

Understanding and Selecting Coriolis Technology for Drilling Fluid Monitoring

Abstract

Continuous, accurate and reliable measurement of drilling fluid volumes and density is contributing to improved efficiency / safety of drilling operations, reductions in Non-Productive Time (NPT) and increased well production. Micro Motion Coriolis flow and density sensors are becoming the technology of choice in a variety of applications and systems in order to provide reliable, continuous drilling data.

Understanding relevant aspects of Coriolis technology in relation to the challenges posed by drilling fluid applications can significantly reduce problems in the field and ensure the successful application of the technology. This paper will highlight the technical aspects of Coriolis sensors in relation to various applications associated with mud logging and wellbore control systems to improve the understanding, selection and successful application of Micro Motion Coriolis technology in the field.

Applying the Technology

Coriolis sensors are classified as a multivariable sensor, as they provide a measurement of mass and volume flow rate, density and temperature. The mass flow rate accuracy is ± 0.05 to 0.1% of rate. The sensor consists of a manifold which splits the fluid flow in two, and directs it through each of the two flow tubes and back out the outlet side of the manifold. See Figure 1.

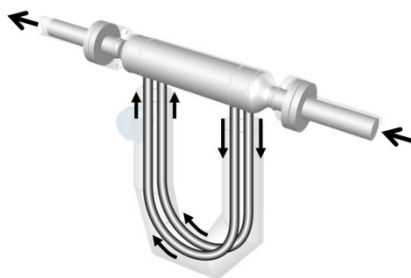


Figure 1. Sensor Flow Path

A drive coil is mounted at the center of the two flow tubes geometry to vibrate the process fluid and tubes at a natural harmonic frequency. A magnet and a pickoff coil are located on the inlet and outlet side of the flow tubes and provide the means for measuring the Coriolis effect. See Figure 2. Because of the vibration, the coil moves through the magnetic field and generates a sine wave proportional to that motion.

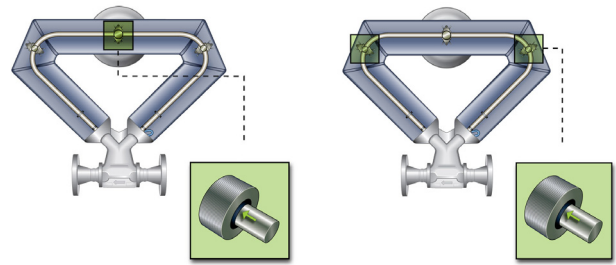


Figure 2. Drive and Pickoff Coils

When the tubes are full of process fluid and at a zero flow condition, the sine waves from the inlet and outlet pickoff coils are in phase. Under flowing conditions, the tubes twist due to the Coriolis effect and the two sine waves shift apart. The time differential between the two signals is directly proportional to mass flow rate. See Figure 3.

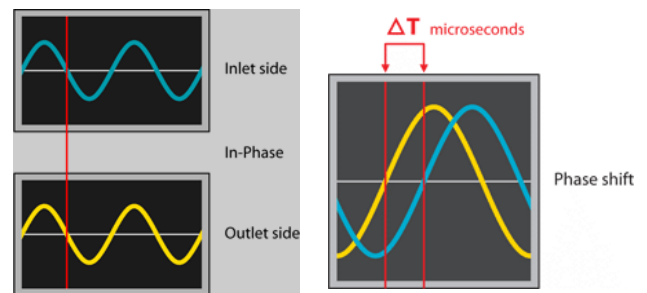


Figure 3. Measuring Mass Flow

Measuring the frequency of the tube vibration provides a direct measure of the density of the fluid in the flow tubes. See Figure 4. The density accuracy is 0.0002 - 0.0005 g/cm³ (0.0017 - 0.004 lb/gal) for liquids only and has an operational range up to 5 g/cm³ (41.7 lb/gal).

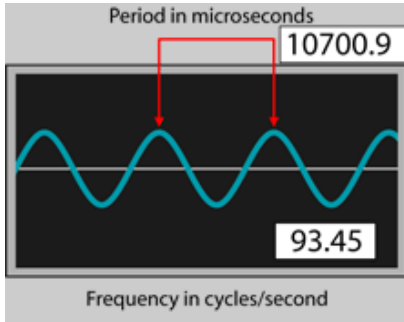


Figure 4. Measuring Density

The fluid volume flow rate at operating conditions is determined by dividing the mass rate by the measured density. For turndown ratios up to 20:1, the volume flow accuracy is the same as the mass rate accuracy specification. The Micro Motion sizing program is used to identify the mass rate uncertainty for flow rates beyond 20:1 turndown and for the ELITE® Series of sensors is typically less than $\pm 0.5\%$ at a 100:1 turndown.

An RTD within the meter is used to measure the temperature of the flow tubes and since it is not immersed within the flowing fluid stream, it can only be used for general temperature monitoring applications and is accurate to $\pm 1\text{ }^{\circ}\text{C} \pm 0.5\%$ of the reading. See Figure 5.

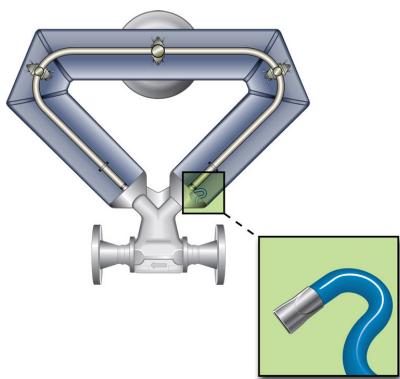


Figure 5. Measuring Temperature

Interfacing Micro Motion Coriolis meters to data logging systems is easily accomplished due to the variety of electronics options offered, which include combinations of analog, frequency and Modbus to transmit both multiple process variables and diagnostics data.

Micro Motion Coriolis meters are currently used in the measurement of drilling fluid downhole and returns volume flow rates and/or density. Both slip-stream and full stream measurement systems are utilized in the following primary applications:

- Mud density during mixing
- Mud flow rate in on-the-fly mixing systems
- Lost circulation and kick detection based on barrel-in-barrel-out (BIBO) rates
- Enhanced kick detection based on returns density
- Lost circulation, enhanced kick detection in Managed Pressure Drilling systems
- Injection rates and mud quality in Cuttings Re-Injection

Application Challenges

Different Base Drilling Fluids With Varying Fluid Properties

Because Coriolis meters provide a direct mass rate measurement, the sensor is not limited to a particular fluid type and has the capability to measure gas, liquids or dense slurries. Changes in fluid properties due to temperature, density, viscosity, and composition do not affect measurement performance. This means the appropriately-sized sensor can be used to measure water, oil or synthetic base fluids including the variety of mud weighting and chemical additives used in drilling fluid.

Flow tube operating temperature and pressure changes the elasticity of the metal flow tubes. These changes are readily compensated for in the mass and density measurements. The relationship between temperature / pressure and elasticity is well known and predictable. An RTD located on the flow tubes is used for automatic, real-time compensation of temperature effects for elasticity.

Pressure effects are also well known and are specified as a percentage of error per psi or bar for pressures above the calibration pressure of 14.5 psi / 1 bar. The actual amount of error introduced varies with the size and design of meter. If the process pressure is expected to stay relatively stable, then entering the operating pressure into the electronics will provide adequate compensation for pressure effect based on a fixed value. If the pressure is expected to continually change over a wide pressure range, a pressure signal into the electronics will provide the necessary dynamic compensation. In most applications, using a fixed value in the transmitter is more than adequate. Table 1 provides an example of the errors associated with a pressure change utilizing a Micro Motion CMFHC3 sensor for drilling fluid flow rate.

BASE CONDITIONS		
Mud Flow Rate	1,200 gal/min	4,542 l/min
Mud density	12.5 ppg	1.5 kg/l
Change in pressure	100 psi	6.9 bar
FLOW		
Volume flow rate error	-2.4 gal/min	-9.1 l/min
% Flow rate error	-0.20%	-0.20%
DENSITY		
Density error	-0.03 ppg	-0.00319 kg/l
% Density error	-0.21%	-0.21%

Table 1. Pressure Effect on Mass and Density

Base Conditions		Fluid Density: 17 ppg	Viscosity: 40 cP	
		Pressure: 75 psig	Temperature: 80°C	
Flow Rate		Mass Flow Accuracy	Velocity	
USGPM	lpm	±% of rate	ft/sec	m/s
1,400	5,300	0.10	14.2	4.3
1,275	4,826	0.10	12.9	3.9
1,200	4,542	0.10	12.2	3.7
1,025	3,880	0.10	10.4	3.2
900	3,407	0.10	9.1	2.8
775	2,934	0.10	7.9	2.4
650	2,460	0.10	6.6	2.0
525	1,987	0.10	5.3	1.6
400	1,514	0.10	4.0	1.2
275	1,041	0.12	2.8	0.9
150	568	0.21	1.5	0.5

Table 2. Turndown Versus Velocity and Accuracy

Erosive Fluids, Harsh Environments and Process Conditions

There are no in-stream mechanical components in the design of a Coriolis meter that can be damaged due to sudden flow surges, gas slugs or large particles. The non-mechanical design contributes to the sensor's reliability in harsh environmental conditions associated with temperature, pressure, transportation (vibration) and pulsating flows from pumps. The operating range of a sensor can range from a -400 °F (-240 °C) to +662 °F (+350 °C). The pressure rating of a sensor is dependent upon the size of the meter and materials of construction, and encompass a range of 1,500 psi (103 bar) through to 2,855 psi (197 bar). Slip stream applications incorporating a Coriolis meter are for density measurements only and the application requirements are easily accommodated. In full stream flow measurements, the concern centers around erosion and the ability to handle cuttings in the drilling fluid returns. Coriolis meters are able to provide an accurate measurement over very wide turndown—typically 100:1. This allows a larger meter to be utilized in an application to reduce the fluid velocity below 12 ft/sec (3.6 m/sec) to avoid erosion without sacrificing measurement performance. The larger size meter also facilitates flowing large particles (cuttings) through the meter without plugging. See Table 2.

Varying Flow Rates

Drilling operations can involve situations where a reduced drilling fluid circulation rate is required, such as during making a connection, pumping of kill mud while circulating out a kick, and manipulating flow rates in Managed Pressure Drilling systems. Coriolis meters offer a high turndown capability without significant impact to the measurement accuracy and sensitivity to flow rate changes. This provides the means to reliably measure small volume changes while operating a reduced circulation rate.

Figure 6 illustrates the typical turndown in flow rate in relation to the % of rate mass accuracy of an ELITE Coriolis meter.

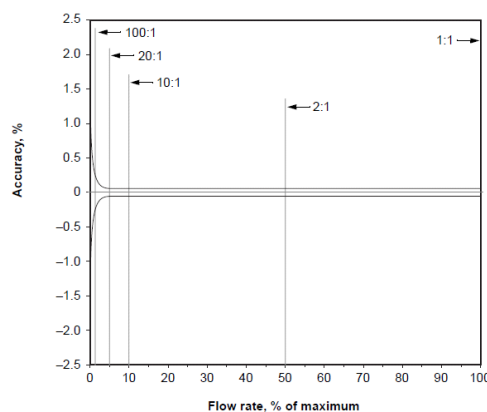


Figure 6. Turndown Versus Mass Flow Accuracy

If we use the lowest flow point from Table 2, a 150 gpm (568 lpm) minute flow rate would be accurate to within ±0.31 gpm (±1.2 lpm) including the combined effects of repeatability, linearity, hysteresis and zero stability. To

ensure maximum sensitivity to a change in flow rate with a high turndown, it is important to confirm that all sources of error are included in the accuracy specification—particularly zero stability when selecting a Coriolis meter.

Entrained Gas

A Coriolis meter will measure the mass rate and density of a two-phase fluid. At low Gas Volume Fractions $\leq 5\%$ the mass flow and density error introduced due to the presence of entrained gas is typically minimal. However, the density measurement will be representative of the respective volume fractions of the two fluids resulting in a lower density reading. Since the volume rate is determined by dividing the mass rate by the combined fluid density, the sensor will indicate an increased volume flow rate due to the presence of gas. Gas volume fractions greater than 5% will result in a degradation of both the flow and density measurement.

The performance of a Coriolis meter under entrained gas situations is highly influenced by sensor design. The best measurement is provided with higher profile, dual-tube sensors with a low tube frequency such as the Micro Motion ELITE sensors. Typically, the smaller the profile of a sensor, the higher the frequency of operation, which causes two-phase fluids to not vibrate with the tube resulting in larger flow and density measurement errors.

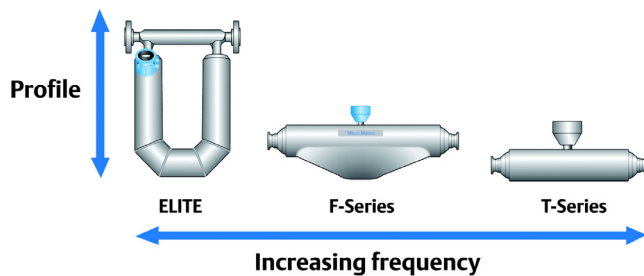


Figure 7. Sensor Profile versus Model Series

The MVD technology from Micro Motion electronics employs digital signal processing (DSP) that allows the transmitter to remove or "look through" the noise imposed by two-phase flow and report only the real flow measurement of the liquid. This is enabled by configuring

the transmitter to operate in "Special Mode" which increases the rate at which sensor data is reported to the transmitter.

Meter Orientation & Footprint

The recommended Coriolis meter orientation for liquids containing suspended particles or entrained gas is the "flag" and "tubes down" position respectively. In reality, the sensors can be oriented in various configurations to accommodate unique application requirements. Drilling fluids is a unique application where standard meter orientation practices can lead to measurement problems. Regardless of whether the meter is installed in a slip stream, a sample stream or full stream application, the three recommended orientations are shown in Figure 8.

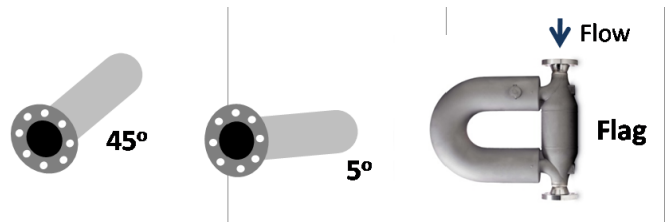


Figure 8. Sensor Orientation

Given the fluid properties involved, these orientations will help ensure suspended materials and/or entrained gas are effectively flushed through the meter and to avoid any point of settling within the meter body and flow tubes.

Operating at a velocity of 3 ft/sec or 0.91 m/sec or higher is a good practice to ensure solids and gas bubbles are being flushed through the flow tubes. These orientations are also considered "best practice" for flushing out any settled materials due to situations where the flow is stopped and then started again. This is particularly important when oil-based fluids are being used in the drilling operation.

Because Coriolis meters do not require any prescribed pipe runs or flow conditioning, they can be installed within a compact space. See Figure 9. It is not uncommon to find situations where the meter has been installed with an elbow on both the inlet and outlet of the sensor.



Figure 9. Compact Installation

Micro Motion Coriolis meters have been successfully applied in return flow / density applications providing there is a rotating head and sufficient hydrostatic pressure on the return line. The objective is to have enough hydrostatic head pressure (Point A) to counter the pressured drop from the meter and an elevated flow line from the meter outlet to the shale shaker (Point B). The elevated line to the shaker ensures the flow tubes of the Coriolis meter are always full of drilling fluid. See Figure 10.

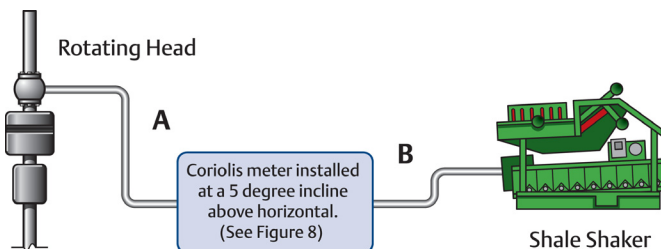


Figure 10. Balancing Hydrostatic Pressure to Ensure Flow and Full Tubes

Reliability

Reliable field measurements are required to ensure quality data for decision making and to minimize interruptions to drilling operations (NPT). Even though all the best practices have been employed to ensure sustained measurement performance with Coriolis flow and density, it still good practice to validate meter performance on a routine basis. Conventional methods of pulling, cleaning and calibrating a meter is not the most convenient procedure given the location of most drilling rigs.

Micro Motion Coriolis sensors and electronics offer a wide range of sensor, electronics and advanced diagnostics to help identify in advance potential device or application problems.

For Coriolis meters, flow tube stiffness is a critical parameter and any changes in tube stiffness due to corrosion, erosion or damage will affect both the flow and density measurement. Micro Motion Coriolis meters can include an advanced diagnostics to enable in-situ meter verification for tube stiffness using the process fluid under flowing or zero flow conditions. The data is compared to baseline values stored in the electronics and a positive indication means nothing has changed the physical integrity of the tubes nor the calibration of the meter.

Summary

Coriolis flow and density sensors are quickly gaining acceptance in a wide range of drilling fluid mixing and logging operations. The ability to provide reliable, accurate and continuous measurements with Micro Motion Coriolis technology has been field proven by several companies. The challenges associated with drilling fluids are quickly countered through a sound understanding of Coriolis technology and the application of the best practices outlined in this paper. Overcoming the application challenges has demonstrated that significant results can be achieved in improving drilling efficiencies and the early detection of kicks and lost circulation.

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