the tube(s). The manufacturer defines the frequency/density relationship for each meter. The Coriolis force and the frequency of vibration are not a function of each other. The amount of Coriolis force exerted on the tubes(s) does not change the frequency of vibration.

Another point to note is that what might affect the frequency of vibration or density measurement does not necessarily influence the Coriolis force or mass flow. For example, the accuracy of a Coriolis meters mass measurement in applications where there is entrained gas in the liquid can be quite good; however, the density measurement of the liquid is in error due to the entrained gas.

Since volume is equal to mass divided by density, Coriolis meters are often utilized to measure volume flow rate. So, in the case of liquid volume measurement, both the Coriolis force and the frequency of vibration are utilized to determine volume rate. It is necessary to evaluate both the accuracy of the mass measurement and the accuracy of the density measurement when considering the accuracy of the volume output. Gas volume at standard conditions (e.g., SCF) is calculated by dividing a measured mass flow rate by a fixed gas density at standard conditions.

There are other effects from process conditions that require corrections for the measured variables of mass or volume and density. These corrections should not be confused with the calculations for net volume calculations. For example, temperature influences the elasticity of the tubes. Most sensors have an internal RTD which measures tube temperature and corrects for elasticity which will increase with temperature. Increases in pressure may also change the stiffness of the tube(s) so pressure effects may also need to be considered. The design of the Coriolis sensor defines the sensitivity to secondary effects such as temperature, pressure, flow, and viscosity. The manufacturers methodology for factory calibration and being able to define the meters response through rigorous testing against traceable standards will determine the meters performance in the field.

Coriolis meters applied to liquid and gas are identical in terms of meter design. Transmitter configuration is used to select liquid or gas application specifics.

Coriolis Meter Installation and System Design

Since Coriolis meters differ dramatically from one manufacturer to another as far as design of the vibrating tube(s) including tube shape and the way flow enters the meter, it is important to review the manufacturers recommendations for mounting of the meter. In general, the meter should be oriented such that the meter is always filled with single phase fluid and in a manner that air (liquid applications) or liquid (gas applications) cannot be trapped inside the tube(s). Proper alignment of the meters inlet and outlet flanges with the process piping is necessary to avoid stresses that may affect the resonance of the tube(s) inside the meter.

Coriolis meters do not require flow conditioning for liquid or gas applications. In other aspects, the metering system design is like other traditional liquid flow metering installations. Unlike meters with moving parts, the Coriolis meter can potentially pass typical pipeline solids without damage to the meter, however, a strainer upstream of the meter is recommended to protect the other components of the metering system including the meter prover. A backpressure valve should be located downstream of the meter and prover connections to avoid cavitation. Consideration should be given to the location of the meter electronics that generate the pulse output for portable provers so that the proving connections and the transmitter are in proximity.

Valves to stop flowing through the Coriolis meter are required for liquid and gas applications. Verification that the meter registers zero flow in a non-flowing condition is required on initial installation and may be part of a routine maintenance program.

Typical liquid system diagrams are provided in the API MPMS Chapter 6. AGA11 includes a typical natural gas installation drawing for Coriolis meters.

Coriolis Meter Proving and Field Verification

Liquid and gas applications require periodic meter performance verification. This is accomplished by liquid meter proving or gas verification procedures.

Liquid Coriolis meters are often field proven following API MPMS Ch. 4 guidance. Since the transmitter pulse output is produced by the electronics package, it is programmable by the user. Consideration should be given to the chosen K-factor (pulses per unit) so that the frequency level of the pulses generated does not exceed the output specification of the Coriolis electronics or the input specification of the prover flow computer.

In general, proving a Coriolis meter as a volume meter does not differ from the recognized procedures for any other type of flow meter.

The proof of a Coriolis meter that is metering in mass units with a volumetric prover (inferred mass proving) requires the additional measurement of density at the prover to determine prover mass. It is recommended that a density meter be installed on the prover to provide a continuous density reading that can be averaged for each proving run. The density meter should be proven and the density meter factor applied in the proving software prior to proving the Coriolis meter. Repeatability between runs and reproducibility of the mass meter factor are directly affected by the density measurement at the prover.

Coriolis meters applied to natural gas measurement may be verified in situ. AGA11 Section 9.1 outlines a verification procedure which uses meter diagnostics and a meter zero versification to ensure meter performance.

Coriolis Meter Applications

Coriolis meters have very few limitations related to the fluids they can measure in gas, liquid, or supercritical phase. As with all metering systems, the choice of flow meter technology should also be based on the cost of ownership.

With no moving parts, the Coriolis meter offers significant advantages for metering heavy or viscous fluids, dirty fluids, and fluids with high solids content, or liquid systems that might generate air slugs that can damage other types of meters. Company costs associated with repair parts and inventory can be reduced. Less maintenance allows more pipeline throughput and less downtime.

The Coriolis meter is multivariable and can provide real time information for diagnostics and system control. This can have enormous cost savings in field labor costs with additional data to better understand what is happening at a metering site on a timely basis.

Advanced meter diagnostics can be used to verify meter performance and support a maintenance by exception program.

Additional Coriolis Meter Benefits

Coriolis meters are inherently bi-directional meters and can be installed for a lower cost since special piping arrangements are not required upstream or downstream of the meter. No requirement for straight pipe and/or flow conditioners allows the Coriolis meter to be installed in locations where space is limited and costly such as offshore platforms. Coriolis meters typically can replace a meter with a smaller face-to-face dimension by building a spool piece. This reduces the cost of installation for retrofits as no piping changes are required to the existing system.

Coriolis meters measure liquid density in addition to measuring flow. Density is required for the calculation of net volume and is often used to monitor product quality. There are considerable cost savings for liquid metering systems that require both flow and liquid density measurement to calculate volume correction factors. Coriolis meters metering flow and density reduce measurement uncertainty because there is no requirement to provide a density meter sample loop. A single device measures the flow and density.

Finally, the same Coriolis meter can accurately measure natural gas. Coriolis transmitters can be programmed to output natural gas mass flow rate or standard volume given a density at standard conditions input.

Conclusion

Industry is continually searching for better measurement. Newer flow meter technology such as the Coriolis meter can offer a higher degree of safety, reliability and/or benefits related to efficiency of the overall operation, thus contributing to the profit of the industry.

References

American Petroleum Institute Manual of Petroleum Measurement Standards, Chapter 5.6, “Measurement of Liquid Hydrocarbons by Coriolis Meter,” December 2021

American Gas Association Report No. 11, “Measurement of Natural Gas by Coriolis Meter”, Second Edition, February 2013