CORIOLIS MASS FLOW METERS FOR GAS AND LIQUID MEASUREMENT

Thomas Koczynski

Cameron Measurement /Division of Schlumberger 3600 Briarpark. Houston, Texas 77042

INTRODUCTION

A Coriolis mass flow meter is a meter that can be used to measure liquids and gases. It directly measures mass and density and these can be used to calculate actual volume flow in liquids. With gas applications the mass can be converted back to standard conditions with some simple math and a verification of the gas composition. Coriolis meters have been around for over 30 years and as time passes are becoming more accepted in industry where a more precise measurement is needed.
This paper will review Coriolis mass flowmeter technology and applications with reference to measurement of liquids and gases, as well as challenges and best practices.

CORIOLIS FLOWMETER PRINCIPLES OF OPERATION

The Coriolis mass flowmeter is a multivariable device that directly measures the mass of the flowing liquids and gases. The meter also measures the density of liquid and the temperature of the sensor tube. The mass flow and density can be used to calculate the gross volume of liquids.
For gas measurement, the mass flow is divided by the weight of the gas being measured at standard conditions. The low density of gas combined with the accuracy of the Coriolis meters density measurement makes using the density unreliable. The temperature measurement is primarily for correcting for the tensile strength of the tubes but can give a rough approximation of the temperature of the fluid. This temperature is not adequate for custody measurements. Coriolis meters are bi-directional.

DIRECT MEASUREMENT OF MASS FLOW RATE

The first direct measurement in a Coriolis flow meter is mass flow rate. The Coriolis meter can be constructed of one or more balanced meter tubes connected at the ends. The tube system (Sensor) uses a center mounted electromechanical system that causes the tube to vibrate. The motion of the tubes is in direct relation to energy applied to the exciter coil. A feedback circuit maintains the amplitude of the tube vibration at the minimum excitation current to keep the tube in motion and oscillating at the resonant frequency of the tube and or tube with fluid. This is the drive gain circuit.

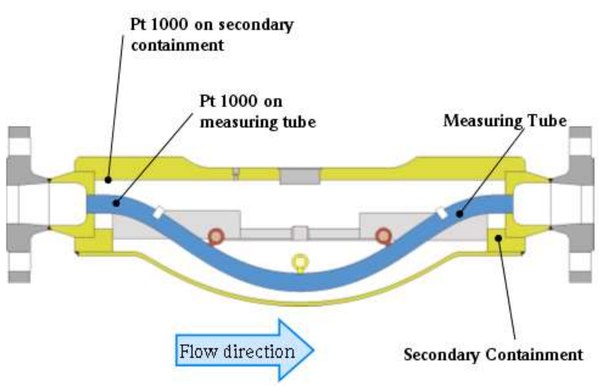

Figure 1. Coriolis Meter

As mass flows through the oscillating tubes and is subjected to a movement which is perpendicular to the direction of flow, a Coriolis effect is generated. This causes a change in the motion of the tubes. This deflection or twisting of the tubes is detected by two pickup coils that are located on each side of the tube system. The mass flow is determined by the phase offset between the inlet and outlet pickup coils. The phase shift will increase or decrease in proportion to. mass flow rate. When the flow stops, the phase shift will go to zero and the tubes will balance out and the drive gain or exciter current will return to an equilibrium state. As temperature increases or decreases, the tensile strength of the tubes can change. An RTD is installed on the sensor tubes to measure this temperature and allow for a correction to be applied based on the temperature of the tubes. There can be an additional RTD on the case of the sensor body for additional inputs. During the calibration process a calibration factor is determined and stored in the memory of the flow meter and calibration data documentation. The temperature correction as mentioned above will correct for changes in tube due to temperature effect.

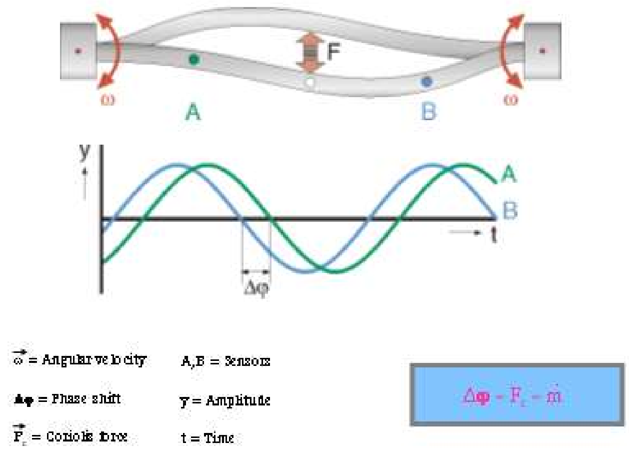

Figure 2. Coriolis Effect

MEASUREMENT OF LIQUID DENSITY

The Coriolis flowmeter also directly measures the density of liquids. The flow tubes are vibrating at a resonant frequency that corresponds to the sensing tube construction and the density of the fluids in the tubes. Feedback from the pickups back to the drive gain circuit allow the drive frequency to travel to the resonant frequency. The resonant frequency increases with lighter products and decreases with more dense products. During the calibration process, the resonant frequency of the sensor is determined for air and water. This becomes the baseline for each sensor and is also stored in the memory of the flow meter. As mentioned before, the RTD attached to the sensor tubes will provide a temperature correction as the temperature changes. It is important to remember that all calibrations are traced back to industry standards.

GROSS LIQUID VOLUMES/ CORRECTED VOLUMES

Because the mass flow rate, density and temperature are directly measured, the gross liquid flow rate can also be calculated. The gross volume is equal to the mass flow rate divided by the density at condition. The Coriolis can be configured to output in volumetric flow units and is like other meters in that the overall accuracy of volume measurement is affected by the accuracy of the mass flow and density measurements. To correctly convert back to standard conditions, it is best to use a flow computer, but some transmitters can calculate a corrected volume based on fixed conditions. There is a risk of reporting the incorrect outputs if the process information is not updated or the product changes.

STANDARD GAS VOLUME

The density measurement accuracy of a Coriolis sensor is not accurate enough to be used for gas measurement. It is necessary to enter the mass flow into a flow computer where the relative density or base density can be entered into it to do the calculations. Using methods such as AGA8 Gross Method 1, Gross Method 2 or Detail Method is the way to do this. You can input a fixed value into the Coriolis sensor to allow for an output, but this would be susceptible to changes in the actual composition of the gas and would lead to erroneous measurement due to not updating the composition in the meter as it changes.

CORIOLIS FLOW SENSORS

The design of flowmeters varies drastically from one manufacture to another. There are single and dual tube designs, varying degrees of bent tubes and some that are straight. The frequencies that are used between manufactures and the drive systems can vary. The various designs often were developed to get the maximum benefit for an application or an industry. Even with the variance of designs, Coriolis meter offer many advantages over other flow technologies. Processes that may affect other styles of flow meters, have minimal effect on Coriolis. They are often used in the following situations:

- High turndown requirements
- Dirty, wet, or sour gas where maintenance can be an issue with other technologies
- There is no room for long straight-runs
- Changing gas composition and density
- Sudden changes in gas flow velocity (fuel gas applications)
- Pulsating gas flows (fuel and compression gas with reciprocating compressors)
- High flow rates
- 8 inch or smaller lines
- 300 ANSI through 900 ANSI

Coriolis meter are not intended to be used in multiphase fluids, specifically mixtures of liquids and gases. It is important to look at pressure drop when sizing a meter. When the pressure drop takes the product too close to the vapor pressure, this can cause flashing that leads to poor meter performance, cavitation and possibly damage to the meter.

CORIOLIS TRANSMITTERS

Transmitters provide power and control signals to the sensors and interpret the raw signals and outputs of the sensor into process information. This information can be transmitted in the form of outputs to be read by external devices. Types of outputs could be pulse, frequency, analog or digital in nature as well as in a protocol format. (HART, Modbus, Ethernet, Device net, etc.) The transmitter can also send triggered fault alarms and diagnostic information that can be used to check meter performance and give a glimpse into the process. The transmitter can also calculate net quantities and concentrations. These transmitters can be remote mounted or direct mounted dependent on the application. As technologies have advanced, the size of the transmitters and the amount of power required have been reduced. These lower power options are typically used in process and not intended for custody transfer applications. There is a processor inside of the transmitter that can be programmed with the meters calibration information and the required outputs and units of measure. Some transmitters have additional functionality to address an industry or requirements and can report in special outputs. Most often, when used for metering gas or liquids, the information goes to a flow computer which performs the correction. In application requiring security, most meters have a form of physical security or password security to prevent unauthorized access.

APPLICATIONS

The Coriolis Flowmeters are recognized in the API Manual on Petroleum Standards and the American Gas Association (AGA) Report Number 11. Most manufactures of Coriolis meters have been approved under evaluation programs and have been found to comply with national and international standards which set the requirements for devices used in trade.

As time goes on. There are more and more applications that Coriolis are being used for. As the meter gets applied to different industries and applications, the requirements and performance has led to additional focus on the standards and product improvements. It is an exciting time as the industry keeps challenging itself to continually improve. Things like diagnostics, self-verification and communications enhancements have made the implementation of this technology accelerate.

Some applications for liquid would be:

- Liquid separators, and net oil
- Crude oil and condensate gathering
- LACT, lease automated custody transfer
- Liquid pipeline measurement
- Refinery applications
- Truck and railcar loading/unloading
- LNG application
- Ethanol
- Viscosity measurement.

Some application for gas would be:

- Natural gas storage, transmission and distribution
- Natural gas fiscal transfer
- Separator gas
- Fuel control
- Combustion control to boilers
- Energy metering:
- Ethylene gas transfer

Applications that are based on mass flow, and density for liquids are ideal for a Coriolis meter.
The ability to measure mass accurately also makes the meter ideal for gas applications. If the product composition of the gas is known at standards conditions, simple division of the mass flow gets you to standard flow.

INSTALLATION REQUIREMENTS

Mounting Coriolis meters correctly is critical to performance of the meter. It is advised to follow the manufactures installation requirements, and to use best practices in the installation of the meters and piping support. There are three positions for mounting which are horizontal up, horizontal down and flag position.

For liquid applications the common positions are horizontal down and flag. The down position will keep entrained gas from being trapped in the meter and causing bad readings. If there are solids that can accumulate in low spots, then the meter is mounted in the flag position with flow going up. This prevents solids from building up in the tubes and causing an imbalance.

For gas applications the common positions are horizontal up and flag. The up position will keep liquids from accumulating in the tubes and causing an imbalance. The Flag position is also used so that if there an issue with condensate it will drain out of the meter. Hopefully the gas is dry, but in some cases, liquid may be an issue.

In slurry application with products than can solidify or get trapped in the meter, the flag position is the best option. This will keep the tubes clean and drained. Mounting in this position will also assist in getting a good performance to mitigate false reading if product is left in the tubes during the process shutdown.

Good general practices in installation will mitigate metering issues. It is very important when mounting the meter, that the piping is aligned so that there is no rotational torque (Twisting) applied to the meter and that there is no mechanical binding (Crushing of the meter between the flanges) as these will affect the meter performance. It is a good idea if you are having trouble with accuracy, an unstable zero or are not getting a constant meter factor in proving, to unbolt one end of the meter. If you can remove the gasket easily and the piping does not shift (in, out or center point of meter), binding is not an issue. If the meter does not rotate then torque is not an issue. The solution is to fix the piping so that the meter rests between the piping and installs without influence of the piping system. If the meter is to be installed later in new construction, install a spool piece to hold the space of the meter.

APPLICATION CHALLENGES

Compared to other metering technologies, the Coriolis meter can handle pipeline solids without damage. The solids will cause a momentary imbalance of the tubes as they pass through, but will not damage the integrity of the meter. Also, the meters tubes can have minor coating and still work. If the density of the coating is the same as the process fluid and it does not change the stiffness or balance of the tubes, the meter can still perform pretty good. Mass flow reading are affected by the change in stiffness and density reading are affected by the density of the coating and stiffness. It is best not to have coating, but this meter is a bit forgiving in those applications.

In measuring gas with a Coriolis, it is important to remember that this is a mass meter. It will measure the mass flow very accurately, but the meter cannot tell that the product in the meter is correct. It is important to take this very accurate measurement and use a flow computer, gas chromatographs, etc. to come up with a molecular weight of product at standard conditions. If the gas composition is stable, you can but a divisor in the Coriolis meter to output a corrected flow rate, but this will become inaccurate if the composition changes. A better method is to send the mass flow rate to a flow computer. If the gas composition is stable, the meter can handle changes in pressure, flow rates and temperature with minimal effect. The resulting gas flow is mass divided by the weight of product at standard conditions so the reading is not affected. If there is liquid vapor in the gas, this will affect the mass flow and the meter will read high. If there is liquid carryover in the tubes, this could cause the tubes to not vibrate correctly and lead to an error. These liquid carryovers can be detected with meter diagnostics and need to be eliminated if possible.

Coriolis meters do not require flow conditioning and they can handle high velocities over the full range of performance. Velocity can become an issue if there are abrasive products in liquid applications and a factor with pressure drop. When measuring liquids that can release gas with a pressure drop or at a critical vapor pressure, maintaining back pressure on the system will keep the meter in single phase flow.

PROVING

Proving the Coriolis as a volumetric flowmeter follows the industry standards for proving other meters.
The proving taps should be placed as close as possible to the meter to maintain the same pressure and temperature operating conditions. The meter electronics that generate the pulse output used with the portable provers should be placed in a position that is easy for the prover technicians to connect to the meter. The requirements for proving are well covered in the industry standards and will not be addressed in this paper, but there are some common issues that should be mentioned.

Stabilized flowing conditions, temperatures and pressures should be reached before attempting to prove a meter. If the flow rates and densities are varying, then the repeatability of the pulse counts will be inconsistent. With inconsistent process conditions, averaging techniques and additional flow runs may be necessary to get a good meter factor. It is necessary to look at the application, make sure the meter is installed correctly, make sure that the configuration is correct, examine the system that is feeding the product to look for issues with delivery and look downstream to see if there are issues that can affect the flow and conditions of the product. Stability is the key, and if the process is fluctuating, this can lead to problems during the prove. The process can be working correctly, but if the output of the Coriolis is incorrectly scaled or the values are not properly loaded in the prover's flow computer, then there will be issues. With Coriolis meters, it is also required for liquid measurement to verify the density factor of the meter. This is done with a densitometer. It is important that this device is also proved before being used to come up with a factor for the Coriolis meter.

EVOLUTION AND ADVANCEMENTS

With improvements in tube design and the development of better microprocessors capable of handling the calculations required with speed and complexity, reliability and accuracy of the meters continue to improve. Today's meter technology with balanced tubes and fully integrated welded cases enable the meters to be able to perform with little interference with the process piping. Often the cases are providing secondary containment as an added safety measure. There are many different types of sensors tube configurations such as straight or bent tubes and single or dual tubes. One manufacturer has even developed a 4- tube high flow design. The newer designs have continued to mitigate tube signal stability issues by better construction practices. The design of the sensors continues to evolve to meet application challenges and to reduce manufacturers cost. Manufacturers are providing larger Coriolis flow sensors for applications like petroleum pipeline and ship bunkering as well as smaller sensors for low flow applications like liquefied petroleum gas odorant additives.

In the past, transmitter outputs were pulse, analog, HART and Modbus. Digital communication continues to evolve to Ethernet capabilities with remote connectivity. There are even some devices that are using wireless communication. Some Coriolis manufacturers are offering units that are loop power as well. Self-verifying technology and advanced diagnostic capabilities are continuing to be developed to provide insight into the health of the meter and the accuracy of the process measurements. Custom applications are being developed by manufacturers to perform specialized measurements and calculations needed by industry.

CONCLUSION

Coriolis flowmeters are easy to apply in liquid applications and natural gas service. The Coriolis technology allows users to get multivariable measurement from a single device. Being able to handle tough applications and still provide a highly accurate measurement, wide flow range, and long-term reliability without many of the issues that affect other flow measurement technologies has led to the incorporation of this technology into many new applications. The Coriolis meter continues to be incorporated into liquid hydrocarbon and natural gas applications. Recognition in industry standards like AGA and API shows the acceptance of the Coriolis flowmeter in the Oil and Gas Industries.

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