FUNDAMENTALS OF MASS MEASUREMENT (CORIOLIS METERS)

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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 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 reaffirmed the standard in 2013. The standard describes methods to achieve custody transfer levels of accuracy when a Coriolis meter is used to measure liquid hydrocarbons.

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 manufacturer's flow calibration factor defines the relationship between the degree of distortion and the mass flow rate.

In addition to the Coriolis force, most meters are capable of measuring 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 have an effect on the Coriolis force or mass flow. For example, the accuracy of a Coriolis meter's 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 very often utilized to measure volume flow rate. So, in the case of 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. Coriolis meters can differ dramatically in their specification of density accuracy and therefore, would differ dramatically in their volume accuracy.

There are potential other affects from process conditions that require corrections to be made to the measured variables of mass or volume and density. These corrections should not be confused with the calculations addressed in the following section which are for net volume calculations. For example, temperature has an effect on the elasticity of the tubes. Most sensors's 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 manufacturer's methodology for factory calibration and being able to define the meter's response through rigorous testing against traceable standards will ultimately determine the meter's performance in the field.

Mass vs. Volume Measurement

Temperature and pressure do not affect a measurement of mass. A pound of fluid, for example, defines the amount of fluid at any process condition demonstrating that mass units provide a very good custody transfer method and also an excellent way to address plant and pipeline balances. A volume measurement, on the other hand, will

differ from one set of operating conditions to another. Thermal expansion and compressibility must be calculated to convert a gross volume measurement made at operating conditions to contractual temperature and pressure conditions.

In spite of the sampling, calculations and additional measurements required to make these needed corrections to a flow meter's gross volume measurement; it is less typical for custody transfer to take place based on a mass measurement in the petroleum industry. The decision to measure in mass or volume is determined by several considerations. One is the availability of the data to correct the volume measurement to contract conditions such as the equations found in Chapter 11 of the API Standards. Another consideration is the potential for solution mixing in multiple component fluids such as natural gas liquids where mass measurement and a chromatographic analysis are commonly used to determine component barrels. For other fluids like ethane, temperature and pressure changes increase and decrease density so much that small errors in their measurement can cause huge errors in volume calculations, so mass is often the measurement of choice. Fluids like CO2 and ethylene that are measured near their critical point are very often metered and transferred on a mass basis. Ultimately, the choice between mass and volume may come down to what type of prover is available in the field.

Coriolis Sensor Considerations

Some manufacturers offer a comprehensive sizing program which provides information regarding accuracy, flow rate, pressure drop and velocity with any given fluid and set of process conditions. The use of this type of program eliminates potential misuse of a more generic published specification. Of course, knowledge of minimum and maximum rates, process conditions including density and viscosity, pressure and temperature are always critical in the selection of any flow meter.

Coriolis meters offer the advantage of a large turndown ratio, more than twice the turndown of most other flow meters. However, at some point the accuracy drops off on the low end. When operating in a meter's nominal flow range, accuracies of as high as ±0.05% of rate can be achieved.

The pressure drop across the meter should be known in order to select the proper size sensor. For example, one size meter may handle a rate of 2500 bbl/hr but have a pressure drop 13 psi. One size larger meter may only have 2 pounds pressure drop at the same rate. Pressure drop should always be considered with any flow meter that is operating near a fluid's equilibrium vapor pressure so that the fluid does not cavitate or flash at the metering point. Air or gas slugs do not damage the Coriolis sensor however, flow and density are affected.
Flow velocity through a Coriolis should also be considered when sizing a meter for an erosive fluid with high solids content, because of pipeline design consideration or proving considerations.

There are temperature and pressure limitations for the sensor but Coriolis meters are available in some designs for extremes up to 800 qF and 6000 psi and for cryogenic service. One issue that is important to note is that the pressure rating of the tube(s) is not necessarily the same pressure rating for the sensor housing.

Coriolis Transmitter Considerations

Coriolis meters are electronic, require power and some associated device that interprets the signals from the sensor and provides useable digital, analog or serial outputs. Most meters today have a separate device or transmitter but others produce an output direct from the sensor. Whether in a separate housing or located on the meter, there is a CPU that processes the sensor signals and makes the calculations that provide for the outputs required. The user has the ability to program the transmitter to output in the required units of measurement.

For custody transfer, the requirement is typically to send a pulse to the RTU or flow computer. Since there is no movement or mechanical action in the meter that can be utilized to produce a pulse, the CPU is programmed to produce the pulse required for proving and for totalization. The user has the choice of this pulse representing mass or volume. The user also defines the number of pulses that will be generated per unit of mass or volume (k-factor). For example, the electronics can produce 100 pulses per pound or 10000 pulses per barrel. For mass measurement, there are no further calculations required in the flow computer except to apply a mass meter factor determined by field proving. For volume measurement, measurements of temperature, pressure and density are required to calculate net volume in addition to applying the volume meter factor.

Given the capabilities of electronics today, additional features are easily a part of a Coriolis transmitter such as alarm and control outputs, averaging, calculation of relative density, and diagnostics. The latest transmitters allow access to historical information and configuration changes.

Since the Coriolis meter is programmable, the means of configuring the meter should be understood in addition to the security of the device after installation in the field.

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 manufacturer's recommendations for mounting of the meter. In general, the meter should be oriented such that the meter is completely filled with fluid at all times and in a manner that air cannot be trapped inside the tube(s). Proper alignment of the meter's 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. In other aspects, the metering system design is similar to 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 located in close proximity.

Valves to stop flow through the Coriolis meter are required. Verification that the meter registers zero flow in a non-flowing condition is required on initial installation.

A typical system diagram is provided in API Chapter 5.6.

Coriolis Meter Zero and Proving

A meter factor determined from a field proving is most often a requirement for any meter used in liquid custody transfer. Frequency of proving and the method for proving is commonly dictated by the contract between buyer and seller.

Since the 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 counter or associated flow computer. Also, consideration should be given to the speed of response to a flow rate change. The manufacturer should be consulted to ascertain that any damping of the pulse output has been removed.

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 calculation of the meter factor is not unique for a Coriolis meter.

The proving of a Coriolis meter that is metering in mass units with a volumetric prover requires the additional measurement of density at the prover in order to determine a meter factor for the mass output. 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 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. For mass proving, it is best to utilize the average meter factor method to determine repeatability as this method indicates the repeatability of all the components in the proving system rather than just the meter pulse.

As part of the normal startup procedure for a Coriolis meter, the sensor output at zero flow is verified in the field. The meter will not zero if the upstream or downstream valves are leaking or if air is trapped inside the meter. The zero can be checked after initial installation; however, a stable (reproducible) meter factor from proving provides proof of a good zero value. If the meter is rezeroed you have created a need to generate a new meter factor. A major change of process conditions, replacement of a sensor or transmitter, or a changeout of other system components in near proximity that would change the piping stresses would be typical reasons for needing to re-verify or re-zero the meter.

Coroilis Meter Applications

Coriolis meters have very few limitations related to the fluids they can handle. Published specifications can identify these types of parameters. As with all metering systems, the choice of flow meter technology should also be based on cost of ownership

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

The Coriolis meter can provide real time information much more than just flow 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. One case in point would be that the control room for a crude oil pipeline could be notified that the meter was receiving slugs of water and react accordingly.

A Coriolis meter is inherently a bi-directional meter and can be installed for less cost for this service since special piping arrangements are not required upstream or downstream of the meter. Also the lack of the 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 that creates a small flow loop with the fluid flowing up through the Coriolis meter. This reduces the cost of installation as no piping changes are required to the existing system to replace another meter.

The Coriolis meter as mentioned previously measures density in addition to measuring flow. Density is required for the calculation of net volume and is often used to monitor product quality. There is a considerable cost savings for metering systems that require both the measurement of flow and the measurement of density or relative density. In the application of a Coriolis meter metering flow and density there is less uncertainty in the measurement of density because there is no requirement to provide a densitometer sample loop that necessitates a representative sample of the fluid at the same temperature and pressure of the fluid in the pipeline. A single device measures the flow and density.

Finally, the large turndown of a Coriolis meter can eliminate the use of a bank of several different size meters to cover the changing rates. This also provides a cost savings and lowers cost of ownership.

Conclusion

The petroleum industry is continually searching for better processes. New technology in flow measurement devices 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, Chapter 5.6, “Measurement of Liquid Hydrocarbons by Coriolis Meter,” October 2002