

STEP CHANGES IN DRILLING FLUID MEASUREMENT

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DESCRIBE HOW A NEW TECHNOLOGY DETECTS
EARLY INFLUXES DURING DRILLING.

As the industry seeks ways to enhance safety during drilling operations, particularly in harsh environments (such as ultra-deepwater and high pressure/high temperature environments), an urgent need exists for an efficient system to detect early influxes during drilling. Coriolis technology provides real time, accurate, and repeatable flow and density mud measurements that have proven to be critical to the early detection of well control events. The technology contributes to improved safety and efficiency



Figure 1. Coriolis meter on a conventional flowline.



Figure 2. Coriolis installed in an offshore MPD system.

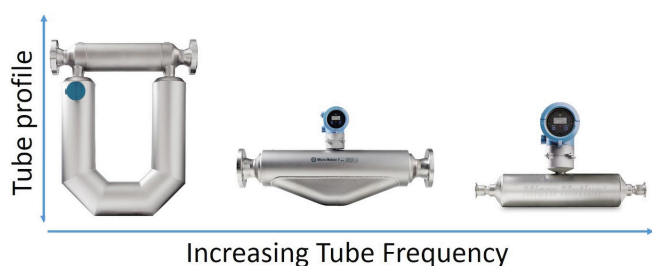


Figure 3. Correlation of sensor profile with tube frequency.

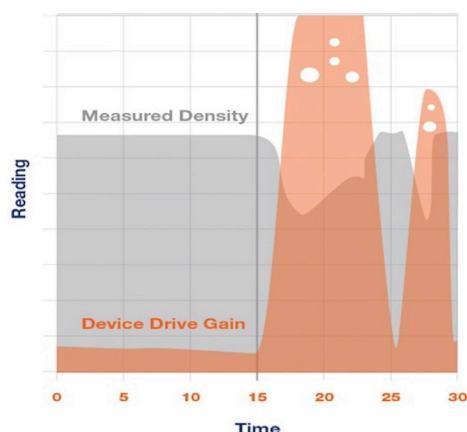


Figure 4. Entrained gas identification with drive gain diagnostic.

of drilling operations, reducing non-productive time (NPT) and decreasing the time to first production. In recent years, Coriolis devices have gained growing acceptance in the industry and have been used in both managed pressure drilling (MPD) and conventional drilling operations.

This article highlights the technical aspects of the technology for mud logging and wellbore control systems, and describes its application by Halliburton.

The technology

The detection of small changes in flow rate is essential to early kick detection and control. Practice has shown that the accuracy of conventional technologies, such as paddle meters or tank volume estimates, can be significantly affected by changes in temperature, density, and/or viscosity, which decreases operator confidence and increases response time to deviations in expected flow and density. The introduction of Coriolis technology to drilling returns measurement has provided the ability to detect small changes in flow rate and density caused by water or gas influx or loss that indicates change of zone or loss of well control. The technology provides real time mass, volume, and density data with improved accuracy, reliability, and confidence. Meters can also be used to monitor drilling mud density to continuously, reliably, and accurately identify deviations in mud density at the surface that could subsequently affect well control. The real time data can be aggregated into the rig control system to display graphics with built-in alarm functionality.

Because the technology's sensors provide a direct mass rate measurement, the sensor can measure oil, water, and synthetic-based muds equally well, regardless of mud weighting or chemical additives. The non-mechanical design and robustness of its meters make them particularly suited for measurement of particulate-containing fluids.

In the sensor, the stiffness of the tubes is critical to measurement reliability. If the tube stiffness changes as a result of corrosion, erosion, or over-pressure, measurement accuracy may be affected. Some sensors provide the ability to verify tube stiffness in-situ without process interruption to detect any changes that may have occurred as a result of erosion or other damage, providing confidence in measurement.

Key applications

Micro Motion™ Coriolis sensors are increasingly being used to measure drilling fluid volume flow rates and/or density for the following primary applications:¹

- ▶ 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.
- ▶ Returns density monitoring for improved hydrostatic estimates and well control.
- ▶ Lost circulation and enhanced kick detection in MPD systems.
- ▶ Differentiation between ballooning and influx for improved drilling efficiency.

Successful operation

The successful operation of the technology in drilling applications relies on proper installation, sensor selection, and sizing.^{2,3} Meter installation should ensure that the tubes are always liquid-filled, and the orientation should enable cuttings to drain from the sensor and encourage bubbles to quickly clear

the meter. Figure 1 and Figure 2 show a typical meter orientation for conventional drilling and MPD. The meter size is selected by considering a conservative maximum flow rate of 5 m/sec. (15 ft/sec.) to minimise the effects of erosion damage to the tubes; however, in practice, many operators exceed this limit and use on-board meter verification to identify the onset of erosion.

Smart et al. (2013) provides additional information about sizing, installation details, and guidelines.²

The performance of a Coriolis sensor under entrained gas conditions is highly influenced by the sensor design. The best measurement is provided with high profile, dual-tube sensors with a low tube frequency, such as the profile shown on the far left in Figure 3. Lower profile meters, including straight tubes, have larger flow and density measurement errors, which explains why U-shaped devices are most frequently found in drilling applications (Figure 3).

Meaningful diagnostics

The multi-variable output of a Micro Motion Coriolis sensor is a key enabler for diagnosing the root cause of measurement fluctuation to both identify entrained gas and read through measurement noise during these events. It is critical to understand that a Coriolis meter directly measures mass flow and density and calculates volumetric flow. Because the meter measures the bulk density of the fluid in the tubes, the presence of entrained gas can greatly reduce the density measured, as compared to the actual density of the liquid mud. Mass measurement, however, is not as severely affected by the presence of gas because the mass of gas relative to the mass of liquid is significantly less, if not negligible. In the case of entrained gas, the volumetric measurement calculation essentially reduces to the mass of the liquid divided by the mass of the mixture and effectively over-calculates the volume. A volumetric calculation based on the mass of the liquid divided by the known density of the fluid will yield a much more accurate volumetric flow rate for liquid flow with entrained gas. This volumetric remediation technique in the presence of bubbles is currently commercially available in some meters.

The positive identification of the presence of gas is an important first step in remediating measurement. In Coriolis meters, the drive gain is a useful diagnostic measurement for quickly identifying gas in the system. Drive gain is a measure of the percent power input to power the drive coils and ensure consistent amplitude of tube vibration. A typical meter drive gain is relatively low, with values of 1 to 30% depending on the meter design. For bi-phasic flow (e.g., mud with entrained gas), tube oscillation is dampened, and additional power is required to keep the tube amplitude consistent, resulting in increased drive gain up to saturation. Figure 4 shows how gas events are indicated by means of drive gain and how they affect density measurement.

Ideally, triggers based on drive gain can be set to differentiate between a composition change of a

liquid versus the presence of gas, and consequently alert when gas is present in the mud measurement.

Field experience

Halliburton uses Coriolis meters extensively for added well control and automated system control in MPD projects. Figure 5 shows a typical North Sea offshore rig-up of the meter used as part of a MPD system.

The meters used by the company are usually built into skids to ensure optimum placement and orientation. The skid design reduces the probability of erratic readings or unreliable data attributable to inadequate rig-up angle or positioning.



Figure 5. Coriolis flow meter used for automated MPD offshore in Norway.

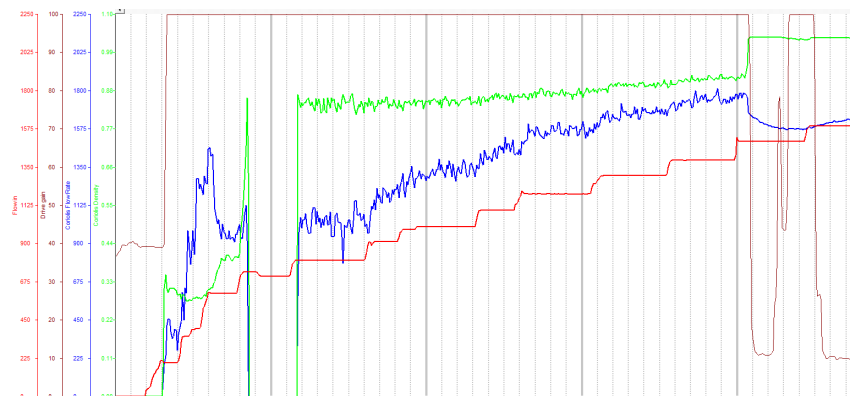


Figure 6. Erratic flow arising from gas entrainment in mud as indicated by low density and saturated drive gain.

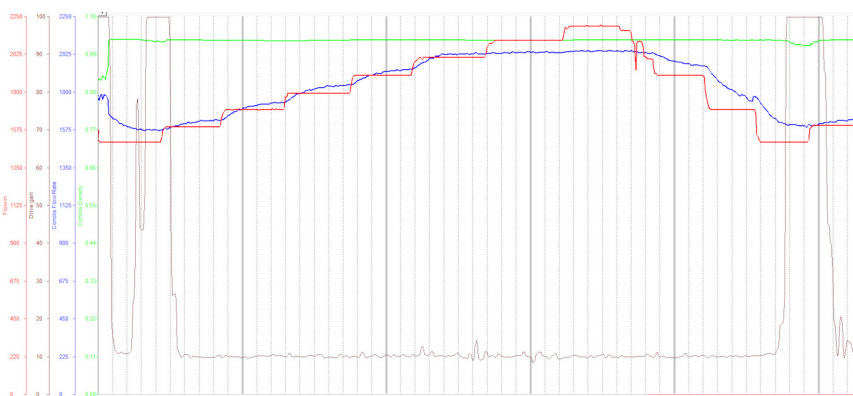


Figure 7. Stable flow regime with gas intrusion at the beginning and end of trend as indicated by the decrease in density and saturated drive gain.

Several parameters, such as drive gain, tube frequency, density, and flow rate, are used with on-board meter verification. This information ensures that wear, blocking, or multiphase issues are detected in an early stage to provide time for planning and for taking corrective measures.

Figure 6 shows an example of these measurements used to determine gas influx as part of an offshore meter provision. The direct correlation between the measurement given by the meter (i.e., density, mass flow rate, and drive gain) enables an operator to confidently attribute the erratic measurement to the presence of gas in the mud.

After all gas has been purged from the sensor, the meter provides reliable readings, as compared to the flow-in signal based on the volume pumped into the system (Figure 7). A small amount of gas in the flow toward the end of the trend shows how the meter is affected. The small decrease in density coinciding with drive gain saturated at 100% indicates the presence of gas in the meter.

The company also uses Coriolis flow meters for standalone flow detection, as shown in the rig-up for a conventionally drilled well (Figure 8). For any well control application, it is of primary importance to use a meter appropriately sized for the section drilled. Similarly, the accuracy also highly depends on being within the flow specifications for the meter with a specific fluid. It is also important that sufficient hydrostatic head is present to



Figure 8. Temporary Coriolis flow meter rigged-up solely for well control purpose offshore Norway.

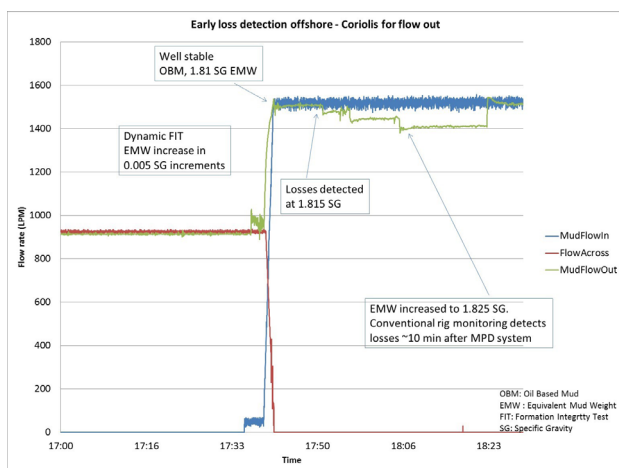


Figure 9. Entrained gas identification with drive gain diagnostic.

maintain flow through the meter. For MPD projects, the majority of sections drilled in the North Sea have been 12 ¼ in. or smaller, resulting in 6 in. or smaller Coriolis meters providing the optimum results. The use of a larger Coriolis meter for similar sized sections and rates will decrease accuracy.

MPD projects offshore Scandinavia most often require operating within very tight drilling envelopes. Minor fluctuations of surface backpressure can quickly result in unwanted influx or loss situations; Coriolis technology is essential to quickly identify any change in conditions and enable fast mitigation. When drilling into new formations in MPD projects, formation integrity tests (FITs) and verification of actual formation pore pressure depend on highly accurate, real time flow measurements. Waiting on normal indicators from traditional tank level measurements results in up to 10 minutes of delay; by that time, a large gain or loss could result in significant well control issues increasing project drilling time. Figure 9 shows a loss scenario from a Halliburton offshore MPD operation in the North Sea in which the dynamic loss detection is compared with the rig conventional monitoring. This comparison illustrates how influx or losses can be detected with the technology with a high degree of reliability, much earlier than with the standard pit volume and flow paddle monitoring. This increased visibility of changes provides a significant benefit in well control capability and drilling efficiency for MPD closed circulation systems monitored by Coriolis technology.

Conclusion

Coriolis flow and density measurements have become critical components of managed pressure and conventional drilling operations, providing accurate measurement of mud returns to quickly identify potential well control events, and lead to safer and more efficient operations. The use of the multi-variable nature of the Coriolis, using mass, volume, and density measurements, as well as the use of diagnostic parameters, such as drive gain, can enable meaningful measurement, even in the presence of gas. The use of Coriolis meters in these applications continues to provide drillers and mud loggers with valuable insight into operations to improve both efficiency and safety of operations.

In April 2015, the Bureau of Safety and Environment Enforcement (BSEE) released a proposal for new well control regulations under 30 CFR Part 250, which recommends real time well monitoring capabilities for deepwater and high-temperature/high-pressure drilling activities.⁴ Based on this rule, even broader implementation of Coriolis technology for drilling fluid management is expected. ■

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