TRANSFORMING VACA MUERTA DRILLING: NEW INTEGRATED DRILLING PLATFORM MITIGATES HFTO, SAVES 4.1 DAYS, AND DRILLS 86% FASTER

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Abstract

The Oil and Gas industry increasingly rely on unconventional extraction methods to meet world's demands, yet it presents technical challenges to drill vertical-curve-horizontal in a single run, especially in Vaca Muerta. In this scenario, operators continuously aim to drill longer sections at a faster pace for increased productivity, which pushes to create new holistic solutions that solves these challenges. A particular challenge that arises in the drilling of production section, especially in the vertical and curve portion for unconventional shale plays at Argentina-Vaca Muerta is the presence of severe high frequency torsional oscillations (HFTO), which decreases the reliability in electronics, and also presents constraints in building capabilities. In the horizontal portion, performance is sacrificed to maintain proper wellbore placement. This project's goal is to develop an integrated drilling platform that allows to complete the production section in a single run, by managing the HFTO, leading to increased tool reliability, and overall reducing operating times, which in turn provides reduction of fatigue-related failures, increases precise wellbore positioning, and enhances safety, ultimately delivering cost and time savings.
This study focused on: a) The deployment of an integral rotary steerable system, enabling a reduced side load for steerability efficiency and reliable data logging in a new ecosystem. b) Implementation of an innovating Damping Tool technology in the bottom hole assembly (BHA) that reduces HFTO c). The use of a three-dimensional polygonal mesh simulation software that allowed to develop a polycrystalline diamond cutter (PDC) drill bit design compatible with the new platform, which provides torsional stability, in addition to an engineered gage and reduced bit-to-bent distance, hence compatible with the application requirements. The outcome of this implementation is the completion of a production section in one single run that saved 4.1 days, translated to 86% faster than allotted time. The afore mentioned study has pushed the boundaries of building capabilities of the BHA, leading to optimize curve trajectory, improve penetration rate by 36%, reduce 90% of HFTO vibrations, ultimately stablishing a baseline for unconventional drilling in Vaca Muerta with the use of predictive modeling, that saves costs, drive down health, safety and environmental impact, and contributes to boosting the Oil & Gas Industry in Latin America.

Introduction

The Vaca Muerta Shale play, located at Neuquén Basin in West Argentina, is one of the most promising known reservoirs in the world, holding the second-largest shale gas and fourth-largest shale oil reserves globally, The region presents significant challenges in terms of geological complexities that demands high-precision drilling and fracking techniques. The most common practice to drill these wells consists of a multi-well PAD drilling (Figure 1), where each wellbore contains trajectories aimed to reach the Vaca Muerta Layer in a way that can allow for maximum number of fracture stages within the horizontal portion. The production sections are drilled in a hole size either 8.5in (0.216m) or 6.75in (0.171m), being 6.75in hole size the most common nowadays. The production section contains a portion, known as Vertical (or low inclination < 10º deg) trajectory between 400-600m vertical section, followed by the Curve portion, where the inclination of trajectory is increased up to 90 degrees Curve. The buildup rate in which the curve is built, greatly depends on the goals for the horizontal section and the geomechanically challenges present in the application. These values are commonly between 5.5º/30m to 7.5 deg/30m. Once reached the Landing Point, which is the point where a horizontal trajectory begins, within the shale layer, the assembly will continue drilling between 2500 to 3500m of Lateral section. Inclination may vary with low dogleg severity to follow the encountered dip angle of the layer to increase the reservoir exposure (see figure 2).

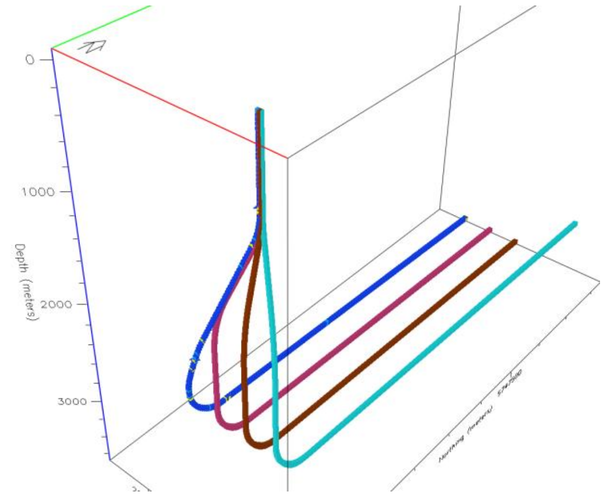


Figure 1.: Typical Four wells PAD drilling in Arg.

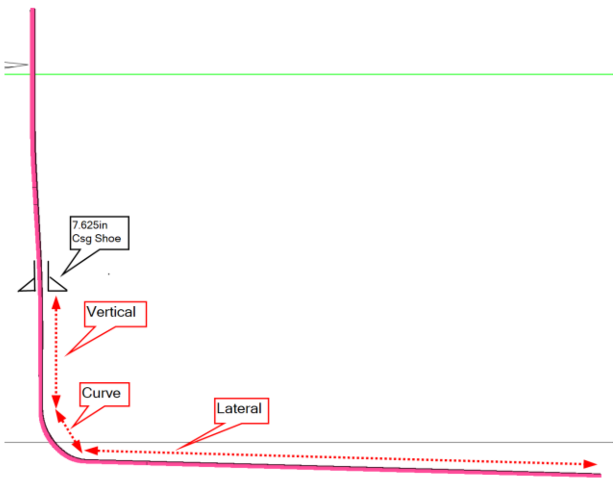


Figure 2.: Typical Unconventional Well in Arg.

At early developments for unconventional drilling to reach the Vaca Muerta Shale, between 2015 and 2016, the goal to was to drill the production section in a single run, using rotary steerable systems that can provide smooth build rates and optimized ROP (rate of penetration). This approach has been known as "Shoe-to-Shoe (S2S)". This ultimate goal aimed to complete the production section avoiding additional trips for BHA change, however, the low experience in the area for drilling the rock formations in the production section, like the Fm. Quintuco, which is an interbedded layer of sandstone, limestone and shale with highly variable rock strength, presented constraints to achieve the aforementioned goal, translating either use a bent motor to build the curve, sacrificing rate of penetration in the Lateral portions, or perform additional trips, translated to additional times and increased cost, utterly, negatively affecting production rates for oil companies and lower efficiencies

Since drilling the first well, the hazard of a vibration prone environment has been identified as a root cause, specially while drilling Quintuco formation, which is present mostly in the Vertical and Curve portions, inducing early downhole tool failure and leading to additional trips. Investigations found that the failures were associated with exceeding the maximum vibrations levels exposures for downhole tools, mostly torsional vibrations, known as Stick & Slip, and commonly labeled as SSLIP, lateral vibrations, known as Whirl, and labeled as SEVXY, and a form of vibration commonly referred to as high-frequency torsional oscillations (HFTO). The HFTO has been a subject of study in recent years, which are recorded by downhole tools that are capable of record higher sampling rates (Jain et. al. 2014, Zhang et. al. 2017).

These HFTO are present between ~50 Hz to above 400 Hz, dependable on the configuration of the BHA (bottom-hole assembly) and the entire string configuration, being the root cause for this type of vibration a self-excitation mechanism in the bit-rock cutting interaction, particularly with PDC (polycrystalline diamond cutter) drill bits, in formations that has medium-high or high rock strength, either onshore and offshore (Oueslati et. al 2013, Oueslati et. al. 2014).
HFTO are known to cause severe damage in the electronic components, as well as to some mechanical components in the downhole tools. For the Vaca Muerta application in Argentina, this means several issues aside of additional trips to complete the production section, like low penetration rates, constraints in achieving the desired build rates, thus missing the targeted landing point, ergo reducing fracture stages, and impacting oil & gas production rates. In addition, for operators and services companies, implies higher costs due to increased maintenance, shortage of downhole tools, delays on drilling and completion times, and overall increasing non-productive time and generally inefficiencies. See figure 3 with an example of a well from Vaca Muerta Basin with UCS (un-confined strength) of the rock with values between 25 – 30 KSI in Quintuco formation and Increased variability in GR (Gamma Ray) both evidence of very hard and interbedded lithology. Within the highlighted dotted square, is the Fm. Quintuco, prior the Fm. Vaca Muerta.

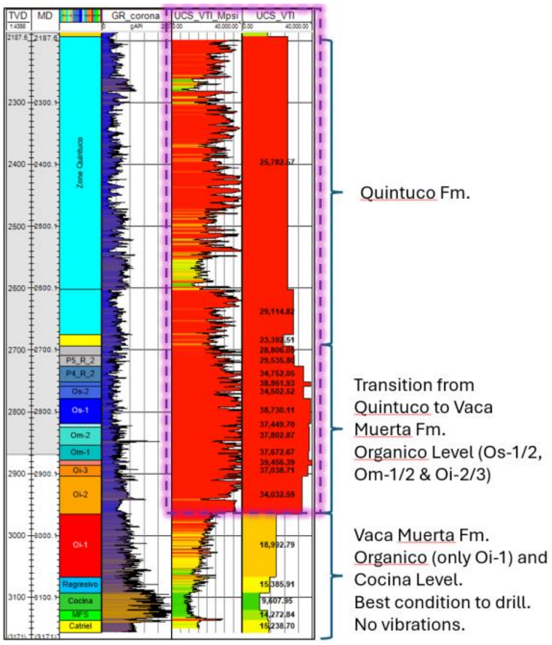


Figure 3. Typical UCS Well Log

Since the know "Shoe-to-Shoe" approach came with excessive costs and delays, the local industry opted for a way around, conveying to perform the drilling of the production section using two different assemblies. The first assembly consist of a PDM (positive displacement motor), suited with a bent angle. The motor offers increased resistance against vibrations and dynamic disfunctions produced by the sub-surface environment. This assembly will carry a PDC drill bit designed to improve directional capabilities in Fm. Quintuco, in sacrifice of aggressiveness that could imply potential higher rate of penetration in the horizontal portion within Fm Vaca Muerta. The other characteristic of the first assembly is it's flexible BHA that can build a curve with less bending stress, hence more reliable operations and reduced time. Once the first assembly reaches the landing point, with 90-100% of Fm. Vaca Muerta, it gets pull out of hole and switched to a second assembly. The second assembly has a rotary steerable system as the drive, the flexibility of the BHA is lower, so it can stay on target trajectory with less efforts and less risks of deviation, and the PDC drill bit design can be optimized for higher rate of penetration. The second assembly also carries an MWD (measure while drilling) tool that will aid in the directional measurements like Azimuth and Inclination, as well as collect downhole data useful for geological interpretation and an optimized geosteering.
Yet, despite de reduced risk and improved performance on both portions of the production section, the "Two BHA" practice, still gives space for improvement, since the additional trip to swap assemblies counts as non-productive time an additional use of resources.

By seeking that window of improvement, a few options were considered to push the technical constraints and find ways to mitigate the drilling dysfunctions and manage HFTO while drilling with RSS in Fm. Quintuco and the transition zone to FM. Vaca Muerta to optimize the curve. Some of these options:

- Motorizing the RSS assembly which mitigates Stick & Slip vibrations (low frequencies) but has little to no effect on HFTO mitigation.
- Adjusting drilling parameters e.g. reducing WOB, RPM and then ROP performing specifics road maps to drill this challenging formation. However, performance is compromised.
- Testing of different drill bit design, which is time consuming and presents uncertainties of effectiveness of solutions.

However, their impact either together or separately proved insufficient, and failures continued to emerge. This document is focused on showcase an integrated solution to withstand the challenge on drilling Fm. Quintuco formation with significant mitigation of HFTO and allow to drill the production section under the "Shoe – to – Shoe" approach with RSS, enabling to save an additional trip.

HFTO in Vaca Muerta Basin

Before delving in the solution, the HFTO needs to be understand. They are a type of vibration phenomenon primarily encountered in downhole drilling operations within the oil and gas industry. In can be defined as torsional resonance—a rapid oscillatory motion around the axis of a rotating drill string. It occurs at high frequencies (often above 100 Hz) and is typically triggered by interactions between the drill bit - formation type – drilling parameters. See figure 4 a diagram separating low and high frequency torsional vibration.

HFTO vibrations are measured through g (gravities) in RMS format (Root Mean Squared) which represent the value of the area below the curve, and it is the best method to represent the energy absorbed by a system instead of taking the average and/or peak value. See figure 5:

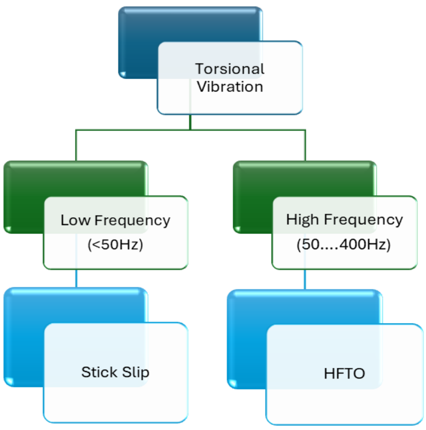


Figure 4. Diagram type of Torsional Vibrations

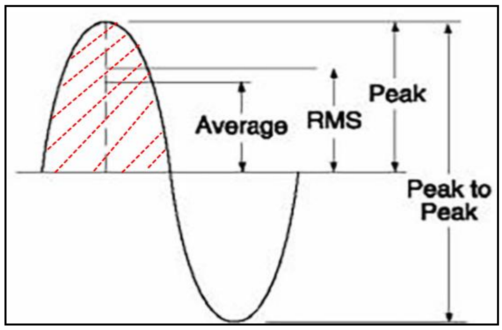


Figure 5. Comparison between Average, RMS, Peak

The HFTO effect can be measured through modern directional tools equipped with high frequencies data capacity allowing the tool to count the accumulated exposition time to a certain level of vibrations type (see figure 6). Tangential and Lateral acceleration in g_RMS usually when shows values between 4 – 6 g_RMS with spikes up to 10 g_RMS or even more (see figure 7) these are evidence of HFTO been triggered. This phenomenon is present in mainly 03 scenarios in Vaca Muerta Basin:

1. **Drilling Quintuco Formation.**
2. **Transition Zone Quintuco – Vaca Muerta.**
3. During Lateral section, changing in layer being navigated. Geosteering request to change the TVD (True Vertical Depth) moves the assembly from one layer to another, which in some cases could be heterogenous/harder accompanied with variations in GR and Tangential – Lateral vibrations while

crossing certain layer. This case is different from last two because in most of the time not reached higher exposure to HFTO but for a couple of seconds-minutes instead.

Tangential Vibration Limits

Tool Size	Unit	Mitigation Category			
	Severity Level	< L4	L4	L5	> L5
4-3/4 in.	gRMS	< 8	8 to < 12	12 to < 15	≥ 15
Time Limit within Specification:		No Limit		3 hr	20 min

Figure 6. Exposition time limits for Tangential vibrations for New integrated Technology

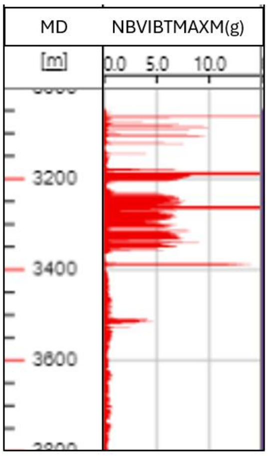


Figure 7. Log from a Lateral well exposed to tangential accelerations during 180m of 5-6g with spikes up to 10g

The subsequent sections of this paper will elucidate how the New Integrated Drilling Platform can withstand the aforementioned phenomena, as well as detail the technologies employed to achieve the defined Key Performance Indicators (KPIs).

Improved Rotary Steerable System platform

Early RSS (Rotary Steerable Systems) technologies, described by Barr et aL. (1995), and Donati et aL. (1998) work on the concept "push-the-bit" where a lateral force is applied from the tool, to contact the borehole wall, influencing the drill bit's position rather than tilting the drill bit angle like a bent motor would do, which has come to know as "point-the-bit". For over 25 years, several different models have been developed around this concept and some of them also work on the "point-the-bit" principle. See figure 8 for a basic illustration on these concepts.

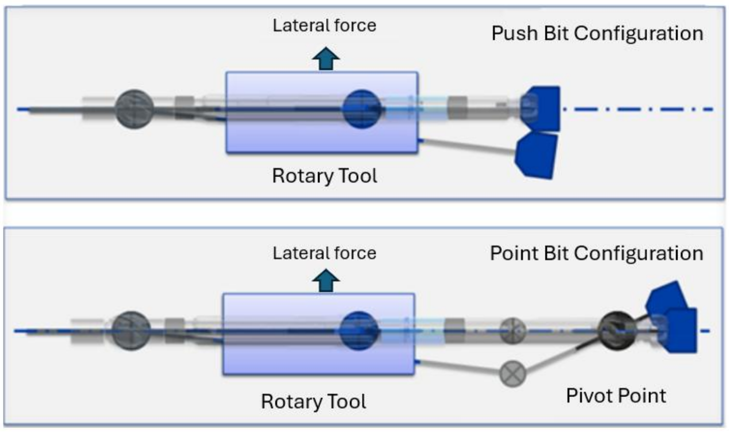


Figure 8. Push-Bit and Point-Bit configuration of rotary steerable system.

Push-bit configuration may be the most utilized concept among current RSS offering, yet most of them work in On-Off cycles, creating ledges along the borehole which can reduce efficiency and creates additional stress on tools, not to mention operational risks, like micro-tortuosity

The new generation rotary steerable system works on an enhanced push-the-bit concept, by applying continuous proportional steering vector force. The platform includes a control system that constantly monitors near-bit inclination, azimuth and the steering vector and automatically adjusts, this in turn produces a smooth borehole; therefore, the risk of high-local doglegs is effectively mitigated.

In this platform, the steering control unit is not affected by drilling dynamics as it works as an independent system with pads powered by internal hydraulic power on a decoupled slow rotating sleeve. As a result, these pads operate independently of system and bit pressure, flowrates, and drilling fluid properties, allowing to optimize drilling parameters to meet the requirements of the application.

However, in applications like Vaca Muerta shale plays, with the challenges like increased torsional vibrations, elevated temperatures and system is designed for challenging applications like performance pad drilling with motorized BHAs, hard rock drilling and/or interbedded formations, for example, gas fields and also for high temperature applications. For this case study, we will focus on the capacity to operate in the drilling environment of vibrations and HFTO.

Since torsional resonances of the BHA cannot be avoided when drilling hard rock with PDC drill bits, BHA components must be designed to be rugged enough to cope with those demanding drilling conditions. Typical resonance frequencies range from 100 – 500 Hz and reach high tangential acceleration as well as high dynamic torque values (Hohl et al 2019, Figure 9). The new generation rotary steerable BHA system follows consistently optimized design concepts (Hanno, 2022), and uses selected components and structures designed and tested to survive at the unavoidable high dynamic load**.**

Design options on the BHA components are simulated and optimized for torsional resonances and their respective frequency and amplitude. The dynamic response from the finite element simulation tool (Figure 9 and 10) is used to identify the critical components within the RSS.

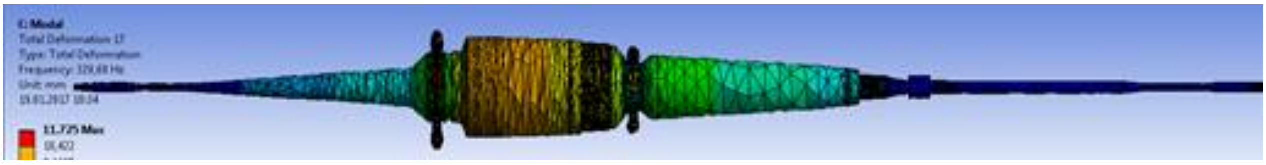


Figure 9. Modal analysis of RSS substructure, showing torsional resonance at 329 Hz

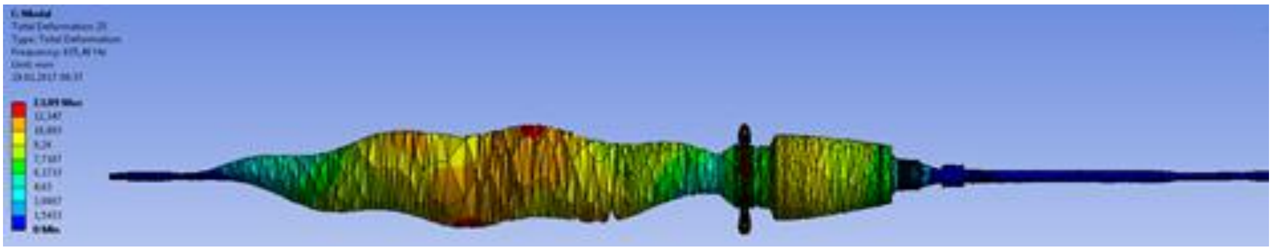


Figure 10. Modal analysis of RSS substructure, showing torsional resonance at 624 Hz

This modal analysis that identifies the potential resonance that will occur in the substructure of the RSS, will continue in an iterative process considering the application specific load cases, supported by historic data. range of torsional resonances that are expected within the drilling environment. This later will be leveled down to the components and assemblies, that are modified, verified, and qualified during lab testing for field application.

Another aspect of a re-design of current RSS platform, considers the deployment of materials that have higher corrosion resistant properties as well as high temperature resistance that can absorb the additional stress and fatigue.

In addition, a new ruggedized, modular thread connection is developed to increase the torque threshold by approximately 30%, as compared to API. This will enhance the communication rate for measurements and loggings from various sensors within the platform. New limits for static torque capacity result in less training and increased margin for Make UP Torque, and increased reliability.

The new platform works on the premise to be a robust option without sacrificing flexibility, thru the shortened length, compared to previous platform, which can aid in the building capabilities. However, this shortened, rugged concept, needs to be extended to other components of the BHA, like the Drill Bit.

Drill Bit Design compatibility

In this section, the document will cover the characteristics that a PDC drill bit needs to attend, in order to act as an integrated platform to further enhance the continuous proportional steering concept and meet the requirement to drill the production section in Fm. Quintuco and Fm. Vaca Muerta in one complete run, attaining to mitigate HFTO and optimize performance and wellbore placement.
The two main characteristics for the PDC drill bit in which the optimization for this case study focused, are torsional stability and efficient steerability.
The torsional stability will complement the mitigation effects on HFTO, by balancing the loads in the cutting structure, so the fluctuations created by the cutting effect of interbedded rock layers are kept to minimum.
By using a three-dimensional polygonal mesh model that can accurately simulates the loads and reactionary forces on the cutting elements that are engaged in the drilling process, the bit-rock interaction can be analyzed to identify bore-hole dynamics, which will allow to identify PDC drill bit features that can adjust the behavior to the desired outcome in the project. The force model discussed in this document is calibrated using high pressure lab data (Ledgerwood and Kelly 1991). It is also relevant the importance of the force model utilized in the utilized software (Matthews 2021).

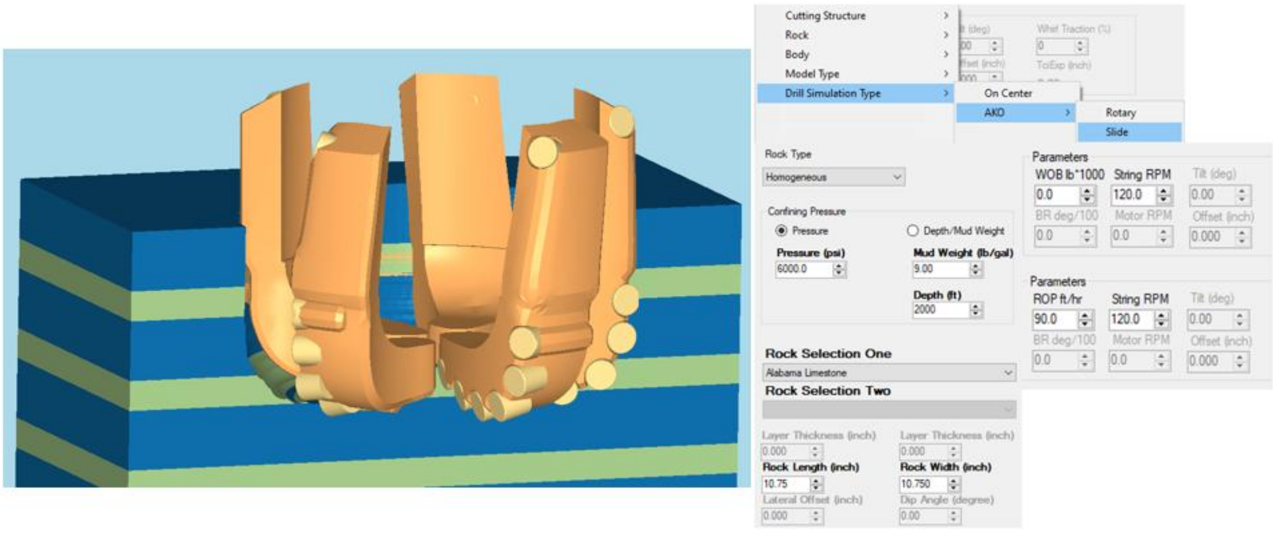


Figure 11. Drill bit polygonal geometry placed on a solid that has rock properties. Input Parameters

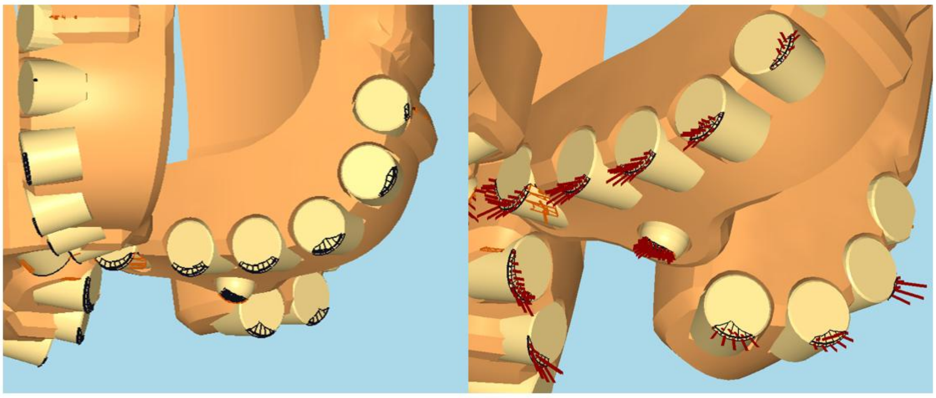


Figure 12. Geometries and force vectors from those Bit-Rock interactions.

The figures 11 and 12 shows how the software can perform the evaluation on stress and loads, by input the drilling parameters, such as Weight On Bit (WOB), Rotations Per Minute (RPM), and it's subsequent outcomes, like Mechanical Specific Energy, Side forces, among other parameters, they can be utilized to further improve the PDC drill bit response to meet the application requirements (Hernandez, 2023).
The goal for the analysis is to have a balance in the loads in each cutter since this behavior will favors a response from the PDC drill bit, that will provide the more stability in the transition of forces across the profile and utterly deliver the required stability to increase the performance of drilling without falling in a vibrations window that can compromise tool reliability and general drilling times.

In this case, a PDC drill bit with 5 blades and 13mm cutter size, identified as "Design A", is subject to the simulation and a response is obtained, illustrated in figure 13. That will serve as the benchmark for the feature-response relationship baseline. The graph shows the workrate on each cutter. The workrate is a term that co-relates axial load and torque, associated to the rotational speed against a rock strength (Pessier, 1998), and although some linear behavior is observed from the center of the PDC drill bit, to the outer area, some values are more sprayed out. This doesn't mean that the PDC drill bit behaves incorrectly.

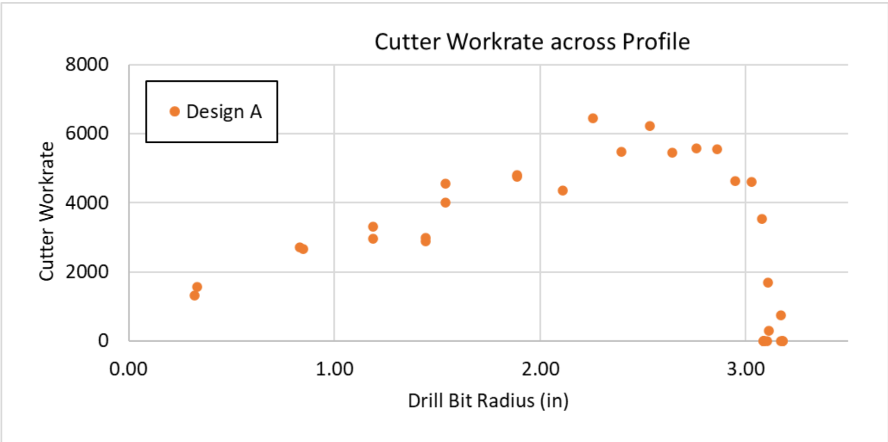


Figure 13. Workrate across PDC drill bit profile. Design A

However, experiences show that a more lineal transition in workrate between center and outer area of the PDC drill bit, shows a correlation in torsional stability when drilling. Meaning that any variation on axial load (Weight on Bit, or variation in rock strength, or a combination of both), translate in less variation of torque. Less vibration of torque means less prone to drilling dysfunctions that can lead to vibrations of the assembly.

Changes in PDC drill bit features, on the same 5 blades and 13mm cutter size design, like modification of backrake, cutter exposition, cutter radial position, alter the workrate under the same condition. These changes are subject to the polygonal model simulation under different tags: "Design B" and "Design C". Results are obtained and compared to each other, at figure 14 and figure 15, for evaluation and selection on the most suitable option.

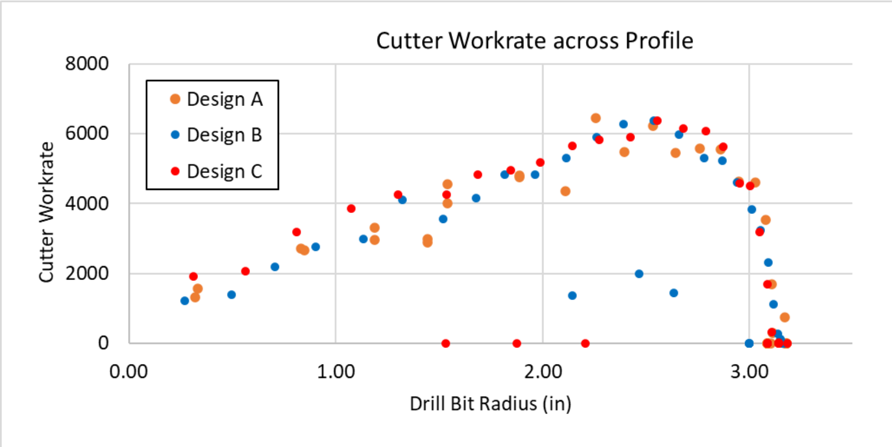


Figure 14. Workrate comparison between PDC drill bit designs A, B and C.

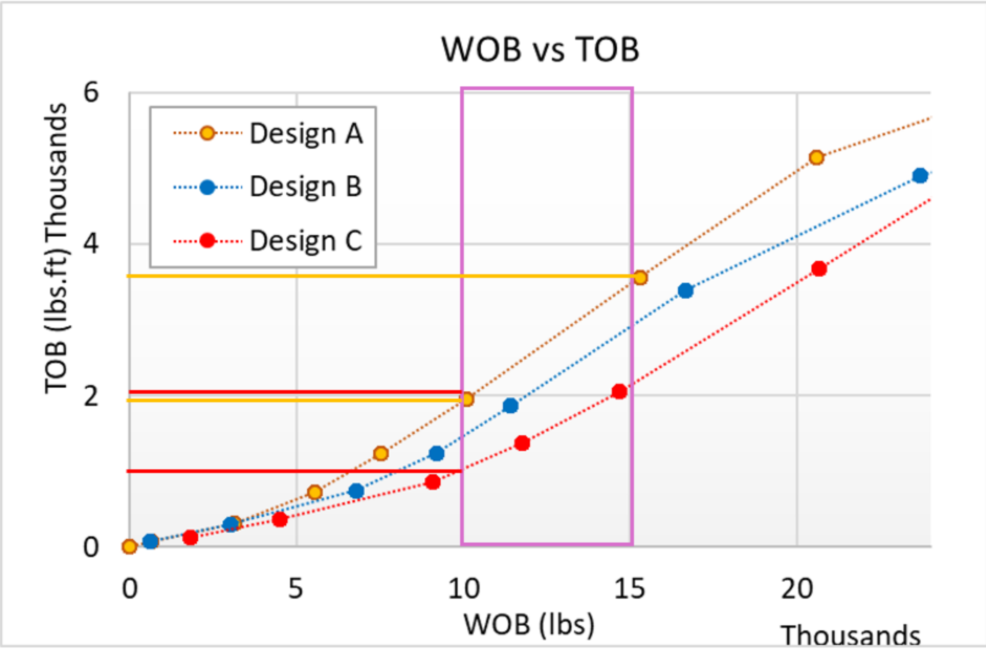


Figure 15. Different Torque variations a same WOB range.

By choosing a PDC drill bit with 5 blades and 13mm cutter size, that has design features and is tagged "Design C", which offers the most torsionally stable response for the challenge to drill a production section in Vaca Muerta, another layer of vibration management is added to reduce the risk of tool failure and potentially improve the performance window.
Yet a second characteristic that is critical for maximum efficiency for both, building the curve and deliver proper steerability efficiency during building Curve and Horizontal navigation, is the PDC drill bit's response to provide appropriate lateral displacement with the minimum side stress at the drive system.
The RSS requires specific geometric configuration and cutting structure layout to optimize the lateral response so it can change direction with minimum stress, thus minimizing dogleg severity and provide low tortuosity in the borehole.
Supported by the Three Contact Point theory that defines the radius of a hole curvature (Cooney, 2017) illustrated in figure 16, the shortest the distance between points A, B and C, the lowest the radius of said hole curvature.

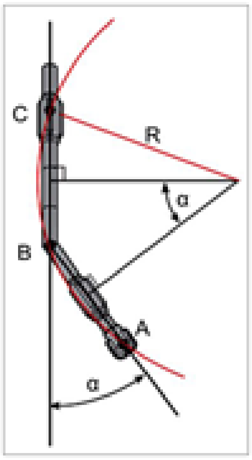


Figure 16. Three Points of Contact defines the radius of hole curvature.

The shortest length of assembly delivers less stress to the assembly when trying to build a curve, or change direction (Harmer, 2016), thus utilizing less stress, and reduced bending moment in the downhole tools, which can benefit the performance and reliability.
With these concepts at hand and supported by recent investigations on the utilization of 3D modeling and polygonal mesh drilling simulation software for PDC drill bits (Valbuena, 2025), the lateral response can also be simulated, evaluated and predicted to obtain the desired behavior that allows to optimize the performance of drilling in the production section at the vertical, curve and horizontal portion.

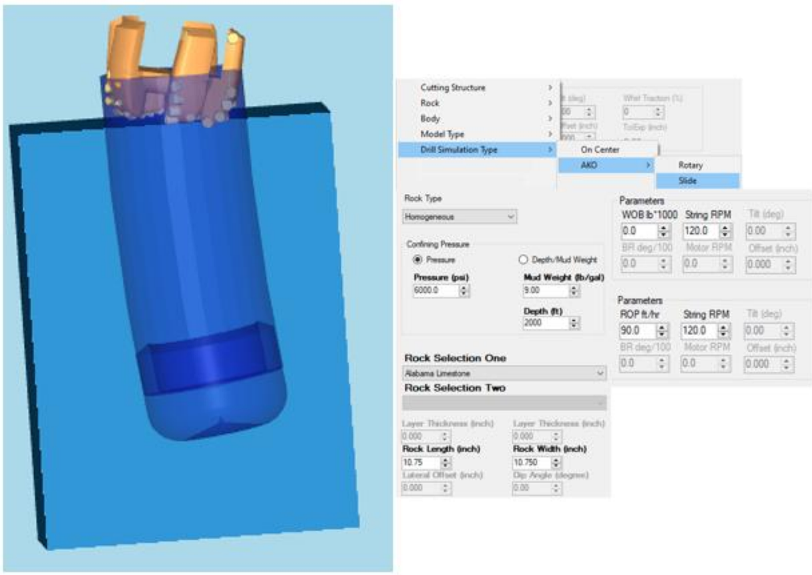


Figure 17. Drill bit polygonal geometry placed on a solid that has rock properties. Input directional trajectory, input parameters

Figure 17 shows the input parameters, both drilling and planned trajectory, using the geometric configuration of the current assembly, in an environment that mimics the rock properties to be encountered when drilling a shale formation like Vaca Muerta top.

The two outputs required from this analysis are: a) the “Cutting Structure Build Force” that measures the amount of side load required to laterally displace the assembly in the desired direction, at the desired build up rate. This is obtained from the sum of vectorial forces in the cutting structure, plus the effects of the rotary steerable system bending stress. b) the “bit total mu” which measures the amount of area of PDC drill bit’s gage in contact with the borehole wall. Both measures need to be the lowest value to increase easiness of steerability.

As with the cutting structure layout, a PDC drill bit design with 5 blades and 13mm cutter is utilized as benchmark, and the results are plotted in figure 18.

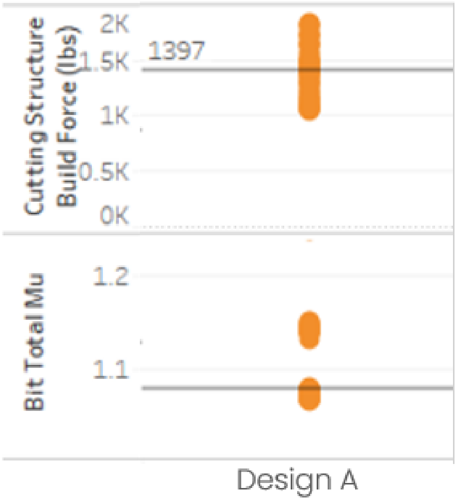


Figure 18. Simulations results on steerable response from the PDC drill bit, Design A.

The solution to increase the steerability response, meaning, to reduce the required forces and bending stress to steer the bit and displace laterally, is to reduce the distance between two of the three points, in this case, reduce the distance between face of the PDC drill bit and the point where the side force is created, which in the Rotary Steerable System that is used, means the direcional PAD. To achieve this, the configuration of the connection was changed from a PIN connection to a BOX connection. Observe Figure 19.

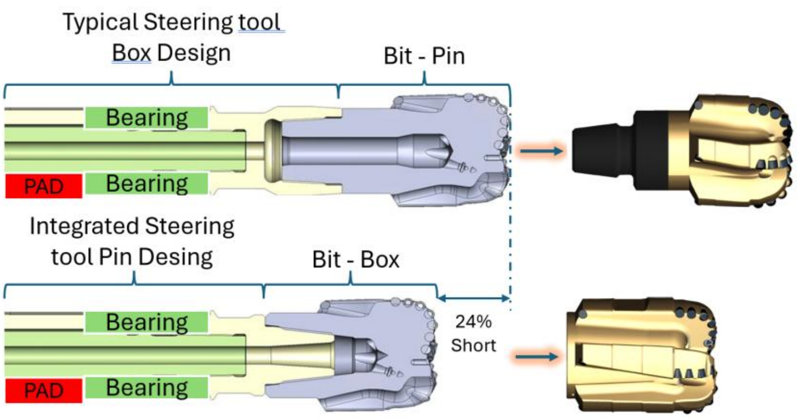


Figure 19. Diagram of drill bit connection configuration to the Rotary Steerable System.

By testing this connection, along with changes in the gage length, for the same PDC drill bit design of 5 blades and 13mm cutter size, Design B and Design C were subject to the simulation, observing satisfactory results for design C. Observe figure 20.

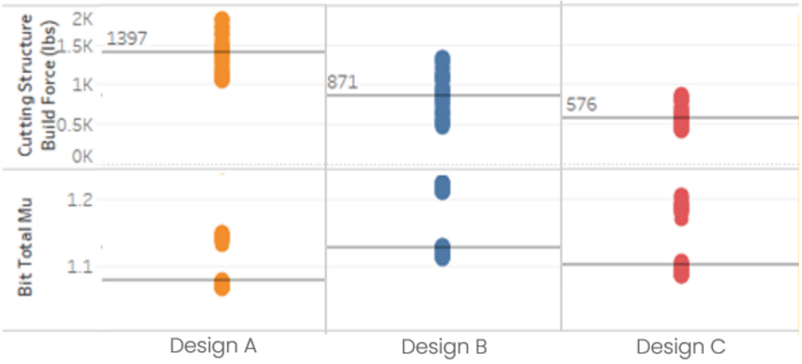


Figure 20. Comparison in simulation outputs to evaluate steerability response of PDC drill bit various designs.

The “Design C” applied to the target well offered an incremental performance demonstrated on figure 21.

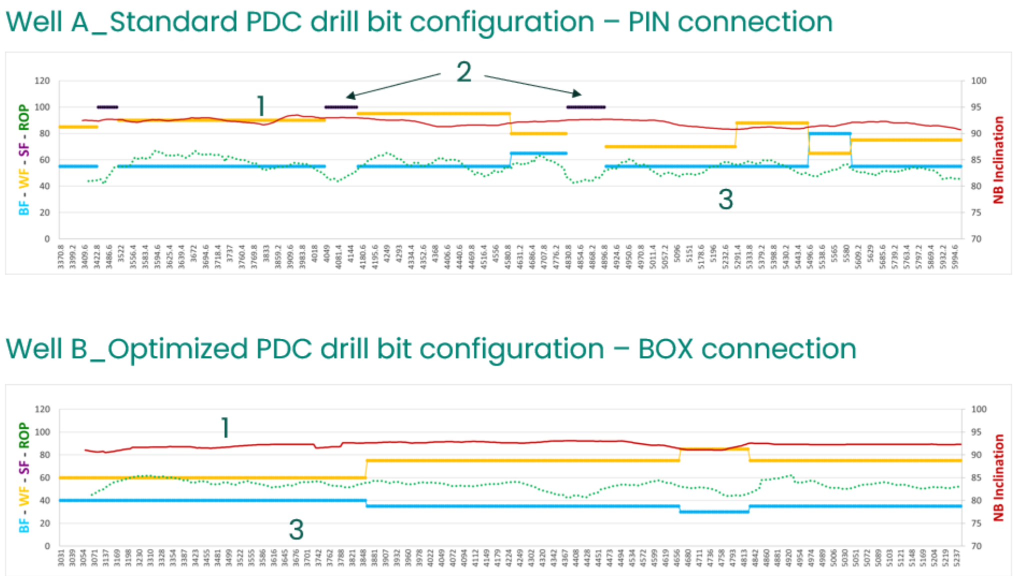


Figure 21. Steerable performance comparisson between standard assembly and optimized assembly.

What is observed in figure 21 are the steerable measurements during the drill of a horizontal section in Vaca Muerta. 1) Near Bit inclination measures the inclination at the Rotary Steerable System. On Well B, the variance is less than in well A, meaning that the directional work performed by the Rotary Steerable System with the optimized drill bit design was within tolerance to keep a steady trajectory, rather than spend more time correcting. 2) portions where the Rotary Steerable System had to manually apply “Side Force” to correct trajectory. This manual mode overrides the automated closed loop control that is used to maintain trajectory. This manual mode is used when the direction of the assembly cannot maintain the target Near bit inclination. In Well B, since the directional response is optimized, the corrections are performed by the automatic closed loop control, thus eliminating the need for manual override, hence reducing correction time. 3) Build force is the force applied by the rotary steerable system to push the assembly upwards during the geo-navigation, and it’s noted that in Well B, this behavior is more steady than Well A, meaning that the general stress regime in the assembly is lower which translate in a drilling operation that is less stressful to the downhole tools, which increases reliability and improves performance by sustaining rate of penetration, rather than having variable rate of penetration as observed in Well A. The results from the analysis and implementation of improvement enhances the efficiency of drilling of production section in the Vaca Muerta Formation.

Torsional Vibration Damping Tool

Within the platform, a third layer of torsional oscillation mitigation works on the concept of “Torsional Vibration Damping tool”. In essence, the dampening elements (hydraulic mechanic) provide additional damping and are activated by the differential movement due to vibrations relative to the stationary rotation of the BHA (Kueck A. et. al. 2022). The TVD tool is depicted in figure 22. For this case study, in the 6.75in section, a 4.75in (120.65mm) diameter tool is evaluated.

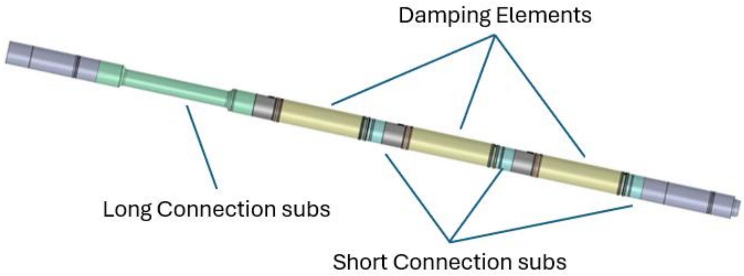


Figure 22. Principal design of 4-3/4in TVD Tool

This tool performs damping effect while drilling without activation from surface, the internal mechanism does not require mud flow nor pressure drop. In regards of BHA configuration, pressure drop, and operation basically acts as simple sub in the drillstring without any effect on BHA operations (e.g steering, BUR capabilities). One HFTO is triggered as a consequences of drilling high interbedded-hard formation the HFTO are dampened for TVD tool while drilling without any adjustments on drilling parameters.

Due to the capacity of TVD tool, it was possible to plan drilling Vertical and Curve section in Quintuco formation as a field test in Vaca Muerta Basin; Previous attempts were with Motorized RSS without any damping tool resulting in high impact damages on directionals tools and low performance. Figure 23 is an example of a Vertical section in Quintuco Fm. running with a motorized RSS (previous technology) where is evident the harmful environment with superimposed Tangential, Laterals and SSlip acting on the BHA components.

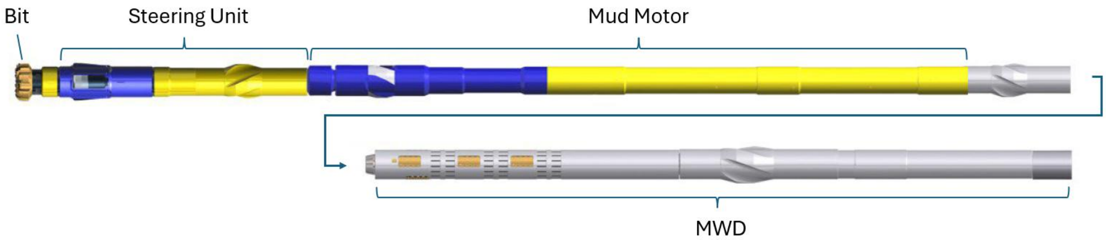
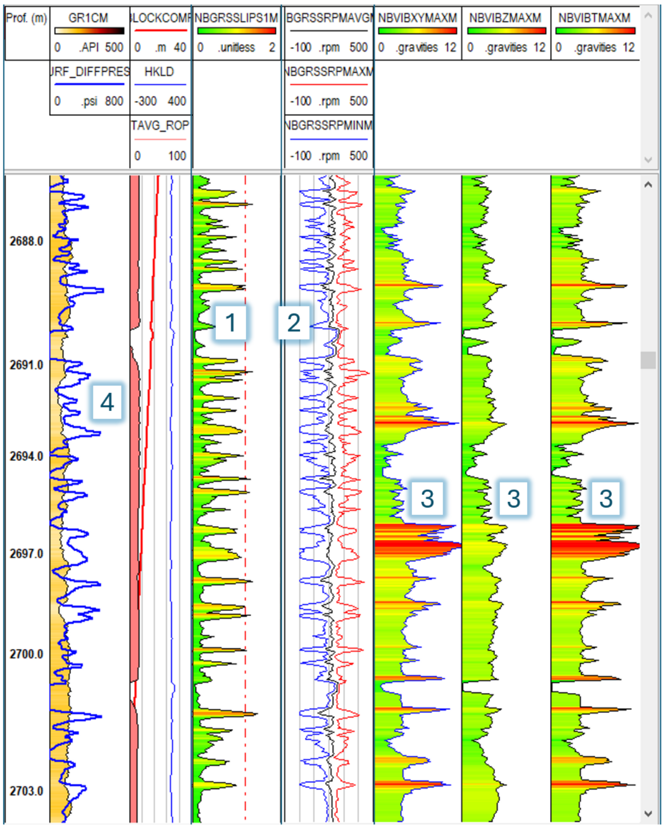


Figure 23. Previous RSS Motorized Technology

In the following log (see Figure 24), will appreciate a typical behavior in Quintuco Fm. with Motorized RSS:



1. **Moderate SSlip Vibrations Level 3 to 4.**
2. **Maximum and minimum RPM reading from Bit (Steering Unit), observing values from 0 RPM to 300 – 500 RPM. This high variations produces increasing in angular accelartion in the BHA, mainly in the Steering Unit.**
3. **Laterals (XY), Axial (Z) and Tangential (T) accelerations showed in scale between 0 to 12 g (gravities).**
4. **It is observed high correlation between micro stallouts from Motor and higher accelerations values.**

Figure 24. Log example Well "X" of a RSS Motorized BHA drilling in Quintuco formation.

The Logs description showed as follow:

GR1CM	Gamma Ray Average
SURF_DIFFPRESS	Diferential Pressure from Motor
BLOCKCOMP	Block Position
HKLD	HookLoad
TAVG_ROP	Rate of Penetration Average
NBGRSSLIPS1M	SSlip Level from Steering Unit
NBGRSSRPMAVGM	Average Bit RPM
NBGRSSRPMMAXM	Maximum Bit RPM
NBGRSSRPMMINM	Minimum Bit RPM
NBVIBXYMAXM	Maximum Lateral Vibration
NBVIBZMAXM	Maximum Axial Vibration
NBVIBTMAXM	Maximum Tangential Vibration

This cycling behavior explains how BHA during micro stallouts (from Mud Motor) due to drilling through interbedded-hard formation layers reduces drastically its rotation close to 0 RPM, accumulating energy and releasing suddenly resulting in high angular acceleration (HFTO) in a very short time span and restarting again accumulating fatigue on BHA components, leading to failures and higher maintenance cost. Because last statement, operators decided to quit "Shoe-to-Shoe" strategy with RSS and switch to 02 Runs avoiding the exposure of HFTO vibrations.

The TVD tool contributed successfully regarding to mitigating this harmful scenario, the arrangement for this BHA was as follow:

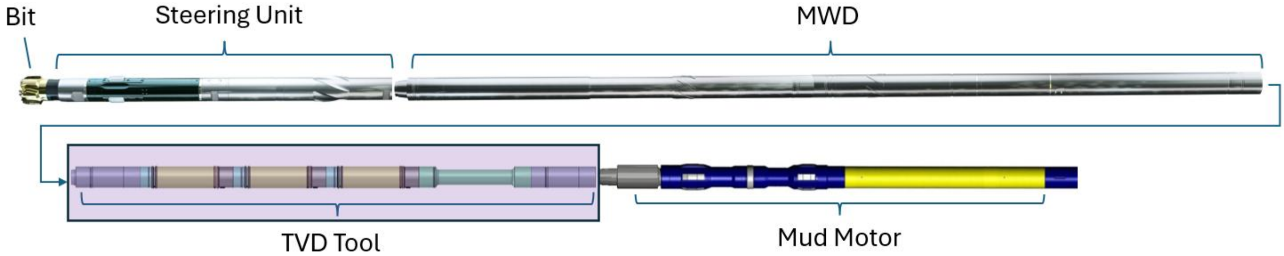
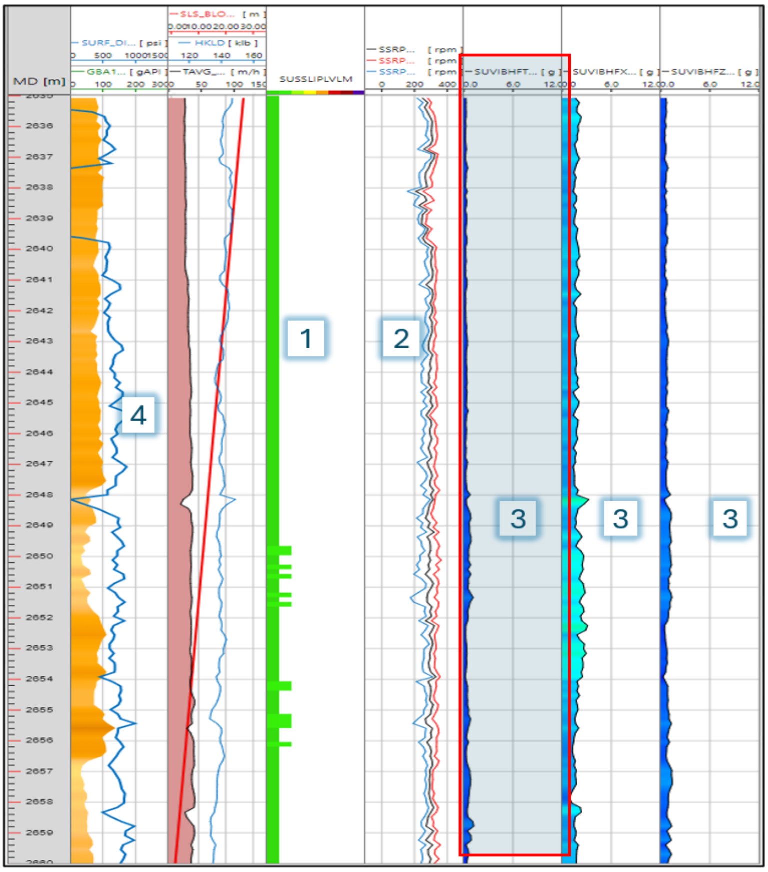


Figure 25. New RSS Motorized Technology with TVD Tool

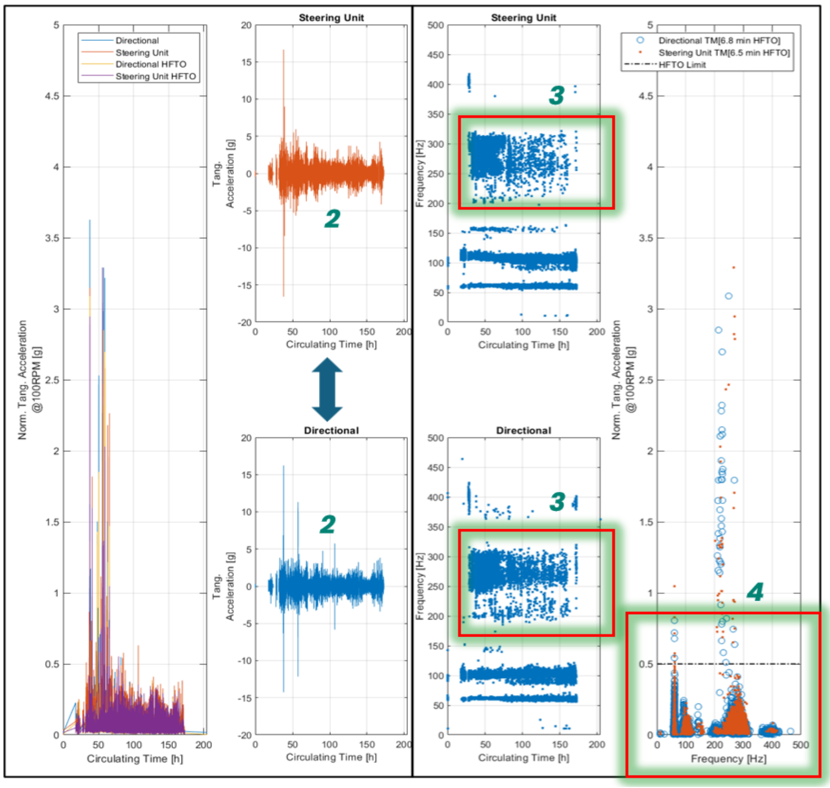
Prior first attempt, engineering analysis was performed focusing on the local application for Vaca Muerta Basin resulting in a design with 03 dampers subs, tagged as TVD Tool, illustrated in figure 25. Well design consisted in 6-3/4in section starting in Quintuco Fm. from 20º at 7-5/8" Shoe, then turning and adjusting inclination with 2.2º/30m DLS for 445m long, at that point start KOP drilling from 11º deg to 51º with 3.3º/30m DLS until transition between Quintuco and Vaca Muerta, then increasing DLS requirements to 5.18º/30m until landing well in Lateral section at 88-89º deg. The most challenging part on this well as mentioned before was drilling Vertical/low inclination section with 450 - 500m long and 300m in Curve Section both in Quintuco Fm. without exceeding the maximum exposure to vibrations and mainly HFTO. In the log illustrated in figure 26, the optimized behavior in Quintuco Fm. with Motorized RSS is demonstrated:



1. **Low SSlip Vibrations Level 0 to 1.**
2. **Maximum and minimum RPM reading from Bit (Steering Unit), observing values from 255 to 292 RPM. This variations does not produce major variations on angular accelerations; It is considered normal for motorized applications.**
3. **Laterals (XY), Axial (Z) and Tangential (T) accelerations showed in scale between 0 to 12 g (gravities). Compared with previous RSS technology, parameters are smoothly without hazard vibrations; TVD Tool during drilling hard-interbedded formation successfully dampens tangential vibrations.**
4. **This stability allowed motorized RSS tool drilling the formation with stable parameters without stallouts and very low Stick and Slip readings. Allowing fulfilling ROP KPI without any risk on damaging directional tools.**

Figure 26. Behavior of Vibrations in Well "Y" while drilling Quintuco formation highlighted Tangential Vibrations.

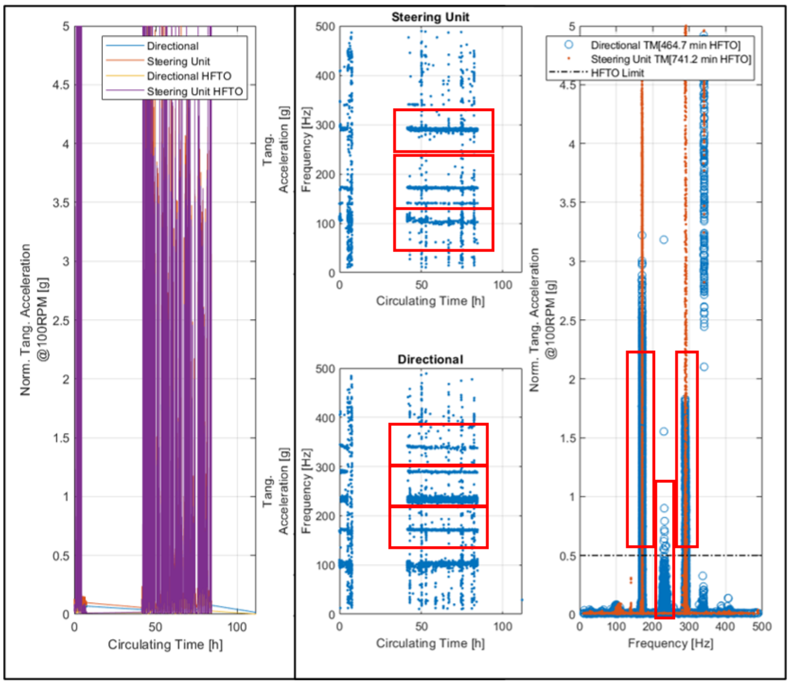
Once the 6-3/4" section was finished, this new technology with its high frequency data capabilities allows to obtain a summary of high energies vibrations during the run dumping, showing as follow in figure 27.



1. **In the graphs, the tangential vibrations are normalized to 100 RPM (Bit RPM).**
2. **The vibrations remained at the same level both in the MWD and in the Steering Unit.**
3. **Since the HFTOs (High-Frequency Torsional Oscillations) were effectively dampened, there is no defined high frequency triggering the graphs. On the contrary, there is a dispersion of high frequencies without any one being predominant (dampened).**
4. **Approximately 90% of the vibrations remained at low levels, averaging between 0 to 2g (this is not considered OOS – Out of Specification). For tangential vibrations normalized to 100 RPM, the limit is 0.5g.**

Figure 27. Summary of Tangential Acc. and frecuencies normalized at 100 RPM fron new integrated technology at Well "Y"

The dispersion at high frequency levels evidences the effectiveness of the TVD tool drilling hard-interbedded formations. In the past, previous technology was exposed to a well-defined high frequencies level, see figure 28.



In the graphs, the tangential vibrations are normalized to 100 RPM (Bit RPM).

Inside red squares can appreciate high frequencies which made trigger during this well drilling Quintuco Formation.

Three well-defined high frequencies were detected by high-speed data vibration sensors, which were mostly 298 and 173 Hz.

Both, reached high level energy on the graph normalized to 100 RPM tangential accelerations greater than 0.5g

Above 0.5g, it is considered Out Of Specification which endangers BHA tools.

Figure 28. Summary of Tangential acceleratrions and frecuencies normalized at 100 RPM from previous technology at Well "Z"

Below is a summary of tangential vibrations and stick-slip over time between wells X (previous technology) and Y (new drilling platform). A drastic reduction in SSLip and HFTO vibrations is highlighted in figure 29.

Well X: 2991m drilled and 138 hrs circulation hours

Stick Slip [level] vs. Time [hours]	
PN:	SN:
Level 0 (Normal State)	78.68
Level 1 (Normal State)	31.87
Level 2 (Torsional Oscillations)	9.93
Level 3 (Torsional Oscillations)	5.04
Level 4 (Torsional Oscillations)	3.36
Level 5 (Stick-Slip)	1.69
Level 6 (Stick-Slip)	2.29
Level 7 (Backward rotation)	2.38

Tangential [severity level] vs. Time [hours]	
PN:	SN:
Level 0	60.24
Level 1	9.56
Level 2	59.34
Level 3	6.97
Level 4	1.63
Level 5	0.21
Level 6	0.21
Level 7	0.12

Well Y: 4545m drilled and 142.4 hrs circulation hours

Stick Slip [level] vs. Time [hours]	
PN:	SN:
Level 0 (Normal State)	123.45
Level 1 (Normal State)	2.25
Level 2 (Torsional Oscillations)	0.10
Level 3 (Torsional Oscillations)	0.03
Level 4 (Torsional Oscillations)	0.01
Level 5 (Stick-Slip)	0.01
Level 6 (Stick-Slip)	0.06
Level 7 (Backward rotation)	0.17

Drastic reduction in Stick-Slip.

Tangential [severity level] vs. Time [hours]	
PN:	SN:
Level 0	126.11
Level 1	1.23
Level 2	0.03
Level 3	0.07
Level 4	0.01
Level 5	0.00
Level 6	0.00
Level 7	0.00

Effective mitigation of Tangential (HFTO)

Figure 29. Comparison between tangential and stick-slip vibrations over time between wells X and Y.

Engineered for high performance drilling environments

The new drilling platform also includes additional advancements that have contributed to the optimization of drilling times, enumerated as follow:

1. The electrical connection between subs has been upgraded to central wet connection without compromising modularity, increasing resilience and eliminating the possibility of failure during MU (Make Up) at the rig site. The new integrated technology features a high-strength, torque-bearing connection, enhancing torque capacity by 100% compared to the 3 ½" API connection which mitigates the risk of twist-offs. Additionally, advanced material combinations and higher-grade components provide increased wear protection.
2. Included a complete directional package. This improvement enables accurate survey quality data measured at 5.9 ft (1.8 m) from the Bit Box. It allows timely informed decision making for reservoir navigation and continuous monitoring of the well trajectory without stop drilling. Also, the Near Bit Azimuthal Gamma located in the RSS enables timely record for real time evaluation on reservoir navigation.
3. New drilling platform provides directional surveys, either with flow-on, or flow-off. The flow off Survey is possible due to batteries designed to be deployed in high temperatures environment as well. Some Vaca Muerta Basin wells during Lateral section drilling can arise to 140 – 148º Celsius.

Application Results

The application of the new drilling platform and associated tools yielded measurable improvements in the performance of drilling operations in the Vaca Muerta Formation. Most notably, the production section—including vertical, curve, and horizontal segments—was successfully drilled in a single run. This operational milestone significantly reduced both time and cost, marking a step change in efficiency (see Figure 30). The incremental performance gains, as evidenced by multiple downhole parameters measured during the operation.

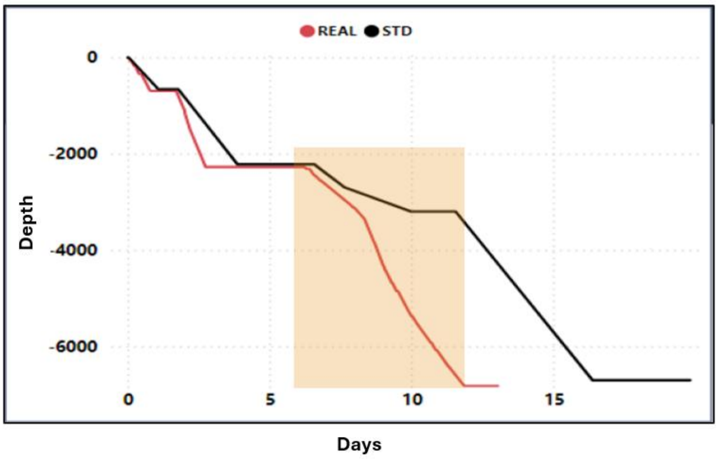


Figure 30. Comparison between Real vs Plan Standard (STD) on Well Y with New Integrated Drilling Platform.

In the well, the Rate of Penetration (ROP) in the 6.75-inch section was improved by more than 60% thanks to the successful Shoe-to-Shoe strategy, which eliminated flat time due to tool changes. Additionally, it was possible to optimize ROP during both the Vertical and Curve sections while drilling through the Quintuco formation. These achievements were the main contributors to the overall drilling time optimization. All of this was made possible by the success of the new integrated drilling technology.

The results were satisfactory regarding the reduction of tangential vibrations between the previous technology and the new platform (comparison between Well X and Y). The improvement in damping high-energy vibrations is clear, which even allowed not only avoiding tool damages but also for the optimization of the Rate of Penetration (ROP) during drilling and the successful achievement of drilling the well with a single Bottom Hole Assembly (BHA).

The Near Bit Inclination data shows a notable reduction in directional variance in Well B compared to Well A. This indicates a higher precision in trajectory control, largely due to the optimized integration between the Rotary Steerable System (RSS) and the drill bit. This level of stability in trajectory implies less non-productive time associated with course correction and improves overall hole quality.

Moreover, the minimized reliance on manual Side Force application in Well B demonstrates a more responsive and autonomous steering behavior. The enhanced performance of the closed-loop control system allowed for consistent adjustments without operator intervention. As a result, directional corrections were smoother and faster, which is directly tied to time savings and operational simplicity.

Additionally, the data on Build Force reveals a more stable stress profile in Well B. This suggests that the downhole assembly experienced reduced mechanical strain, leading to greater tool reliability and extended run life. In contrast, Well A showed a more erratic build force pattern, correlating with fluctuations in the rate of penetration and a more demanding operational environment. By sustaining a steady rate of penetration and minimizing tool wear, the new technology configuration enhanced overall performance.

Conclusion

The successful deployment of the new drilling platform in the Vaca Muerta Formation has direct implications for the broader oil and gas industry. By enabling the completion of complex production sections in a single run, the platform addresses two of the most critical challenges in drilling operations: operational efficiency and cost containment.

From a technical standpoint, the seamless integration of an advanced Rotary Steerable System with an optimized bit design improves trajectory control, reduces corrective interventions, and maintains mechanical integrity across all drilling phases. The deployment of TVD tool, as part of the integrated technology, enabled the successful achievement of the ultimate challenge: drilling a well in the Vaca Muerta field in a single run (Shoe-to-Shoe), without tool failures, environmental damage, zero (0) HSE incidents; This achievement was made possible through the mitigation of tangential vibrations, which had previously caused severe damage to downhole tools, resulting in non-productive time and additional operational maneuvers. This, in turn, significantly reduced both drilling time and operational costs, marking a major step forward in performance and reliability. The reduction in build force variability and decreased need for manual overrides signify a leap in drilling automation, bringing operations closer to fully autonomous wellbore placement.

For operators, these advancements translate into real-world value—lower operational risk, faster time to production, and better resource utilization. The reduced wear and extended durability of tools further contribute to sustainable field development, particularly in resource-intensive environments like Vaca Muerta.

More broadly, adopting such platforms can enhance project economics across shale and unconventional plays. By consistently delivering better drilling performance with fewer inputs, this approach aligns with industry goals of efficiency, reliability, and long-term cost reduction. As exploration continues to push into technically challenging formations, these innovations will be vital in shaping the future of drilling performance worldwide.

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