High-Frequency Torsional Oscillation

Understanding these destructive drilling forces and searching for possible solutions

Drilling parameters are getting more extreme and tools are being pushed to complete wells faster and cheaper. Bottomhole assembly (BHA) failure modes are eliminated but new ones are taking their place. A wide range of downhole vibration types—the enemy of efficient drilling— are occurring, creating wasted energy that is no longer available for cutting rock.

As operators chase drilling milestones and demand higher rates of penetration (ROP) and more footage per day, impacts on downhole tools with sensors and electronics must be considered to ensure tool life expectancy doesn't suffer. High-frequency torsional oscillation has recently begun generating significant interest—coupled with plenty of uncertainty—due to its potential effects on these tools. Operators and service providers want to learn more about HFTO because they're frustrated with inexplicable tool failures it might have caused.

Understanding drilling dynamics

Three principal types of drilling dynamics can occur downhole, independently or together:

- Torsional (stick-slip oscillations, bit/BHA whirl)
- Axial (bit-bounce)
- Lateral (bit/BHA whirl, bending, bit chatter)

Torsional vibration is most noticeable to the driller and is commonly referred to as stick-slip. Its symptoms can cause power fluctuations that are required to maintain a constant rate of surface rotation. These fluctuations are caused when the drill bit momentarily stops rotating (stick), which builds torque in the drillstring. The torque builds to a point where it suddenly releases (slip), and the bit and drillstring unwind rapidly to catch up. Stick-slip causes fatigue to drill-collar and pipe connections, invokes bit damage, and slows down the drilling operation. A typical frequency range is 0 to 5 Hz. Stick-slip can be managed by increasing bit RPM and reducing weight on bit (WOB).

Axial vibration, commonly called bit bounce, is produced when the drill bit can't maintain constant contact with the formation. It can be detected at the surface by variations in hook load as the drillstring bounces up and down. Most common with roller cone bits in hard formations, bit bounce can destroy bits, resulting in slower drilling and more bit trips. Increased use of PDC bits has reduced focus on axial vibration as a contributor to downhole tool damage. The typical frequency range for axial vibration is 1 to 10 Hz.

Lateral vibration produces a whirling drillstring in which the rotational axis of the string is not aligned with the center of the borehole. This damages downhole tools, but also creates a borehole that is larger than the diameter of the bit, furthering bit damage and reducing drilling efficiency. Typical frequency ranges are 5 to 100 Hz for bit whirl, 5 to 20 Hz for BHA whirl, and 50 to >350 Hz for bit chatter.

While lateral vibration can be the most damaging type of drilling dynamics, torsional dynamic vibration is probably the least understood. Torsional dynamics can be divided into three types:

- Full stick-slip (FSS): the common stick-slip dysfunction in which the bit comes to a complete stop during drilling
- Low-frequency torque oscillations (LFTO): sinusoidal oscillations in the drillstring caused by RPM and torque variations
- High-frequency torque oscillations (HFTO): characterized by oscillations over 50Hz, which may range above 500Hz HFTO has been difficult to measure and quantify due to the lack of downhole sensors that can detect the high-frequency readings and attenuation that occurs as these oscillations move up the drillstring

Advances in drilling practices stress downhole tools

Downhole tools are constantly being put to the test to reach total depth more efficiently and cost effectively. Advances in drilling motors, which boost the hydraulic horsepower delivered to the bit is one such drilling improvement that has likely led to an increased number of downhole tool failures.

When combined with more aggressive bits, the result is a significant increase in torque, rotary speeds, and maximum flow rates (measured in gallons per minute). While these increases have generally helped reduce the time to drill a well, they are not without consequence.

Motors with higher torque output are typically paired with highly aggressive PDC bits. Motor stalls may occur due to formations that are not homogeneous. When this happens, the resulting drilling torque spikes are affecting the drill collar connections, causing damage from over-torqueing, fatigue failure, or damage to downhole tools. Gains in drilling motor horsepower and performance create new failure modes, contributing to an increase in destructive drilling dynamics.

Insights into HFTO Research

Recent improvements in downhole sensors and measurements have led to an additional interest in HFTO research. Drilling dynamics information from tool sensors with increased bandwidth or data obtained from dedicated high-frequency (HF) sensors should improve and advance the necessary research to better understand vibration phenomena occurring downhole, and how to best mitigate destructive effects. However, positioning HF sensors on or near the bit is challenging.

While proximity to the bit is necessary to measure vibration close to the source, sensors are traditionally placed in the shanks of bits or embedded in logging-while-drilling (LWD) tools or rotary steerable systems (RSS).

More data is always better. Obtaining data from multiple sensors in the BHA and further up the drillstring (in a specially designed sub) can be challenging, but it can help drillers understand how vibration occurs, where it originates, and how to mitigate it.

An alternative view suggests that HFTO is not real

Despite additional data and information becoming available on HFTO, some research suggests an alternative view: that HFTO is not a true phenomenon and occurs as a sensor artifact. In 2017, Theresa Baumgartner published her dissertation, Maximizing the Value of Information from Downhole High-Frequency Drilling Dynamics Data, and presented it at The University of Texas at Austin.

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Baumgartner's research led to an alternative explanation of fluctuations in tangential acceleration measurements previously attributed to HFTO. Her research "illustrates that the location of the sensor within the measurement sub must be considered when processing or analyzing downhole drilling high-frequency data. Because the path of the sensor is different from the path of the center of the string (due to the sensor's eccentric position within the drillstring), additional accelerations are recorded that do not represent the motions of the drillstring.

For this reason, perfectly valid models of vibrations may not match up with measurements, unless sensor artifacts, such as the one described here, are considered" (Baumgartner 2017). She agrees that stick-slip and whirl occur but argues that

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HFTO could just be an artifact. She backs up her hypothesis with several whirl simulations in different hole sizes. HFTO or not, it is generally accepted that high levels of vibration, left uncontrolled, can lead to premature tool failures.

Combating vibration-induced failures

As simple as it sounds, making the most robust RSS possible can minimize the risk of downhole failures. If failures occur, they are typically attributed to excessive levels of vibration energy. Every downhole tool that contains internal electronics is susceptible to damage in aggressive drilling environments with high output drilling motors, high rotary speeds, and elevated WOB.

Because this is the drilling world we live in, D-Tech Rotary Steerable is constantly optimizing and ruggedizing its tool to eliminate failure modes and increase performance, eliminating weak points in a systematic fashion and increasing vibration resistance. As evidence of this ongoing process, the Company has implemented seven changes in the past three months related to sensor packaging inside the RSS drill collar. By tightening internal tolerances in sensor packaging and introducing novel shock mount solutions, D-Tech has significantly reduced vibration transmissibility to the electronics, leading to a more robust, reliable system.

Improving performance by increasing rig site communication

While it will not eliminate damaging vibration, having a D-Tech performance engineer onsite or monitoring operations through their 24-hour real-time center can save tools. By their count, at least 19 incidents have been prevented by having the real-time center involved, saving an unplanned trip. As more experience is gained and more footage is drilled, D-Tech's basin-specific knowledge of lithology and formations grows as well.

This knowledge helps minimize vibration and vibration-related failures by communicating drilling and BHA recommendations to the rig and providing input on selecting the most suitable drilling parameters to minimize vibration and maximize ROP. The D-Tech team has provided recommendations, such as slowing down while drilling a certain formation, increasing weight to push through a section, keeping drilling parameters within published RSS specifications to lengthen run times, etc. to help customers achieve their drilling performance objectives.

Summary

Despite exhaustive research into destructive drilling dynamics, vibration-related failures in downhole tools still occur at a high rate. HFTO presents an area of research where opinions are divided. D-Tech believes HFTO is a true phenomenon and are working to implement higher-bandwidth downhole measurement sensors in their rotary steerable tool. These sensors will capture higher-frequency drilling data to better identify prevalent vibration modes. Understanding the true source of damaging vibration will guide their engineering team in further enhancing and ruggedizing the tools to improve performance and stay in the hole longer.

References

Baumgartner, T. 2017. Maximizing the Value of Information from Downhole High-Frequency Drilling Dynamics Data. The University of Texas at Austin, Austin, Texas (May 2017).