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Drilling Faster: The Role of Vibration Mitigation in Well Drilling

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Abstract

Operators seek to drill faster than ever before, even when contending with complex well designs, which makes mitigating vibrations essential not only for safe execution but also for ensuring the integrity of downhole tools.

This paper examines four types of downhole vibrations that can be encountered in a drilling campaign as well as the typical types of vibration suppression tools used to counteract them. This presentation also introduces advanced techniques and a field-proven approach to optimizing drilling performance that protects downhole bottomhole assembly (BHA) components and at the same time substantially increases rate of penetration (ROP). The paper will demonstrate how this approach allows the lateral and curve to be drilled in one run without having to pull out of the hole and will explain how this method is enabling operators to increase drilling speeds by as much as 20 percent and in some applications save multiple days per well, enabling associated rig spread rate cost savings.

Introduction: The Current State of Drilling

Drilling longer horizontal wells and laterals is enhancing well economics, increasing reservoir exposure and production potential. This is especially true in the well-established Permian Basin in West Texas and adjoining southeastern area of New Mexico, a region encompassing more than 7,000 producing oil-and-gas fields (RRCT, 2024).

Permian drillers continue to push technical limits with complex path drilling techniques to maximize the ability to hit multiple accumulations from a single well location. Using this approach is a cost-effective method to produce less waste and surface impacts than drilling multiple wells (API, 2024).

Drilling 3- to 4-mile laterals is driving efficiency gains, and this positive trend does not appear to be slowing down based on the U.S. Energy Information Administration's (EIA) analysis of the annual average and maximum lateral length per well (Enverus, 2010-2022). According to research by Rystad Energy, one in five new wells in the Permian Basin in 2024 were expected to include horizontal wells that were 3 miles or longer, indicating longer average length for horizontal wells in the United States by completion year (Bloomberg, 2023). In addition to longer laterals, well profiles are slimming from traditional diameter hole sizes. Adding one to two horizontal miles to the drilling path and navigating more demanding well profiles increase the risk and complexity of drilling in harsh, remote locations like the Permian Basin; a flagship for U.S. oil production. In the Permian as well as in other difficult targets, expectations are set on drilling as fast and efficiently as possible, with a limited budget, and using more digitally enabled downhole tools and technologies to control drilling dysfunctions.

To that end, vibration remains a critical challenge that can impact campaign success. Mitigating the risk of four types of vibration at the source—and crucially, ahead of time—is vital to meeting today's drilling programs and controlling the complex dynamics of drilling challenging reservoirs.

Evolution of Well Designs and Downhole Tools

The continual development of shale oil in the Permian and other tight shale plays around the world is driving the development of new technologies that push wells deeper and farther horizontally, while drilling faster than ever before.

In shale environments where an expedient factory-model approach to drilling is common, more wells are moving to the slim-hole design as an efficient and cost-effective solution that still meets performance criteria. In addition to slim-hole drilling, using smaller surface and intermediate casings, the trend of U.S. well designs is poised for another revolution in the Permian. The advent of U-turn (horseshoe or paperclip) wells allows drillers to reposition laterals 180-degrees to continue drilling within the same target formation, increasing reservoir utilization and optimizing productivity in tight lease spaces.

Today, rotary steerable system (RSS) technology accounts for 35 percent of wells drilled in the United States compared to 80 percent globally (Spears Directional Drilling Market, 2024). Traditional point-the-bit BHAs with fixed bent motors have given way to more efficient but more costly push-the-bit, motor-assisted RSS BHAs in response to horizontal production sections extending past the 2-mile length.

The impact of this evolution is that the risk of drilling dysfunction also increases with well design complexity. In particular, those driven by low- and high-frequency axial and torsional vibrations created at the bit with increased lateral vibrations are a by-product of drilling a more tortuous wellbore.

In this rapidly evolving landscape, key advances such as drilling a curve and lateral in one run are not uncommon. Drilling smoother, straighter wellbores is possible due to a greater focus on shock and vibration (S&V) management and the use of various techniques that address single or multiple sources of tri-axial vibration, such as vibration dampening or depth of cut management.

Before analyzing vibration challenges and mitigation tools, it is important to understand how current well designs differ from those of the past five years and how downhole tools and technologies are advancing to support the latest techniques in well drilling.

Fast Factory Drilling Approach

Factory drilling by nature is economizing by scale. This approach requires larger well pads and the use of higher horsepower rigs to drill longer wells that expose larger production zones, activities that require more robust downhole tools that can deliver power to the drill bit. The drilling industry is solving the problem of losing energy stemming from friction in the wellbore from the top drive to drill bit with various techniques and tools.

Some techniques break friction in the drillstring, while other solutions are advancing the transmission of more near-bit energy to replace energy lost up hole, using powerful positive displacement motors that convert hydraulic energy into mechanical energy. This enables more efficient, controlled drilling than traditional rotary steerable drilling systems by delivering higher torsional energy to drill longer extended reach wells in less time.

Slim-Hole Drilling and U-Turn Well Designs

Slimhole drilling is a technique gaining widespread use for tapping into reserves in mature fields, as it significantly decreases waste volumes and reduces the surface footprint of drilling operations by as much as 75 percent (API, 2024).

Slimhole drilling designs utilize a smaller surface and intermediate casing, while preserving the 5 ½-inch production casing in a 6 $^{1}/_{8}$-inch or 6 ¾-inch hole section. This approach has improved ROP for one major operator in the Permian by approximately 30 percent. In addition to better drilling performance, the company reported that using this method reduced drilling and completion costs by more than $500,000 per well (COP, 2021).

First introduced in a Permian play in 2019, the U-turn well is a novel and economical design that is rapidly gaining ground. The number of U-turn wells is increasing in year-on-year adoption by operators in great part because of the cost savings it can deliver. The total cost per completable foot for one 2-mile U-turn well is approximately 25 percent less than two 1-mile laterals (OGI, 2025). Although a U-turn well generally is slightly more costly to drill than a 2-mile lateral, this approach does not leave as many stranded reserves in the ground, making it a more efficient and cost-effective overall.

Vibration Suppression Systems

Faster drilling has obvious advantages, but it introduces violent forces that can damage the electronics in the BHA and the cutting structure of the drill bit.

In more demanding well profiles, additional energy must be transferred to the drill bit. This has been made possible with advances in motor-powered steering assemblies; however, these advances also have increased damage to drilling tools, in many cases, reducing ROP and making it necessary to trip out of the hole prematurely.

The interaction between the wellbore and the tools is manifested in a waveform, where the amplitude and frequency of vibrations have become key performance indicators. New tools and technologies, generally referred to as vibration suppression systems (VSS), have been developed to address the damaging mechanisms of drilling dysfunction.

The Consequences of Faster, Aggressive Drilling

Increasing drilling speed means increasing instances of drilling dysfunctions such as axial, lateral, and torsional and radial vibrations downhole. The need to reduce these vibrations cannot be overstated, especially when drilling challenging wells in exacting downhole environments. Unless service companies introduce solutions to mitigate drilling dysfunctions caused by near-bit vibrations, pushing the limits of drilling equipment in tighter rock formations will continue to increase the risk of damage to expensive downhole tools and electronics.

This problem is being compounded in the Permian Basin because many drillers are taking a well-factory approach to developing unconventional assets. The constant drive to drill longer and more tortuous wells faster introduces higher energy interaction at the drill bit/rock interface when more weight on bit (WOB) and torque are applied to increase ROP. The excitation of energy develops into vibrations that propagate. Generated at the bit, the vibrations travel torsionally and axially up the drillstring, causing fatigue along the way. This occurs both during low-frequency or high-magnitude events (e.g. stick-slip [<1Hz] and axial shocks) and at high frequencies such as those created by high-frequency torsional oscillations (HFTO).

Vibrations Downhole

The four types of vibrations that are damaging to the BHA and negatively impact overall costs are described below along with their consequences:

Axial Vibration causes “bit bounce,” which can damage the drill bit cutting structure and drillstring components (which experience fatigue failure over time) and create wellbore instability.

Torsional Vibration in the form of low-frequency torsional oscillations (caused by stick-slip) can cause premature bit wear and cutter damage, increase fatigue failure of the drillstring, and instigate downhole motor failures.

HFTO Vibration can cause significant damage to downhole drilling tools, especially tools with electronics (like the RSS and measurement-while-drilling and logging-while drilling tools), and also can cause premature bit wear and fatigue failure in all downhole components.

Lateral Vibrations are generally caused by the dynamic forces acting between the drillstring and the wellbore. Bending moments, which result in one side of the structure experiencing compression while the other side experiences tension, can lead to stuck pipe or an enlarged wellbore, potential loss of directional control, drillstring and BHA fatigue failure and if severe enough, can lead to drillstring separation.

Although drilling engineers expect all these types of vibrations, they normally cannot incorporate adequate measures in the well plan to address all vibration types, particularly in the world of factory drilling because of the “design, build, drill and repeat” type of approach it requires.

Most motor assisted RSS BHAs have a standardized design that provides one space below the motor and above the MWD for a VSS tool. This allows the drilling engineer to easily switch out tools. Although vibration suppression technology is beneficial, not all VSS tools are created equal. Most attempt to address the symptom of one or, in some instances, two types of vibration, which leaves drillers deliberating about which vibration type to prioritize. In instances where multiple vibration types introduce significant challenges, drillers are forced to add multiple tools.

HFTO has become the latest buzzword in the world of drilling. The HFTO harmonics travel up the BHA and coalesce at varying bands on the frequency spectrum (Johnson et al, 2022) with differing levels, measured as a force of acceleration (e.g. gRMS). Shocks and vibrations create drilling dysfunctions, reducing the effective energy required for the bit to drill a clean and straight wellbore. The condition of the wellbore impacts the amount of lateral vibration, which can occur at a high enough frequency and acceleration to exceed the specified limits of BHA tools such as RSS. Extreme vibration can reduce the life of the drill bit and can potentially require a costly trip out of hole.

The latest efforts to address HFTO over the past decade have introduced some interesting technologies. One solution is an internal counterforce mechanism that rotates and moves axially at a different rate from the BHA, transferring mechanical energy to heat. The objective of this approach is to reduce the amplitude of torsional vibrations by absorbing and dissipating them via a change in momentum enabled by the internal counterforce mechanism. Although this is effective in reducing the damaging effects of HFTO, it only addresses a symptom of the vibrations generated at the bit/rock interface. It does not address the HFTO problem that is created by the interaction of the drill bit with the rockface.

Other solutions are equally constrained. Conventional VSS tools are not only limited by their inability to manage more than one type of vibration but also by their inability to manage the drill bit depth of cut or improve ROP. Adding multiple VSS tools to the BHA to compensate for this can lengthen and complicate BHA design and substantially increase costs.

The benefits of mitigating all four vibrations simultaneously in real time with one tool is self-evident.

Solving Vibration at the Source

A number of drilling problems begin downhole at the drill bit. Mitigating drilling dysfunctions caused by near-bit vibrations is crucial to increasing WOB, which in turn leads to gains in ROP without compromising the drill bit or damaging the BHA.

Importantly, a patented spring power pack and cable design singularly addresses all types of vibrations by preventing vibration generation at the source—at the drill bit and the rock interface—so operators can maintain or increase their planned drilling parameters, while protecting the drill bit and downhole BHA from vibration dysfunctions. The cable mechanism modifies the drill bit’s depth of cut at a high frequency, thereby preventing dysfunctions from occurring. This capability is essential for scaling success in factory drilling.

The intention of a VSS tool combined with a rotary steerable BHA is to dampen the form of vibration that each specific VSS was designed to mitigate. This allows the drillstring to perform more optimally to drill a better and faster well.

The cable design VSS tool uses a combination of disc springs and hydraulic force to balance with the cable heart assembly as it manages downhole torque and automatically controls the drill bit depth of cut.

The cables in the heart assembly are a fixed length and are installed at an angle around a near frictionless internal mandrel. When torsional force that exceeds the calibrated setting is encountered, the tool is activated, and the cables wrap around the internal mandrel to contract and shorten its length. This activation is near instantaneous and allows for drill bit depth of cut management in real time.

The cables are flexible during compression and strong when tensioned. For example, when an axial shock is encountered, the flexible cables do not resist. This allows the tool to respond faster to changes in formation while drilling regardless of whether vibration frequency is high or low, so that the PDC cutters remain engaged with the formation.

In the Permian, a number of operators employing the cable design VSS tool have reported fewer downhole BHA failures, which has allowed them to drill vertical-curve-lateral wells in one run more often. They also have reported ROP increases of up to 20 percent. With fewer trips and significant ROP improvement, these Permian operators are saving significant costs in an area where a typical spread rate is approximately $1/second.

Successful Field Examples and Results Achieved from Vibration Mitigation in U.S. Shales

VSS Tool Increases WOB to Achieve 25% Faster ROP

In the Denver-Julesburg (DJ) Basin, a directional drilling company deployed a single VSS tool with a low-friction internal cable mechanism. The goal was to employ the tool to mitigate the generation of all four types of vibration through the cable’s high-frequency response to formation changes at the bit. The VSS performed as designed to stop generation of the dysfunction at its source, allowing the driller to increase the WOB to a new and sustainable ROP that was 25 percent faster than the driller achieved previously. Furthermore, by reducing vibration damage to the RSS, the driller was able to reuse it. Where previously the driller needed to replace and/or fix the electronic circuitry of the RSS after drilling each well, the VSS tool extended the field life of the RSS so it could be used on as many as four wells. With the ability to employ the VSS to consistently improve the founder point and enhance drilling programs in the DJ Basin, the company has now adopted the cable mechanism as a standard across eight of its 12 rigs in its slimhole wells in the Permian Basin, where it is experiencing a similar improvement in ROP. Because the VSS has enabled the company to improve drilling efficiency and performance, it has ramped up to drilling 25 to 30 more wells per year using the same number of rigs.

Reducing Vibration in Novel U-Turn Wells

To date, more than 100 U-turn wells have been drilled since the technique was first trialed in 2019. Because of the drilling trajectory, with a high dogleg severity (10 degrees to 15 degrees+/100 ft) to land the curve, followed by a 5,000-ft horizontal section before drilling a 180-degree azimuthal turn that precedes drilling another 5,000-ft lateral, downhole dynamics change considerably over the course of the drilling program. Each section introduces different issues that can damage the tool and slow drilling operations. The cable mechanism VSS tool has demonstrated the value of reducing vibration and enhancing drilling speed and efficiency on three U-turn wells, and additional implementations continue to deliver positive results.

However, more research is needed to investigate increased wear using this technique compared to drilling long straight laterals. Performance on the three U-turn wells indicates there are new issues that require attention (such as BHA design, hole cleaning, and increased torque and drag issues that could limit WOB). The process of standardizing BHAs and parameters, which is required to make this a factory drilling technique, is ongoing, however history has shown that the learning curve will not be steep and progress is expected to be rapid.

Conclusion: Drilling the Impossible, Vibration-Free Hole

Mitigating vibration downhole is not optional in complex drilling campaigns—it is a necessity to ensure smooth, efficient well drilling. Using a cable design VSS tool that mitigates all four types of drilling dysfunctions can help operators push drilling limits by extending tool life, reducing the number of trips downhole, and increasing ROP. This level of predictable performance will allow more wells to be drilled faster in a well-factory approach to more rapidly and cost-effectively develop unconventional assets while potentially optimizing long-term costs for the life of the well.

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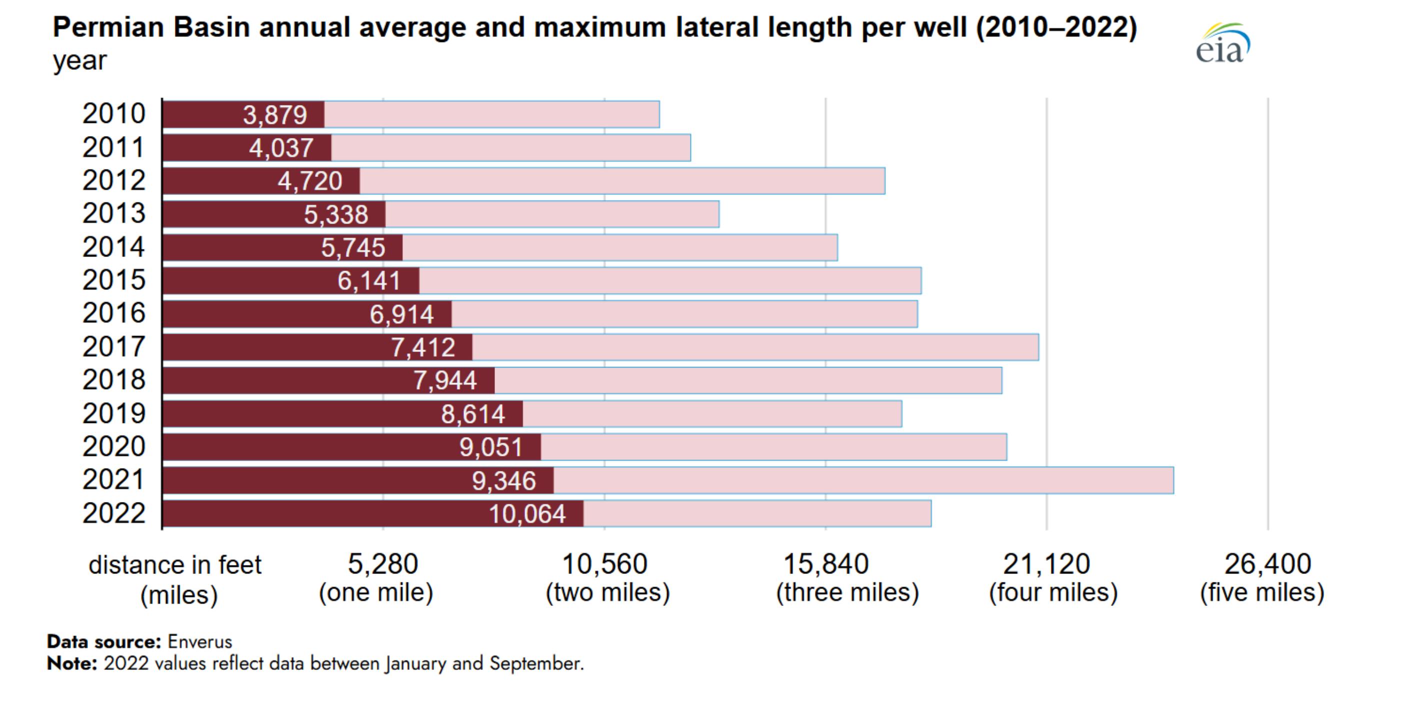
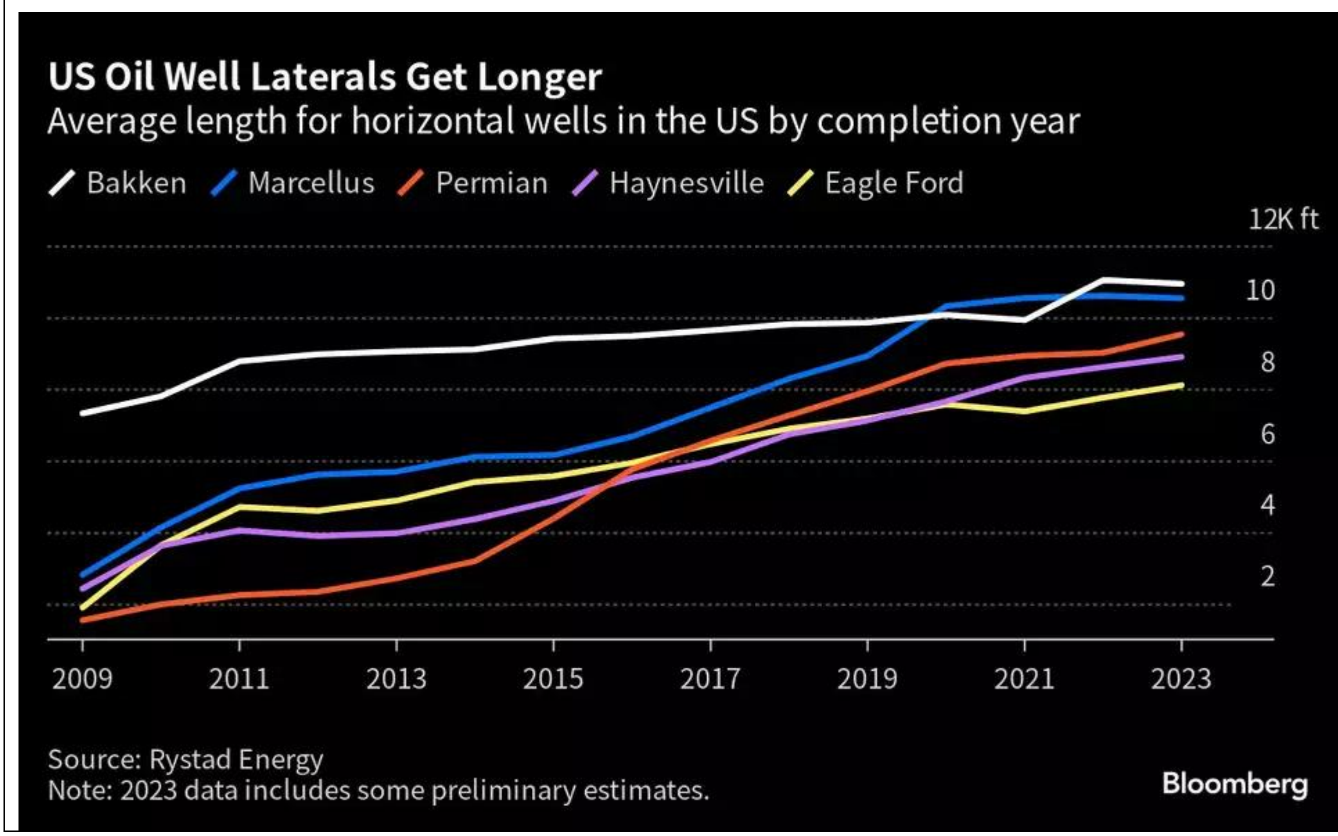

Permian Basin annual average and maximum lateral length per well (2010–2022)
year
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
3,879
4,037
4,720
5,338
5,745
6,141
6,914
7,412
7,944
8,614
9,051
9,346
10,064
distance in feet (miles)
5,280 (one mile)
10,560 (two miles)
15,840 (three miles)
21,120 (four miles)
26,400 (five miles)
Data source: Enverus
Note: 2022 values reflect data between January and September.


US Oil Well Laterals Get Longer
Average length for horizontal wells in the US by completion year
Bakken
Marcellus
Permian
Haynesville
Eagle Ford
12K ft
10
8
6
4
2
2009
2011
2013
2015
2017
2019
2021
2023
Source: Rystad Energy
Note: 2023 data includes some preliminary estimates.
Bloomberg