# MASS METERS FOR LIQUID MEASUREMENT

Class LM 2260

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## Introduction

There are several types of flow meters that respond to the mass of the flowing fluid rather than volume, area, or velocity. Examples of mass flow meters are thermal mass meters, gyroscopic mass meters, angular momentum mass meters, and Coriolis mass meters. This paper will address only the Coriolis flow meter.

A meter utilizing the Coriolis force to measure mass flow was first patented in 1978. Coriolis meters are still considered by some today as an “emerging technology,” however, thousands of meters are in service in the hydrocarbon industry to meter both mass and volume of a wide variety of fluids. This paper will review the technology and convey differences in this technology versus mechanical meters in an attempt to clarify some of the issues surrounding the use of Coriolis meters especially for custody transfer in the petroleum industry.

## Mass vs Volume Measurement

Since the Coriolis force is a measure of mass flow, it is reasonable to address the use of Coriolis technology to meter fluids on a mass basis. A mass measurement does not depend on the temperature and pressure conditions at which the measurement is made. A pound of fluid defines the amount of fluid at any conditions 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, can differ from one set of operating conditions to another. Thermal expansion, compressibility and, in the case of crude oil the percent S&W of the fluid, must be considered to convert a gross volume measurement made at operating conditions to contract conditions (net volume).

In spite of the sampling, calculations and measurements required to make these needed corrections to a volume measurement, it is rare for custody transfer to take place based on a mass measurement in the petroleum industry. Natural gas liquids are measured on a mass basis but custody transfer is based on the volume of each individual component. Fluids like CO2 and ethylene that are measured near their critical point are very often metered and transferred on a mass basis.

Most Coriolis meters can measure the density of the fluid in addition to the mass flow rate. Therefore, since volume is equal to mass flow divided by density, the associated electronics package can be programmed to output in volume. At this point, Coriolis meters become volume meters and can provide an output similar to such other meters as positive displacement and turbine meters. 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.

## Principle of Operation of Coriolis Meters

The Coriolis force as first identified in 1835 referred to the deflection relative to the earth's surface of any object moving about the earth. This force can also be produced on a vibrating tube(s). 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 measurement 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.

In addition to measuring the Coriolis force, most meters are capable of utilizing the frequency of vibration of the tube(s) to measure density. Density is related to frequency, though not linearly, by the following equation:

$$\rho = C0 + C1T^2$$

Where,
$\rho$ = Density if fluid
C0 & C1 = Constants
T = Tube time period

The design of the Coriolis meter's vibrating tube(s) defines the potential density accuracy of the transducer. In particular, the design defines the fundamental sensitivity, repeatability and linearity of the frequency to density relationship. Secondly, it defines the transducer's sensitivity to secondary effects such as temperature, pressure, flow and viscosity. Just as in all vibrating element densitometers, the manufacturer's methodology for factory calibration, being able to define the meter's response against traceable standards, will ultimately determine the meter's performance in the field.

A point should be made here that the effects on frequency or density do not necessarily have an effect on the Coriolis force or mass flow, but density does have an effect on the volume metered by the Coriolis meter.

## Coriolis Sensor Considerations

Some manufacturers offer a comprehensive sizing program which offers information regarding accuracy, flow rate, pressure drop and velocity with any given fluid and process condition. The use of this type of program eliminates potential misuse of a published specification that may be based on a calibration fluid at laboratory conditions.

Coriolis meters offer the advantage of a large turndown ratio, more than twice the turndown of a turbine meter. Flow velocity through a Coriolis meter is generally high. Velocity should always be considered when sizing a meter for an erosive fluid with high solids content and when considering piping limitations including pressure drop. The pressure drop across the meter should be known in order to select the proper size sensor. For example, a 4" meter can handle a rate of 2500 bbl/hr but has a pressure drop at this rate of 13 pounds (with a viscosity of 1 cps). A 6" meter, the largest size Coriolis meter available today, has 2 pounds pressure drop at this 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. Coriolis meters are not intended to meter multiphase fluids, specifically fluids that are a mixture of gas and liquids, though air or gas slugs do not damage the meter.

There are temperature and pressure limitations though Coriolis meters are available in some designs for extremes up to 800 °F and 6000 psi. One issue that is important to note is that the pressure rating of the tube design is not necessarily the same pressure rating for the sensor housing.

Accuracy statements for Coriolis meters are generally stated for mass measurement. Accuracy statements typically include the effect of zero offset. Like other meters, uncertainty increases as flow rate approaches zero. Again, volume accuracy would be the combination of the mass accuracy and the density accuracy.

## Coriolis Transmitter Considerations

Coriolis meters are electronic, require power and some associated device that interprets the signals from the meter and provides useable digital, analog or serial outputs. Most meters today have a separate device or transmitter but advances in technology have produced meters that produce an output direct from the sensor. Whether in a separate housing or located on the meter, there is a CPU that is programmed to provide the outputs required. The CPU is programmed with the meter's calibration coefficients and is programmed to output in the required units of measurement.

Since there is no movement or mechanical action in the meter that can be utilized to produce a pulse, the CPU is also programmed to produce the pulse required for proving and for totalization.

Given the capabilities of electronics today, additional features are easily a part of a Coriolis transmitter such as alarm and control outputs, averaging, and calculation of relative density.

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 tubes 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). Solids settlement, plugging or trapped condensate can affect the meter's performance. The alignment of the inlet and outlet flanges is critical to avoid piping stresses that may affect the resonance of the tube(s) inside the meter. Though possible dependent on the construction and design of the meter, external piping vibration should not affect the meter but could if the external vibration or pulsation approaches the resonant frequency of the meter. Follow the manufacturer's recommendations in providing piping support for the meter.

Only a limited number of Coriolis meter designs have been utilized for custody transfer. The experience thus far indicates that the meter does not require flow conditioning. In other aspects the metering system is similar to other flow metering installations. Unlike meters with moving parts, the Coriolis meter can handle typical pipeline solids without damage to the meter however, a strainer upstream of the meter is recommended to protect the meter prover. A backpressure valve should be located downstream of the meter to avoid cavitation. Proving facilities downstream of the meter should be provided to facilitate proving of the meter under conditions as close to the normal operating conditions as practical. Consideration should be given to the location of the meter electronics that generate the pulse output 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. The zeroing procedure requires as a minimum a block and bleed valve downstream of the meter and it is preferable to have a shut-off valve upstream to block the meter in during zeroing.

A typical LACT system is shown in Figure 1.

<u>Coriolis Meter Zero and Proving</u>

The procedure to establish the meter sensor's signal outputs at zero flow is relatively simple and requires only a few minutes. The meter will not zero if the upstream or downstream valves are leaking or if air is trapped inside the meter. After the zero is set on initial installation, periodic checking by closing the valves and verifying that the meter reads zero is recommended instead of actually resetting the meter's zero electronically. By changing the zero setting, you have created a need to generate a new meter factor. A change of process conditions or a changeout of other system components that would change the piping stresses would be typical reasons for needing to repeat the zeroing procedure. Again, the zeroing procedure should be done prior to proving the meter.

A meter factor must be developed for a Coriolis meter used in custody transfer. Many questions

**Typical Coriolis Arrangement**

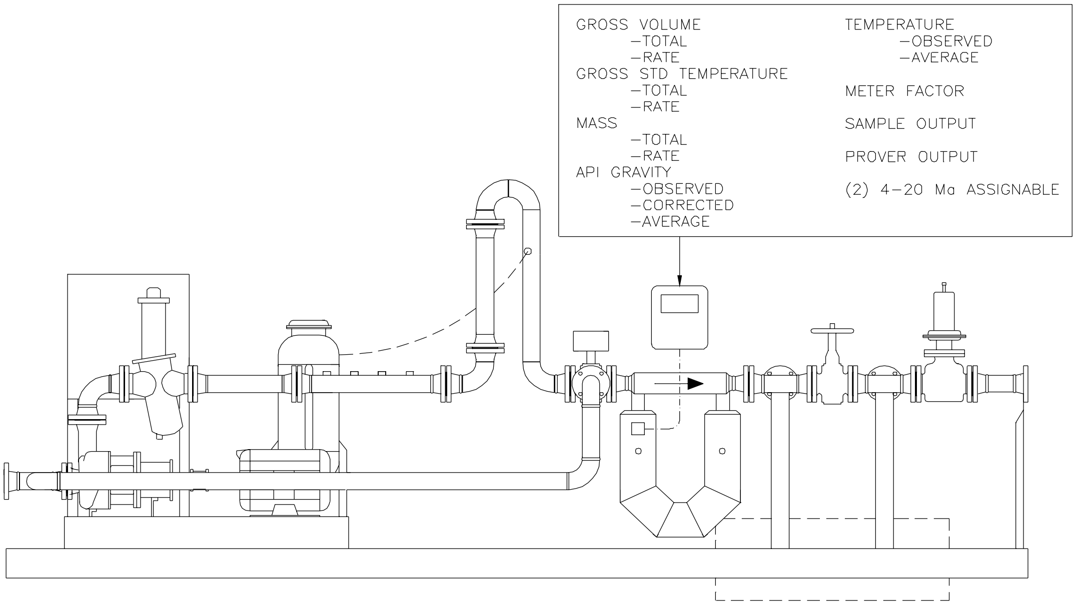

Figure 1

related to proving were initiated when Coriolis meters were first introduced to the petroleum industry. The two most significant issues were based on proving these meters with traditional volumetric provers and having the meter produce a suitable pulse that could be accurately counted by the prover counter or flow computer. Most custody transfer Coriolis meters are being utilized to meter volume and are proven each month just like other flow meters. Some questions still remain regarding proving in the field on a mass basis and the ability to accurately determine density. There are also some remaining issues regarding the use of a small volume prover that relate to the short time duration of the prove and the ability of the Coriolis electronics to provide a uniform pulse output.

However, in general proving the meter as a volume meter does not differ from the recognized procedures for any other type of flow meter. If the meter is utilized for volume and if the meter is able to produce a high-resolution pulse such that it can provide the required level of pulses to a prover counter associated with a volumetric prover, then the proving procedure is not unique. 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. Often densitometers are mounted on the prover inlet for this purpose. It is critical that during this type of proving that the density of the fluid remains stable throughout the proving.

## Coroilis Meter Applications

Coriolis meters have very few limitations related to the fluids they can handle. The flow rate a Coriolis meter can handle is limited by the sizes available, the size limitation due to the ability to electronic vibrate a resonator of significant weight and size. As with all metering systems, the choice of flow meter technology should be of based on cost of ownership

With no moving parts, the Coriolis meter offers significant advantages for metering of heavy or viscous fluids, dirty fluids, fluids with high solids content, or systems that might generate air slugs that can damage other types of meters. There are little to no maintenance costs involved and no parts to replace except those related to the meter's electronics. In the petroleum industry, the Coriolis meter is widely used for the measurement of crude oil and asphalt.

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 on 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 like 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.

The Coriolis meter as mentioned previously acts as a densitometer in addition to measuring flow. Again, there is a considerable cost savings for metering systems that require both the measurement of flow and the measurement of density or relative density when the measurement can be made with a single instrument. In the application of a Coriolis meter metering flow and density there is less uncertainty in the measurement of density. This is 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.

Finally, the large turndown of a Coriolis meter can eliminate the use of a bank of several different size meters to cover the rates again providing a cost savings for the metering system.

## Conclusion

The petroleum industry is continually searching for better processes. Being "better" is not only related to accuracy, but should be evaluated on a cost of ownership basis. Often better measurement technology 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.