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ROTARY STEERABLE AND UNDERREAMER TECHNOLOGIES MERGE FOR COST-EFFECTIVE BOREHOLE ENLARGEMENT

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Abstract

Underreaming with Rotary-Steerable Systems (RSS) is becoming commonplace simply because significant cost savings can be obtained by eliminating the need for a designated hole-opener run. RSS underreamer assemblies are often challenged with bottom-hole-assembly (BHA) instability, excessive vibration and stick-slip problems. Pre-job BHA analysis and optimal drilling parameters are critical to the success of RSS underreamer assemblies.

This paper describes case histories of directional wells that have been drilled utilizing point-the-bit and push-the-bit RSS with the underreamer positioned above the measurement-while-drilling (MWD)/logging-while-drilling (LWD) tool. Various assemblies and borehole sizes will be discussed detailing the pre-job BHA planning, BHA stability, directional response and overall drilling performance.

Each assembly will be analyzed using the RSS onboard vibration, stick-slip and caliper sensors. The overall system efficiency of RSS underreamer technology will be evaluated to establish the optimum configuration for each application.

Introduction

RSS underreamer assemblies are often challenged with BHA instability, excessive vibration and stick-slip problems when the two different cutting structures (bit and underreamer) interact with significantly different formations.

In the past, a combination of steerable motors and bi-center bits was the only viable option for concurrent directional drilling and hole enlargement where casing pass-through was an issue. However, this practice was soon found to be undesirable since the use of bi-center bits/tools and eccentric hole-opener tools commonly suffered from excessive shock/vibration, torque fluctuation, poor directional control, and irregular and/or spiraled hole.

The combination of RSS and underreamers provided a better alternative solution for directional drilling that requires simultaneous hole opening. Since the RSS steers while fully rotating, an RSS BHA is carefully designed to incorporate an underreamer behind an RSS and MWD/LWD tool. The RSS underreamer technology has brought many benefits such as drilling "shoe-to-shoe" in one run, high ROP, good LWD log quality, high-quality borehole and consequently good directional results.

The particular RSS used in the programs has unique features suitable for underreaming applications. A non-rotating steering unit of the RSS de-couples the steering unit from the string and ensures that any low-level stick-slip generated by the additional cutting structure of the underreamer does not affect the efficiency of the RSS steering control system. Automated steering features enable the system to efficiently drill vertical and tangent sections. Integrated Real-time Stick-slip and Vibration Detection (RSVD) delivers lateral, axial, and stick-slip measurements to the surface operator for underreamer BHA stability monitoring.

Rotary Steerable Systems

The specific RSS can be configured as a push-the-bit or point-the-bit, depending on the application. Drilling Engineers typically have a preference as to which type of system has performed best in their region in the past. The system typically runs in push-the-bit mode if hole wash-out is expected or higher DLS are required. When superior hole quality is desired for low-dogleg well profiles, the point-the-bit RSS will give the best results.

Non-Rotating Steering Unit

The RSS steering unit is designed with three independent, hydraulically actuated steering pads. These pads also act as an anti-rotation device to maintain the steering unit substantially stationary. Since the pads on the steering unit apply a constant force to the borehole wall, they act as a hydraulically dampened bushing to dampen vibration in the lower part of the BHA. The RSS adjusts the pad positions at the steering unit and creates a geometrical bias in the desired direction (toolface) and amount (offset) from the center of the borehole. The pad extension is measured by an accurate position sensor and is controlled by an on-board processor in a closed-loop fashion.

Automated Steering Mode

When drilling vertical or tangent sections with the system, Hold and Cruise Control Modes can be used. These steering modes are automated closed-loop functions that allow the RSS to automatically target and maintain operator-defined inclination and azimuth settings as illustrated in **Figure 1**.

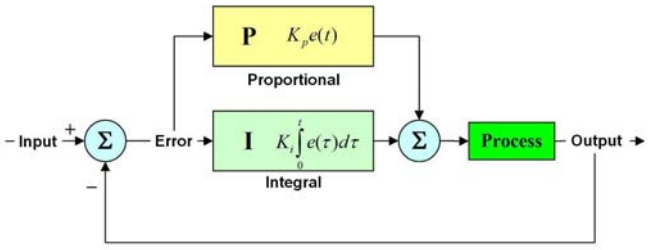

Figure 1: An example control algorithm

Actual inclination and azimuth are continuously compared against the target inclination and azimuth, and depending on the error (difference between target and actual values), programmed toolface and offset are adjusted accordingly to minimize the error in the next iteration. If the well path or drilling target positions are moved, the target inclination and azimuth values can be modified using a downlink while drilling ahead. Automated directional control is typically used in a long tangent section to reduce operator interaction and to make the system much more efficient, providing substantial savings in rig time.

RSVD – Real-Time Stick-Slip and Vibration Detection

The vibration problems associated with hole enlargement while drilling have been well documented in the past. Early detection of potential failure caused by vibration and/or stick-slip (**Figure 2**) is the design principle behind the implementation of RSVD.

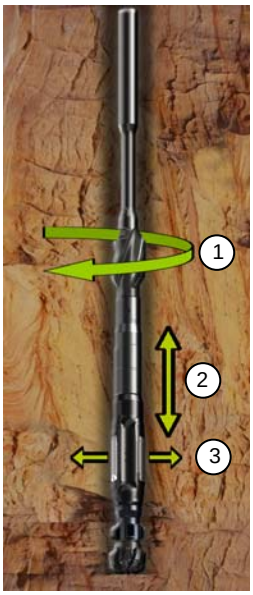

Figure 2: Typical Downhole Vibration — 1) torsional, 2) axial, and 3) lateral.

Vibration related failures can become more common on reaming while drilling BHAs simply because there are two hole sizes, and consequently two cutting structures to manage. Vibration related failures can compromise the significant cost savings that the RSS underreamer technology provides. The RSVD provides early warning of unwanted vibration and stick-slip that could potentially cause failure of BHA components, MWD/LWD and RSS. When high levels of vibration and/or stick-slip are detected, the Directional Driller can change the surface parameters to reduce vibration and/or stick-slip to acceptable levels.

RPCC – Real-Time Pad-Contact Caliper

Another unique feature of this particular RSS is a Real-time Pad-Contact Caliper (RPCC) measurement. Since the steering unit uses pad extension to measure offset from the center of the hole, the same measurements are used to calculate accurate hole caliper. Hole caliper measurements while drilling are very useful to determine borehole conditions. It is well known that reduced steering performance and DLS capability are a result of an over-gauge hole. Knowing the actual hole diameter close to the bit helps the system to maintain accurate constant curvature drilling as well as to alert the operator in real time that hole enlargement may be present in the pilot hole.

Concentric Underreamers

Three commercially available activating/de-activating concentric underreamers have been used in combination with the PathMaker RSS. The concentric underreamers were chosen because their design is inherently more stable than that of eccentric reamers. All three underreamers are hydraulically activated. Hole enlargements from 13" to 17 ½" have been performed with 12 ¼" pilot hole using the RSS. For each run, PDC bits were selected based on matching the cutting structure with the underreamer. It is well known that matching or synchronizing the cutting structures will lead to a more balanced assembly. The following section describes case histories with one particular manufacturer's concentric underreamer.

Well Results

Throughout 2006 and 2008, PathFinder has successfully used the RSS underreamer combination to drill directional wells in the Mediterranean Sea and Nile Delta (Egypt). A few examples of the case histories show the BHA configurations, formations, directional/automated control and real-time vibration/stick-slip.

Mediterranean Sea

This well (**Figure 3**) was drilled from a semi-submersible drilling rig in the Mediterranean Sea. Originally planned as a vertical well, a stuck BHA at 3968 m in the 14" section meant that the RSS underreamer had to be utilized. With a rig spread rate of $250,000 per day, the use of an RSS underreamer assembly could significantly reduce the AFE for the well, especially with the unplanned sidetrack.

A 6-blade PDC bit with 13 mm cutters and 3" passive gauge was used in combination with a 14" underreamer as shown in **Figure 4**. The BHA consisted of 12 ¼" PDC bit – 12 ¼" NB Stabilizer – RSS – Resistivity LWD – Sonic LWD - 12 1/8" String Stabilizer – MWD – 12 3/16" String Stabilizer – 14" underreamer – 8" Drill Collars.

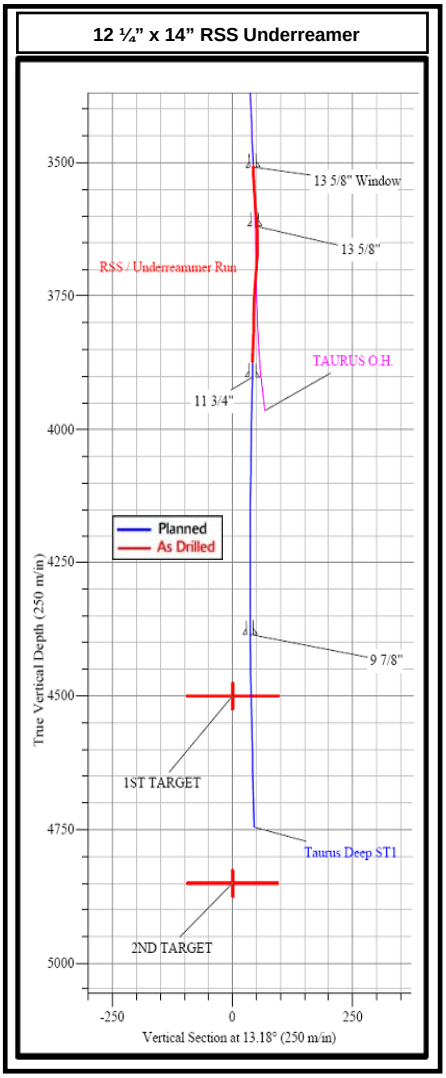

Figure 3: Comparison plot

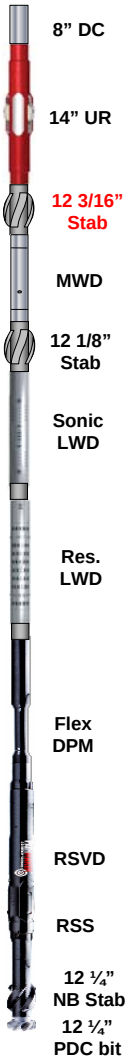

Figure 4: 12 ¼" x 14"

With the underreamer clear of the casing window, the RSS was downlinked into Steer Mode, steering on high side toolface to depart from the original hole. At a bit depth of 3615 m, the underreamer ball was dropped for activation. The assembly then commenced opening the hole to 14" from 3524 m to bottom.

Since the original hole had deviated from vertical, the well was heading in a northerly direction away from target center as shown in **Figure 5**. The PathMaker RSS was used to turn the well through 180° at low angle so that

the well was now heading in a southeast direction towards target center before the 11 ¾" casing point. A consistent DLS of 4.2°/30m (utilizing 70% deflection) was achieved through the critical section of the low-angle turn.

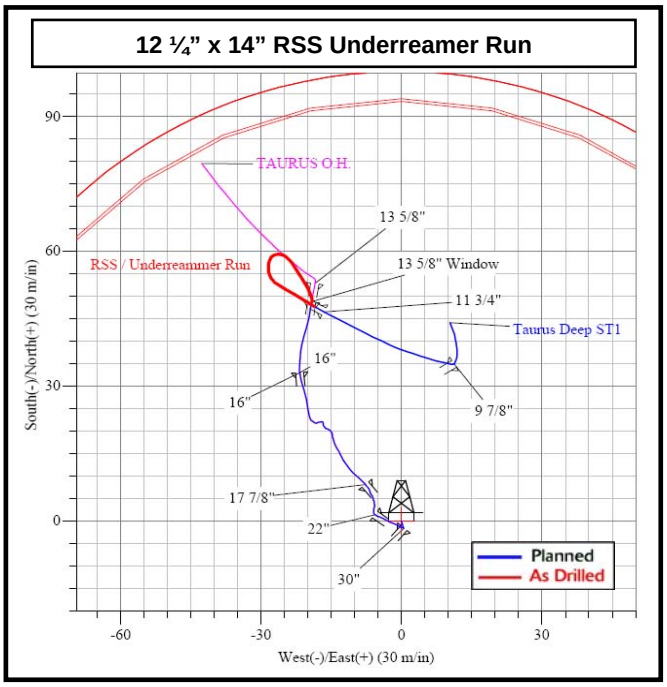

Figure 5: Comparison plot of Planned (blue) versus Actual (red) wellpath

With the well lined up on a 120° azimuth, the RSS underreamer assembly drilled in Hold Mode to maintain well angle at 4.9°. Prior to this run, this specific RSS had never been used in the Hold Mode at such a low inclination. From 3789m to 3908m (Section TD), Hold Mode maintained the inclination at 4.9° ± 0.1° and the azimuth at 122.4° ± 2° as shown in **Table 1**.

Table 1: The Hold Mode result at low hole inclination

MD (m)	Inclination (°)	Azimuth (°)	TVD (m)	Mode
3789	4.92	123.43	3787	HOLD
3819	4.84	122.40	3817	HOLD
3850	5.01	121.65	3848	HOLD
3876	4.84	120.14	3873	HOLD

While achieving all directional objectives, the on-bottom penetration rate of the 14" section through the Sadi Salem (claystone) formation was optimized to 20 m/hr, resulting in an average overall ROP of 14 m/hr.

The automated drilling mode reduced operator interaction from surface, hence saving rig time. The RSS underreamer assembly saved the operator approximately one million US dollars, by drilling 378 m of directional hole in four days while simultaneously enlarging to 14" with an underreamer.

Throughout the run, BHA lateral and axial vibration were very low while the assembly drilled through interbedded formations at varying ROP. The near-bit caliper was very steady in the pilot hole.

In this well, the use of the underreamer had no effect on the stability, steerability, drillability or durability of the PathMaker RSS. After the run, very little wear was observed on the drill bit and the underreamer. No problems were experienced running casing on this section.

Zaafaran, Egypt – Push-The-Bit

This well was drilled onshore in Zaafaran, Egypt. It was originally planned to drill the 16" hole to 1340 m and set 13 3/8" casing. The hole was drilled successfully with a steerable motor assembly, but unfortunately it was not possible to get the 13 3/8" casing past 1000 m. The casing was cemented in place at 1000 m.

Due to the 13 3/8" casing being set shallow, another hole section had to be added to the well design. The 13 3/8" casing shoe was drilled out with a 12 ¼" steerable motor assembly. The plan was to drill to 11 ¾" casing point and enlarge the hole with a designated 14 ¾" underreamer run. While drilling the 12 ¼" section the hole was accidentally sidetracked due to very soft formation. The decision was made to cement back up to the 13 3/8" shoe and drill out with an RSS underreamer assembly to enlarge the hole while drilling. **Figure 6** shows the original, accidental sidetrack and planned sidetrack well schematic.

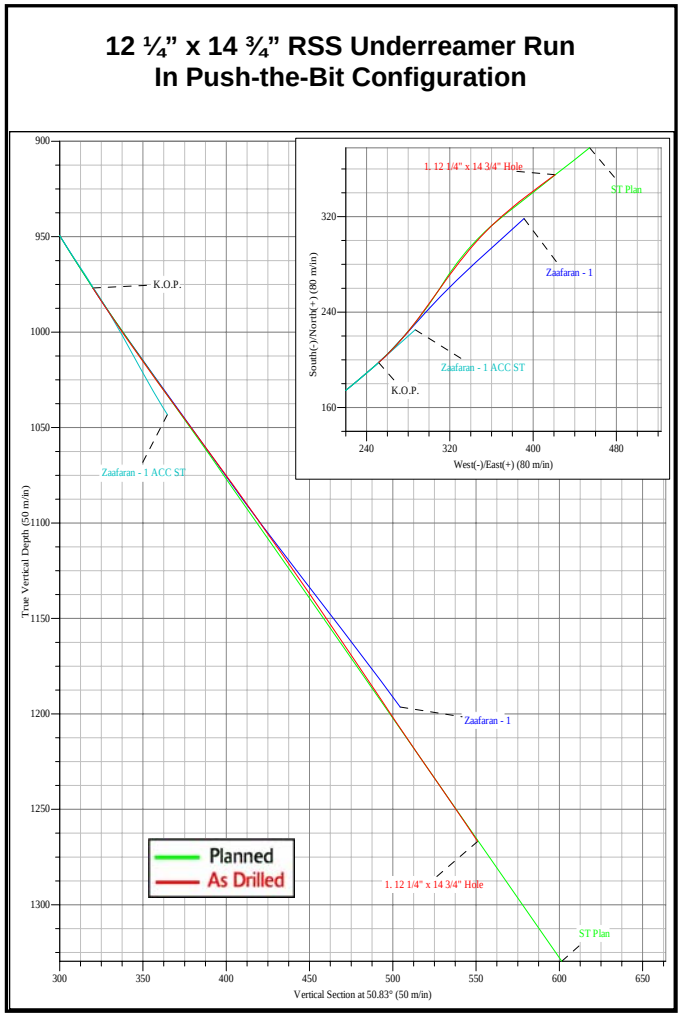

Figure 6: Comparison plot of Planned (green) versus Actual (red) wellpath.

The RSS was run in push-the-bit mode for this application due to the very soft formations expected at the start of the section. A 6-blade PDC bit with 19 mm cutters and 2" active gauge was used in combination with a 14 ¾" underreamer. This PDC bit is specifically designed for push-the-bit RSS with enhanced sidecutting capability. The underreamer was a 3-cutter block design with 13 mm PDC cutters. Each cutter block has a stabilizer section in the middle of the blade for enhanced stability and centralization. A 12 1/8" stabilizer was run directly below the underreamer to provide extra stabilization in the pilot hole. This BHA consisted of 12 ¼" PDC Bit –

Push-the-Bit RSS – Resistivity LWD – MWD – 12 1/8" String Stabilizer – 14 ¾" Underreamer – 8" Drill Collars as shown in **Figure 7**. This assembly resulted in a bit-to-underreamer spacing of 34 m.

The push-the-bit RSS and underreamer assembly was used to sidetrack the well just below the 13 3/8" casing shoe. Confirmation of the sidetrack was achieved by observing 100% formation (in the returns) and the assembly was pulled up to get the underreamer just below the 13 3/8" shoe. The underreamer was activated by dropping a ball. A torque increase from 15K ft-lbs to 22K ft-lbs was observed at surface, providing a positive indication that the reamer had activated. The RSS underreamer assembly started opening the 12 ¼" section to 14 ¾". The formation drilled was 80% sand and 20% shale.

The hole was enlarged for the first 10 m with 250 GPM then the flow rate was gradually increased to 550 GPM until reaching bottom. Concurrent directional drilling and hole opening 12 ¼" x 14 ¾" commenced, following the directional plan and reaching to the casing point at 1384 m. The tangent section was drilled in automated Hold Mode for 10.5 hours, maintaining well inclination at 40.6º as shown in **Figure 8**. Throughout the run, no stick-slip or vibration issues were encountered.

At casing point depth, the Drilling Engineers decided to continue to drill until the formation was 100% claystone. TD was called at 1460 m. Drilling parameters through the section were 10-25K WOB, 100 RPM and 500-600 GPM. An off-bottom torque of 13K ft-lbs and drilling torque of 15-18K ft-lbs were recorded through the run.

After the run, very little wear was observed on the drill bit and the underreamer. The RSS underreamer assembly avoided accidental side-tracking of the pilot hole, which occurred with the conventional 2-trip reaming method in these soft formations. This new practice enabled simultaneous drilling and hole opening while achieving all the directional objectives. Upon completion, no problems were experienced running casing through the section.

Figure 7: RSS UR

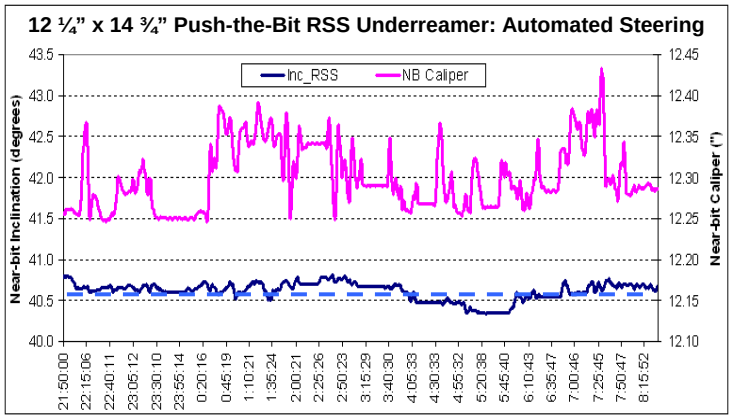

Figure 8: Automated Hold Mode was used in the tangent section at 40.6°.

Conclusion

The RSS underreamer combination has proven to be a cost-effective alternative for directional drilling while enlarging holes from 12 ¼" to 14 ¾". The combination of a point- or push-the-bit RSS and the concentric reamer in the formations described above does not generate excessive vibration that could compromise tool reliability. The RSS underreamer assembly achieved all the directional objectives while providing excellent borehole quality, which meant that all casings were run to bottom the first time. The successful case histories have delivered the following conclusions:

- Optimizing the specific RSS BHA configuration with the correct stabilization and underreamer placement resulted in minimal vibration while drilling, reaming and back-reaming.
- The RSS underreamer run avoids accidental side-tracking of the pilot hole, which could occur with conventional hole opening operations, especially in soft formations.
- The unique steering mechanism on this RSS aids in BHA stability resulting in several wells that have been drilled without vibration or vibration-related failures at the MWD/LWD and RSS.
- Automated Cruise Control and Hold Mode reduces operator interaction from surface and minimizes the tortuosity of the borehole, delivering a high-quality LWD log to the customer.
- The Real-time Stick-slip and Vibration Detection feature alerts the RSS operator to harmful downhole vibrations while drilling with the RSS underreamer assembly.
- Real-time near-bit caliper aids the Directional Driller in ensuring that DLS results are predictable and consistent.

Enlarging the borehole from 12 ¼" to 14 ¾" in one run with a combination of the specific RSS and an underreamer is an economical solution to all directional wells that require hole opening. Performance success has been observed in a variety of hole sizes and hole-opening applications internationally, including North America, Africa, and Europe.

Acknowledgments

The authors would like to thank different operating companies for their willingness to publish this data obtained with the 12 ¼"-hole-size PathMaker® RSS. We are grateful to PathFinder Energy Services for permitting the publication of this work.

Nomenclature

AFE	=	Authorization For Expenditure
BHA	=	Bottom Hole Assembly
DC	=	Drill Collar
DLS	=	Dogleg Severity (degrees per 100 feet)
DPM	=	Dynamic Pressure Module
GPM	=	Gallons Per Minute
LWD	=	Logging While Drilling
MD	=	Measured Depth
MWD	=	Measurement While Drilling
NB	=	Near Bit
PDC	=	Polycrystalline Diamond Compact
ROP	=	Drilling Rate Of Penetration
RPM	=	Revolutions Per Minute
RS	=	Rotary Steerable
RSS	=	Rotary Steerable System
RSVD	=	Real-time Stick-slip and Vibration Detection
SS%	=	Stick-slip Severity in Percentage
Stab	=	Stabilizer
TD	=	Target Depth
TVD	=	True Vertical Depth
UR	=	Underreamer
WOB	=	Weight On Bit