Session 12:

Drilling Efficiency Utilizing Coriolis Flow Technology

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Abstract

Continuous, accurate and reliable measurement of drilling fluid volumes and densities are contributing to improved efficiency / safety of drilling operations, reductions in Non-Productive Time (NPT) and increased well production.
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 Coriolis Technology in the field.

Introduction

Coriolis meters are classified as multivariable sensors providing measurement of mass and volume flow rate, density and temperature. These devices are currently used in the measurement of drilling fluid downhole and returns volume flow rates and/or densities. 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's model CMFHC3 sensor for drilling fluid flow rate.

Table 1. Pressure Effect on Mass and Density

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%

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 and refer to Table 2.

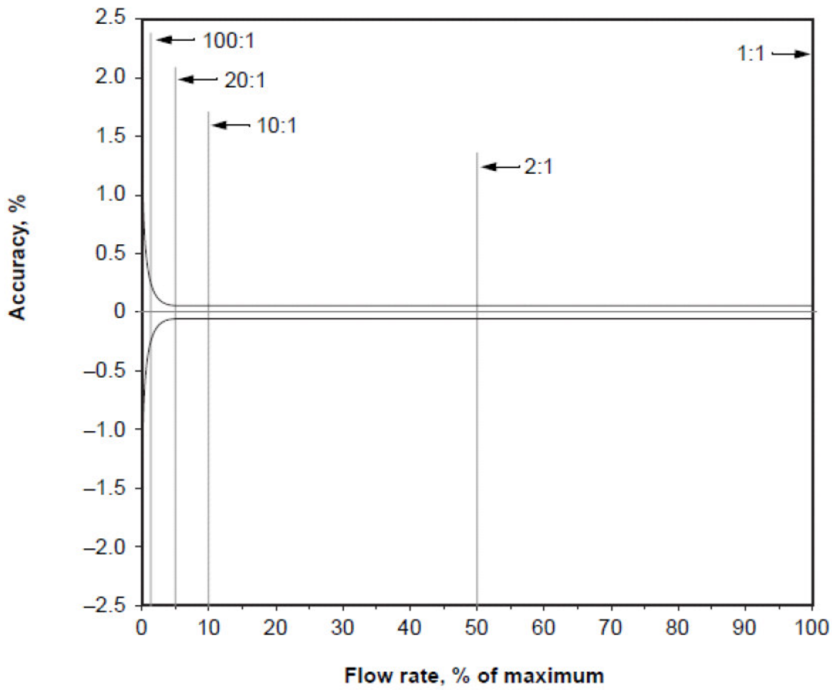
Table 2. Turndown versus Velocity and Accuracy

Base Conditions		Fluid Density: 17 ppg Pressure: 75 psig	Viscosity: 40 cP 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

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 1 illustrates the typical turndown in flow rate in relation to the % of rate mass accuracy of a Micro Motion ELITE Coriolis meter.

Figure 1. Turndown Versus Mass Flow Accuracy



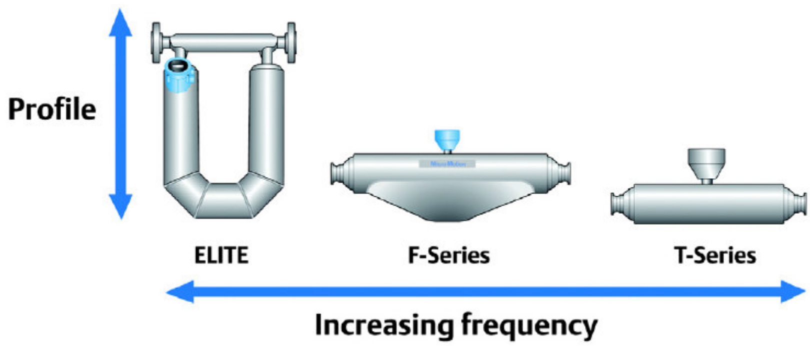
To ensure maximum sensitivity to a change in flow rate with a high turndown, it is important to confirm that all sources of error are included in the in the accuracy specification – particularly zero stability when selecting a Coriolis meter

Entrained Gas

A Coriolis meter will measure the mass rate and density of a two-phase fluid. At low Gas Volume Fractions ≤ 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 degredation 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. 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 2. Sensor Profile Versus Model Series



Coriolis Meter Applications in Drilling Management

On-the-Fly and Batch Blending of Drilling Fluid

During the oil drilling process, a continuous and accurate volumetric supply of drilling fluids is required to successfully complete the job safely and on schedule. In addition, the quality of the drilling fluid is crucial to the overall efficiency of the drilling operation. The quality of the drilling fluid is determined by the fluid properties, which are specifically engineered to the type of well being drilled and the drilling formation conditions. Drilling fluid blending (on-the-fly or batch) mixes liquid and weighting materials to achieve the specific fluid properties of the drilling fluid. A critical parameter and indicator of drilling fluid quality is the density of the blend, which is typically determined through manual samples and analysis in the field or with the use of continuous density meters.

Taking a manual sample for density does not provide a real-time measurement and the process is subject to operator error. Nuclear density meters, used to provide continuous density measurements in the blending operations, require special handling, safety training, and licensing; and, do not measure the volumetric flow rate of the drilling fluid. Achieving a reliable and accurate volumetric flow measurement of the drilling fluid is critical to ensure the proper supply of the fluid is delivered. This is especially true for on-the-fly blending operations where establishing the required volumetric rate of the drilling fluid with the right quality of the fluid is crucial. Additionally, the accuracy of the flow measurement devices can be affected by the type of base fluid or the changing fluid properties of viscosity, density, and conductivity. Thereby, the potential inaccuracies in volumetric rate can adversely affect the proper delivery of drilling fluids downhole. The delivery of off-spec drilling fluids or the inability to meet volumetric demand can significantly contribute to Non-Productive Time (NPT) and the overall cost of the drilling operation.

Coriolis meters measure both the volumetric flow rate and density, regardless of the base fluids, thereby eliminating the need for multiple measurement devices. The meter density accuracy exceeds the typical 0.1 lb/gal requirement and provides a continuous and reliable density measurement to help eliminate the delivery of off-spec drilling fluids. Because of the non-nuclear design of the meter, the coriolis meter also reduces the issues and costs related to safety compliance, licensing, transportation, storage, and disposal of the nuclear product. The meter's non-mechanical design allows it to be used in applications that involve the measurement of slurries and suspended solids without damaging the meter or impacting its measurement performance. This provides a reliable volumetric measurement of drilling fluid to ensure you meet the operating demand.

Full stream density & flow coriolis meter skid

Enhanced Kick Detection and Lost Circulation

Mud Density on the returns side of drilling process is monitored to confirm mud quality and to detect if any formation fluids (water, oil, gas) that may have flowed into the drilling fluid. The density of the fluid returns to the shaker can be monitored through manual sampling (once every half-hour) or continuously with density measurement devices. Coriolis meters are widely used in either a slip stream or sampling line configuration to provide continuous, reliable density measurements. Measuring the flow rate provides assurance an adequate sampling rate in being maintained. This is particularly critical when the sample line is also being directed to a laboratory de-gassification system so any hydrocarbons contained in the drilling fluid can be analyzed through gas chromatography.

Barrels-In-Barrels-Out (BIBO) is an industry term for comparing the downhole flow rate to the returns flow rate. Mud pump strokes (number of strokes x known chamber volume) is the most common method for determining downhole flow rate. The returns flow rate can be determined using an insertion paddle wheel meter on the flow line or by monitoring mud pit level. Comparing the downhole and returns volume flow rate can detection large influxes of formation fluid into the drilling fluid (kick) or fluids flowing into formation cavities (Loss Circulation). In-line Coriolis meters monitoring the returns volume flow rate provide early , reliable detection of both kicks and loss circulation. Drilling rigs with conventional or rotary heads have both been successfully retrofitted to accommodate Coriolis technology using hydrostatic head pressure to flow drilling fluids through the meter.

Managed Pressure Drilling

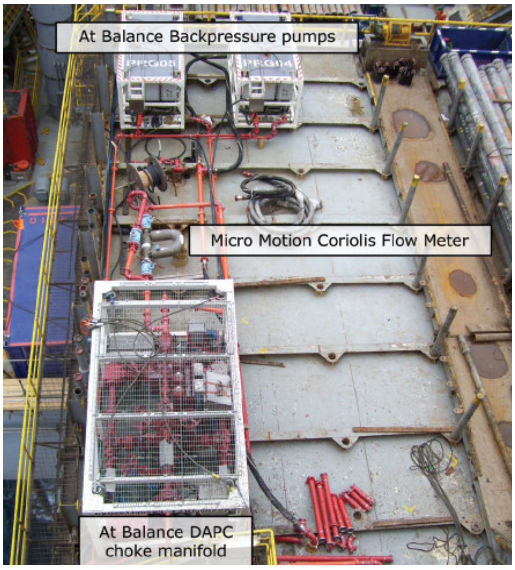
Managed Pressure Drilling (MPD) is a new drilling process that allows greater, more precise control of the Bottom Hole Pressure (BHP) in a well bore. This is typically achieved through a closed, pressurized fluid system in which flow rate, mud density, and back pressure on the fluid returns (choke manifold) are used to set and control the BHP under both static and dynamic conditions.
Managing the BHP accurately within a narrow window or margin helps to mitigate the risk of critical drilling events and improves drilling performance and well control.
In managed pressure drilling, flow rate measurements are used to mitigate potential well control risks through :

- Early kick detection, which involves detecting, as early as possible, the influx of fluids from permeable or fractured formations into the wellbore.
- Detection of lost circulation, which involves detecting the loss of drilling fluid from the wellbore into permeable or fractured formations.

Eliminating or minimizing drilling fluid influx and losses reduces costs, improves safety, increases wellbore stability, and decreases formation damage. Increasing stability and decreasing damage enables oil companies to drill difficult and or otherwise impossible-to-reach targets with less cost.

An important component of constant BHP control service is accurate flow rate measurement during all phases of drilling. Meter integrity is critical to achieving continuously accurate flow rate measurement. Measuring circulation rates around the clock enables “At Balance” to maintain the correct flow for constant BHP under all conditions, and to detect kicks and lost circulation events earlier than conventional methods allow. The drilling fluid is continuously circulated through the choke manifold and the flow meter. The At Balance control system contains proprietary software that monitors the flow in and out of the well to detect any variations in the two. If the flow-out is higher than flow-in, then fluid is being gained. If flow-out is lower than flow-in, then mud is being lost. The former indicates a potential kick while the latter indicates lost circulation.

Coriolis meters have proven to be up to the task of performing in the harsh conditions associated with MPD applications



Managed Pressure Drilling (MPD) using Coriolis meter

Summary

Reliable and accurate field measurements are required to ensure quality data for decision making and to minimize interruptions in drilling operations. Coriolis flow and density sensors are quickly gaining acceptance in a wide range of drilling fluid management applications. The ability to provide reliable, accurate and continuous measurements with 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.

References

Emerson Process Management - Micro Motion Oil Field Services Application Notes and White Papers