BY DENVER SMART, CHRIS RUSSELL, MARK SIMONS
MICRO MOTION, INC.

KNOWLEDGE
WWW.micromotion.com

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 due to its accuracy and reliability in drilling applications.

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.

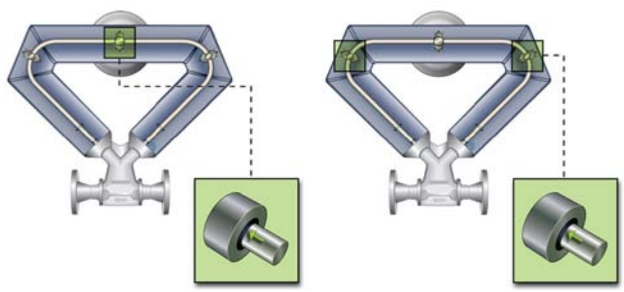

Figure 2. Drive and pickoff coils

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.

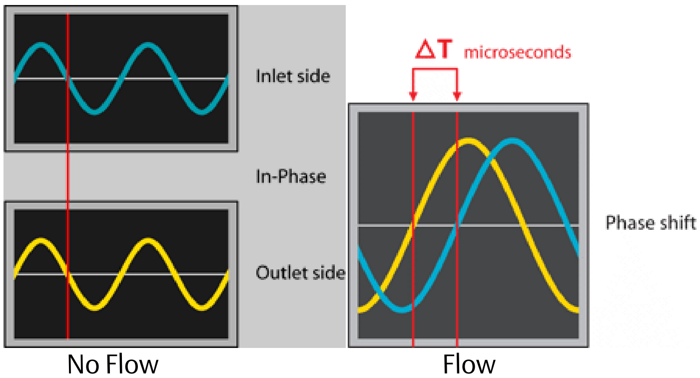

Figure 3. Measuring mass flow

Micro Motion

EMERSON
Process Management

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).

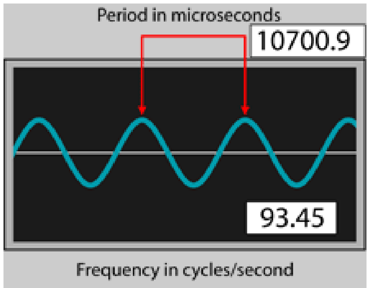

Figure 4. Measuring density

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. For drilling applications, an accuracy of +/-2% across a wide operating range can be expected.

A Resistance Temperature Detector (RTD) within the sensor 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 ±1 °C ±0.5% of the reading. See Figure 5.

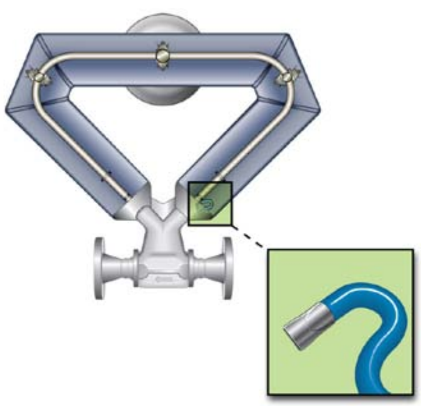

Figure 5. Measuring temperature

Interfacing Micro Motion Coriolis sensors 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 as well as wireless data transmission and Smart Meter Verification diagnostics.

Micro Motion Coriolis sensors are currently used in the measurement of drilling fluid volume flow rates and/or density. All of the following applications can be accommodated with full stream measurements while density-only measurements can be accommodated via slipstream measurement:

- 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
- Monitoring returns density for improved hydrostatic estimation and well control
- Lost circulation and enhanced kick detection in Managed Pressure Drilling systems
- Injection rates and mud density in cuttings reinjection
- Differentiate between ballooning and influx for improved drilling efficiency
- Improve operational efficiency through positive identification of sweep and spacer performance with real-time density measurements

Application Challenges

Different Base Drilling Fluids With Varying Fluid Properties

Because Coriolis sensors 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 an appropriately sized sensor can be used to measure water, oil or synthetic base fluids containing a variety of mud weighting and chemical additives used in drilling fluid.

Erosive Fluids, Harsh Environments and Process Conditions

There are no in-stream mechanical components in the design of a Coriolis sensor 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 -400 °F (-240 °C) to +662 °F (+350 °C). The pressure rating of a sensor is dependent upon the size of the sensor and materials of construction, and range 1,500 psi (103 bar) through to 2,855 psi (197 bar).

In full stream flow measurements concern centers around erosion and the ability to handle cuttings in the drilling fluid returns. This allows a larger sensor to be utilized in an application to reduce the fluid velocity below 15 ft/s (5 m/s) to avoid erosion without sacrificing measurement performance.

Varying Flow Rates

Drilling operations can involve situations where a reduced drilling fluid circulation rate is required, such as while making a connection, pumping of kill mud while circulating out a kick, and manipulating flow rates in Managed Pressure Drilling systems. Coriolis sensors 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.

Entrained Gas

A Coriolis sensor will measure the mass rate and density of a two-phase fluid. At low Gas Volume Fractions ≤ 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 sensor 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.

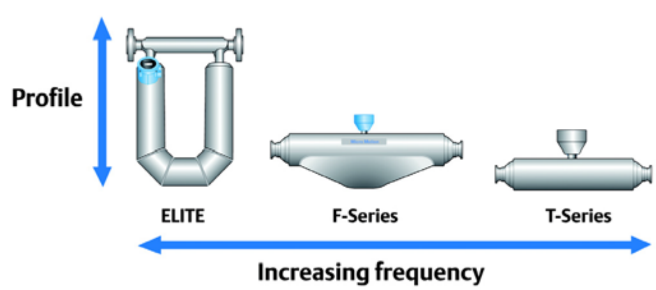

Figure 6. Sensor profile versus model series

Diagnostic measurements available via Micro Motion Coriolis sensors allow a driller to identify the presence of entrained gas and make the critical distinction between decreasing mud density and an errant bubble of gas. Increase in drive gain coupled with marked decrease in measured tube amplitude at the right and left pickoff coils gives positive indication when gas is present.

Equipment Selection

Sensor Sizing

During the equipment selection process, it is imperative to identify accurate flow rate requirements for the intended measurement range. Accurate flow rates are of particular concern for the drilling applications since the expected flow rate may change significantly over the course of drilling the well with larger hole diameters typically requiring higher flow rates than the small hole diameters drilled near the planned toe of the well. This large difference in expected flow rates between the initial leg of the well versus the toe section may necessitate dual meters be installed to adequately handle flow measurement from spud to toe. When considering meter size, the max flow rate allowable must consider erosion limits while considering low flow meter performance.

For tubes up installations, a minimum flow rate of 3 ft/sec (0.9 m/sec) is required to flush any air or gas out of the tubes. The maximum flow rate should be limited to 15 ft/sec (5 m/sec) in order to minimize the effects of erosion damage to the tubes. Accuracy of the sensor at the high and low flow rates should be considered when sizing the meter. See Table 1 for suggested sizing. The below numbers should be modified based on the specific flow requirements of the customer using the sizing program.

Sensor	Rate Required to Clear Free Gas from Sensor (3 ft/sec) (GPM/LPM)	Rate Limit to Prevent Erosion (15 ft/sec) (GPM/LPM)	Max Pressure Drop (psi/bar)
HC4	500/1900	2400/9000	2.5/0.2
HC3	350/1325	1450/5500	2.5/0.2
HC2	220/830	1000/3800	4.5/0.3
CMF400	100/380	650/2450	4.3/0.3

Table 1. Example sizing recommendation for drilling mud at 14 lb/gal (1.68 SG) and 20 cP

Transmitter outputs

It is recommended that a transmitter with Modbus is selected so that the flow, density, temperature and diagnostic channels can be continuously logged to the customers' control system.

This information can be used for troubleshooting, diagnostics, evaluation and process monitoring (i.e. kick detection, loss circulation, sweep efficiency, mass balance of the well, etc). The suggested channels to log and record are: mass flow, volume flow, density, temperature, drive gain, right pick off (amplitude & voltage), left pick off (amplitude & voltage), tube frequency, live zero, delta temperature.

Installation

Rotating Control Device

When a Rotating Control Device (RCD) is present, the sensor can be mounted in any tubes up orientation or flag up position. This mounting recommendation is to allow cuttings and mud to drain from the sensor. When mounted in a tubes up position, the recommended minimum flow rate is based on a velocity of 3 ft/sec (0.9 m/sec). This minimum flow rate serves to flush entrained gas from the meter. When gas is not present, repeatable measurement is achievable at lower rates. The presence of gas in the tubes can be identified with diagnostic measurements.

It is also recommended to have a bypass around the sensor to allow continued operation in the event that the sensor plugs or becomes inoperable.

Figure 9. Example of a Coriolis installation at a 5 degree incline for RCD rig type

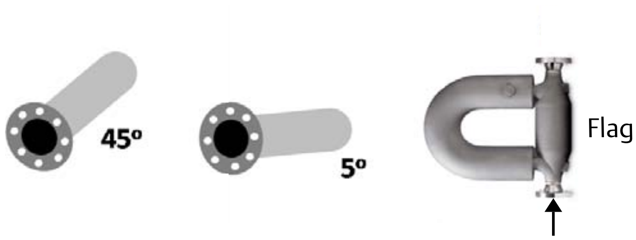

Figure 7. Sensor orientation

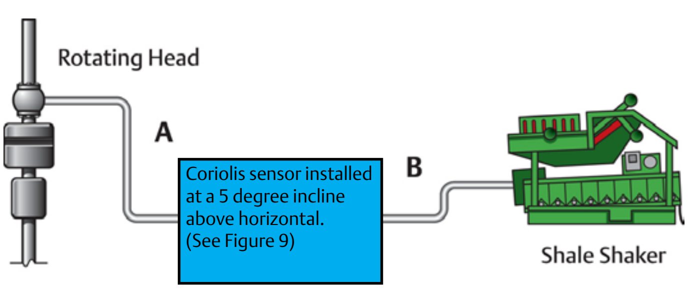

Figure 8. Balancing hydrostatic pressure to ensure flow and full tubes

Figure 10. Example of a Coriolis installation in a flag position for RCD rig type

Conventional Rig

Figure 11. Example of a Coriolis installation for a conventional (bell nipple) rig type. Note the bypass and flow direction through the Coriolis from bottom to top.

When dealing with a Conventional Drilling application (bell nipple), the sensor needs to be mounted in a flag position with the flow going up through the sensor. In selecting placement of the sensor, ensure sufficient hydrostatic head so fluid and cuttings can pass through the system. The recommended hydrostatic head calculation is 2 feet per psi (8.8 meters per bar) of pressure drop through the system (including the sensor). For example, if the estimated pressure drop at maximum flow rates through the line in which the Coriolis is mounted is 3 psi (0.2 bar), a minimum of 6 ft (1.8 m) of hydrostatic head will be required to keep fluid and cuttings moving through the system.

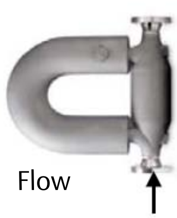

Figure 12. Sensor orientation

It is recommended to install a bypass around the sensor to ensure flow in the case the sensor becomes inoperable. Best practice would involve installing pressure sensors on either side of the Coriolis. In the event that the measured differential pressure across the sensor exceeds a set nominal value, the bypass valve would open and valves on both sides of the Coriolis sensor would close. This would enable drillers to quickly achieve flow rates that may exceed the capacity of the meter or ensure continuous operation in the event that plugging of the meter occurs.

Start Up

Excluding installation, which should be conducted by experienced Micro Motion personnel, standard operating procedures apply as per the manual delivered with the sensor.

Troubleshooting and Diagnostics

Consult factory.

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 sensor performance on a routine basis. Conventional methods of pulling, cleaning and calibrating a sensor 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 sensors, 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 sensors 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 sensor.

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 many 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 in the event the sensor becomes inoperable.

WWW.micromotion.com

Emerson Process Management
Americas
7070 Winchester Circle
Boulder, Colorado USA 80301
T +1 303-527-5200
T +1 800-522-6277
F +1 303-530-8459

Emerson Process Management
Europe
Neonstraat 1
6718 WX Ede
The Netherlands
T +31 (0) 318 495 555
F +31 (0) 318 495 556

Emerson Process Management
Japan
1-2-5 Higashi Shinagawa
Shinagawa-ku
Tokyo 140-0002 Japan
T +81 3 5769-6800
F +81 3 5769-6840

Emerson Process Management
Asia
1 Pandan Crescent
Singapore 128461
Rebuplic of Singapore
T +65 6777-8211
F +81 6770-8003

Micro Motion®

EMERSON™
Process Management