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Rotary Steerable Drilling Systems Enable Single Trip runs for Larger Hole

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Abstract

Rotary steerable systems can be used for both vertical and directional drilling in hole sizes from 5 ¾” to 18 ¼”. The versatility of rotary steerable is being used to minimize trips, reduce BHA changes and markedly increase overall rates of penetration. In deepwater wells, rotary steerable technology is now one of the keys to achieve technical drilling limits.

This paper will address the specific application in deepwater wells where rotary steerable BHAs are used to kick off from vertical in larger hole sizes. In many cases, a complete hole size section is drilled in one run by combining shoe drill out, vertical drilling, build and tangent sections resulting is significant savings over conventional slide drilling. Some examples will be presented including the operational parameters achieved using the Schlumberger rotary steerable system. Benefits and implications to well design will be discussed.

Introduction

Rotary steerable systems have provided a step change [(1)] in directional drilling performance both by extending wellbore reach and by reducing drill time through improving on bottom efficiency. Exploitation of rotary steerable systems has been most common in high cost environments and especially in deepwater directional and horizontal wells. In 2002, with advent of larger rotary steerable systems for hole sizes up to 18 ¼”, a trend of using rotary steerable for surface holes has evolved resulting in time savings over conventional motor drilling. This paper will focus in on the bit sizes from 14 ¼” to 18 ¼” which are often used deepwater surface holes below 16”, 18 5/8” or 20” casing strings.

Technical limit drilling operation seeks the fastest possible sequence of events on the critical path of operations. Surface hole, depending on well design, can involve up to four distinct operations which are drilling out the conductor shoe, drilling vertical hole, kicking off from vertical at acceptable build rates and then drilling a smooth tangent section to surface casing seat depth. A general premise is that deepwater large hole optimization should aim at drilling each hole size in a single run and that rotary steerable tools are uniquely suited to this task.

The improvement to overall ROP of rotary steerable tools compared to conventional directional drilling with bent housing motors is well established. Efficiency improvements come both from avoiding the time wasted orienting and sliding of conventional steerable assemblies and from improving instantaneous ROP. This paper will evaluate some of the other considerations which make rotary steerable systems economic in large diameter directional wellbores and which also reduce the risk to drilling.

Rotary Steerable tool general description

Rotary steerable systems for the bit sizes listed are provides by several companies. Comments in this paper will be limited to experience gained with the Schlumberger push the bit type rotary drilling systems designated as PowerDrive and PowerDrive Xtra. Bit diameter used with each size of rotary steerable tool is given as follows:

Bit Diameter	Tool Designation	Flow Rate
12 ¼” – 14 ¾”	PD 900	480 – 1900 gpm
14 ¼” – 18 ¼”	PD1100	480 – 1900 gpm

Steering commands are given to the tool via a sequence of pump rate changes. The optional Xtra series provide a link from the rotary steerable tool to the MWD so that real time drilling data can be used to monitor shocks and vibrations near the bit. In addition, real time data provides directional feedback closer to the bit.

A sample of a large diameter BHA is given if Figure 1. The BHA incorporates a PDC bit, rotary steerable tool, MWD, LWD tools, and traditional drill collars and drill pipe.

Drilling out shoe with rotary steerable

The first requirement in achieving single run performance for a hole size is the ability to drill the shoe track of the last casing set. Although a complete set of worldwide statistics on shoe drill out were not readily available, several 16” and 20 shoes have been drilled out with a combination of PDC bits and Schlumberger rotary steerable tools. The few problems experienced are mainly due to damaged bit cutters or very high shocks encountered while drilling out leading to MWD or other down hole tool failure.

To drill out the shoe track, the rotary steering tool is put the neutral mode that does not provide any directional bias. Precautions must be taken, the same as standard rotary assemblies to ensure that the bit is not damaged while drilling up float equipment. In general, because the assemblies do not have offset which produce wobble, it is felt that less bit damage should occur than when using tight tolerance bent housing motors.

The caveat for economic use of rotary steerable systems in the casing shoe track is that there should be a high probability of attaining the desired FLOT or PIT. If the casing shoe must subsequently be cement squeezed, the rotary steerable BHA may not be the ideal choice. In extreme circumstance and in ER wells, cement plugs have been successfully set with rotary steerable assemblies, however this is not expected to be a normal occurrence.

Vertical Drilling

A deepwater wellbore may then require some distance of vertical wellbore beneath the surface shoe until kick off point is reached. Depending on anticollision or other well design requirements, there may also be a need to actively steer to keep vertical. The requirement of keeping a well vertical is very efficiently accomplished since the Schlumberger rotary steerable system has proven ability to maintain vertical hole through closed loop steering control. The system works by comparing information in the tool's accelerometers and giving the bias commands to drill to the low side of the hole. Experience to date is that large diameter holes can be kept under 0.25° inclination.

The alternative in traditional rotary drilling is to use a pendulum assembly such that when WOB is reduced, there is a restoring force on the bit that will bring the wellbore back towards vertical. Since rotary steerable does not need to reduce WOB to actively steer to vertical, an increase in ROP can result in cases when vertical hole is required and where there is a formation tendency to produce wellbore deviation.

Using the rotary steerable tool for large hole vertical drilling has also proven extremely successful in salt drilling in the Gulf of Mexico. In one well, a 6132 ft section of 18 ¼" hole was drilled vertical through salt with only 3.2 ft of horizontal displacement from start to finish [(2)].

A further benefit of large diameter rotary steerable systems is seen where a slight nudge correction is required for anticollion purposes or shallow hazard avoidance. The rotary steerable systems have the ability to quickly perform a small nudge and then bring the well back to vertical. Another advantage is that the rotary steerable can hold a low tangent angle (a near vertical situation) easier than a bent housing motor assembly producing a smoother, faster wellbore.

Kick off from vertical

The next key to an efficient one trip BHA in the larger hole sizes is the ability to build smoothly at the planned rates. The experience has been very positive in both harder (salt) and softer (shale/sand) geologies. Build rates of 4°/100 ft in 17 ½" – 18 ¼" bit size and 5°/100 ft in 14 ½" – 14 ¾" bit sizes have been reliably achieved. Flex collars may be required to achieve the higher build rates. In most cases the requirement of well design DLS is for less build than is available with the rotary steerable tools.

To produce a reliable kick off from vertical in the desired direction, the Schlumberger system first uses magnetic azimuth readings from magnetometers to control bit direction while building from 0 to 5° inclination. The reason magnetic reference is preferred is that gravity reference to the high side of the hole at low inclination cannot precisely determine azimuth kick off. Once 5° inclination is achieved and kick off azimuth is well established, the steering control of the tool is then switched to accelerometers that reference relative to high side of the hole.

In soft formations, care must be taken not to program flow rates and bit nozzles that may cause excess erosion of the wall diameter. Flow mud rates should be kept to a minimum as needed for hole cleaning purpose yet maximized so that control drilling is not needed. Requirements will vary per area and local geology. In the Gulf of Mexico deepwater a general flow rate for 17 ½" – 18 ¾" is in the 1000 - 1450 gpm range and for 14 ¼" – 14 ¾" is in the 800 - 1000 gpm range.

If flow rates are a concern for hole cleaning, there is an option to add an upjet flow sub to split flow such that bit washout is kept to a minimum and adequate weight is maintained on the bit. Once flow rate and mud system combination is cleaning the hole, the rotary steerable systems can make excellent ROP at lower WOB.

Rotary steerables have performed well in unconsolidated formations. In a recent well offshore Canada, a PD1100 with 17 ½" DS69 PDC bit was run in a water base system and was able to maintain a build through an unconsolidated sand whereas the 5 previous runs with bent housing motors were unable to build and had actually lost inclination.

Kick off from vertical has been done in both water base systems and oil base systems. In a review of Gulf of Mexico mud systems used by operators in 14 ½” – 18 ½” hole the majority of wells used synthetic oil base muds but there were also some water base muds including salt saturated and a couple with seawater/sweeps. Oil base muds often give better hole condition and are therefore preferred from a drilling standpoint, but waterbase mud is often beneficial from both a cost/unit basis and on an environmental basis. When using water base mud in clay sections it is recommended to maximize flow rate, and therefore bit HSI, to prevent bit balling.

In general, kick off in large diameter has been successful in achieving planned build rates but there have be disappointments. The type of problems attributed have been:

- Failure to build angle at required rate
- Miscleanous failures of MWD
- Miscellaneous failure of Rotary steerable tools.

Active investigation and diagnosis of any failures is contributing to more reliable systems.

Drill Tangent section

The final requirement of a BHA in a single run scenario is to drill some sort of a tangent section. It may only be a 100 ft tangent for casing shoe or a high inclination tangent of several thousand feet. Again, rotary steerable systems have proven extremely adept at meeting the drilling requirements for tangents. An increase in overall ROP is generally seen when compared to bent housing motor assemblies because no time is needed to orient and slide for inclination corrections. An additional benefit is that wellbores also tend to be smoother than ones drilled with slide drilling techniques that create micro doglegs from multiple slide/rotate sequence.

The rotary assemblies have additional performance differential if the tangent hold angle is less than 15° inclination since lower angle become increasing harder to hold with bent housing assemblies. Also, when using higher tangent angles superior hole cleaning is achieved by continuous rotating of drill string which reduces risk of hole problems.

Bit selection

The ability to drill a single hole size in one BHA will increase the demands in drill bit selection. A balance must be struck between a large junk slot area beneficial in drilling out the shoe plus anti balling and the bit life considerations of cutter density sufficient, blade count and cutter size and type. Depending of formation, we have been able to utilize bits with larger PDC cutter size because torque related steerability issues while sliding do not come into play. Results of using larger cutters often result in larger overall ROP.

Of particular importance is the gauge geometry and ability of bit for side cutting. Where majority of wellbore will require building or high build rates are needed, the bit side cutting should be maximized. Where the build section uses moderate DLS and is then followed by a long tangent, a less aggressive side cutting tendency may benefit to drilling the tangent. Lateral stability, bit length and integration with the steering mechanism of the rotary steerable system should be also considered.

Tricone bits can also be used where bit life and field conditions warrant. Tricone bits suitable for use on motors are recommended for rotary steerable systems.

Failure risk can be reduced and bit life extended by real time monitoring for adverse drilling conditions. The Schlumberger rotary system has the option of sending accelerometer output directly from the rotary steerable tool via link with the MWD. This allows better identification of drilling shocks and excess lateral vibrations and aids in selecting drilling parameters for best performance. Active rig site interpretation of this data is required to make timely changes.

Underreamers

A frequent requirement for a one run does all BHA, especially in deepwater wells with multiple casing strings, is the need for hole enlargement beyond drift of the surface casing string. This task is accomplished through the use of underreamers positioned in BHA somewhere above the rotary steerable tools. Bicenter bits are not used with the PD900 and PD1100 as they will compromise the steering ability of the tools. Also, it should be noted that drilling with underreamers is not a viable option for conventional slide drilling because hole enlargement will not occur while sliding.

Underreamers with rotary steerable systems have had a good history with the experience in the following sizes used in the Gulf of Mexico on the jobs reviewed:

- 12 ¼” bit x 14” UR
- 14 ½” bit x 16” UR
- 14 ½” bit x 17” UR
- 14 ½” bit x 18 ¼” UR
- 18 ¼” bit x 20” UR
- 17 ½” bit x 24” UR
- 18 ¼” bit x 26” UR

Underreamers have been used both with nozzles and without nozzles. Underreamers with nozzles normally allow higher overall flow rates for better hole cleaning. Particular attention must be paid to the flow split and pressure drop between the bit and underreamer. One operating constraint is that pressure differential across the bit should be from 600 – 800 psi range for efficient operation of the rotary steerable tools. With proper pre planning this can be achieved.

Rotary steerable BHA incorporating underreamers have been successfully used for drill out of casing shoes. Coordination with underreamer manufacturer should ensure tool is not activated until below the shoe.

Another important observation from field experience is that underreamers seem to have little or no effect on the steerability of the rotary steerable system.

Motors for Additional RPM
In 12 ¼” bit sizes and smaller, there are many examples of placing a positive displacement motor above a rotary steerable system to generate higher bit rpm. However, for bit sizes 14 ½” to 18 ¼”, use of a motor above the rotary steerable tool is not well established.

Well Design Recommendations
A brief discussion is given below on some pertinent design considerations for deepwater wells where rotary steerable may improve performance. Build rates, as previously discussed, should be a maximum of 4°/100 ft for 17 ½” -18 ¼” hole and under 5°/100 ft for 14 ½” to 16” bit sizes. Figure 2 is an example of a well profile with a 17 ½” that contains a vertical section, kick off from vertical and high inclination tangent section.

Well collision risks are often a concern in development drilling from multiple well templates. Rotary steerable assemblies can first be used to maintain precisely vertical upper hole sections where collision risk is generally higher. When nudges are required for anticollion purposes they can readily be done. Rotary steerable assemblies also give the directional driller the advantage in that at low tangent angle in softer and unconsolidated formations can be more reliably maintained than with a bent housing motor assembly.

KOP can be positioned as best fits structure development, anticollision requirements or risk reduction philosophy. Since lower tangent angle can be efficiently drilled with RSS in larger diameter holes, a KOP can be designed higher in a well where required. Also, if unconsolidated formations will be encountered, the rotary steerable systems can provide a reliable way to maintain inclination.

On extended reach (ER) wells or very deep directional wells, use of rotary steerable in the upper hole section should strongly be considered to minimize doglegs. The rotary steerable will produce smoother build than a bent housing motor doing slide/rotate sequences and therefore minimizing side forces and reducing casing wear and torque and drag magnitude. If an incremental variable build profile (build rate increases with depth) is required for torque reduction, the rotary steerable BHA can also reliably drill.

Use of larger diameter rotary steerable in ER or deep directional wells gives the ability to set larger casing strings at deeper depths. This larger casing may in turn enable larger production tubing if required for increased production potential.

Alternately, cost savings may be entertained by slimming wellbore design. The increased reliability of achieving directional targets with rotary steerable systems should encourage well designers to drop a casing string and reduce the need for a contingency string.

Conclusions
The trend in deepwater wells towards using larger rotary steerable systems for bits sizes from 14 ½” to 18 ¼” is emerging. The rotary steerable systems are a key enabling strategy to reach the technical limit goal of completing each hole size with one BHA run. Benefits are seen both in vertical and directional drilling. Rotary steerable BHAs in the above bit sizes have been able to complete single runs involving drilling out of casing shoe, vertical drilling, kick off from vertical, build to a tangent angle and drilling tangent wells. In addition, underreamers have been incorporated for final hole sizes as large as 26” giving the well designer a valuable option in the upper well of selecting trajectories to minimize collision risk and reduce torque and drag in the lower wellbore.

All these benefits are in addition to a general overall increase in directional drilling ROP compared to bent housing positive displacement motors. Therefore, in deepwater wells, well designers should strongly rotary steerable systems for the upper hole in directional wells. Rotary steerable systems are becoming the BHA of first choice where well design is driven by technical limit optimization.

Nomenclature
Define symbols used in the text here unless they are explained in the body of the text.

BHA = bottomhole assembly
DLS = Dog leg severity
ER = Extended Reach
FLOT = Fluid leak off test
HSI = Hydraulic Horsepower per square inch
KOP = Kick off Point
LWD = Logging while drilling
MWD = Measurement while drilling
PDC = Polycrystalline Diamond Compact
PIT = Pressure integrity test

ROP = drilling rate of penetration
rpm = revolutions per minute
RSS = Rotary Steerable System
TD=total depth
TVD=true vertical depth
UR = Underreamer
WOB = weight on bit
Xtra = Schlumberger trade name designating ability to transmit real time drilling data from the rotary steerable tool to the MWD.

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References

1. Charlie Pratten, "Rotary Steerable Systems in the Gulf of Mexico – A Step Change in Drilling Performance", AADE Paper number AADE 01-NC-HO-22, presented at the AADE 2001National Drilling Conference, Houston, Texas, March 27-29, 2001.
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Figure 1 - Sample BHA - PD 1100 Tool + Xtra + 17 ½" BIT

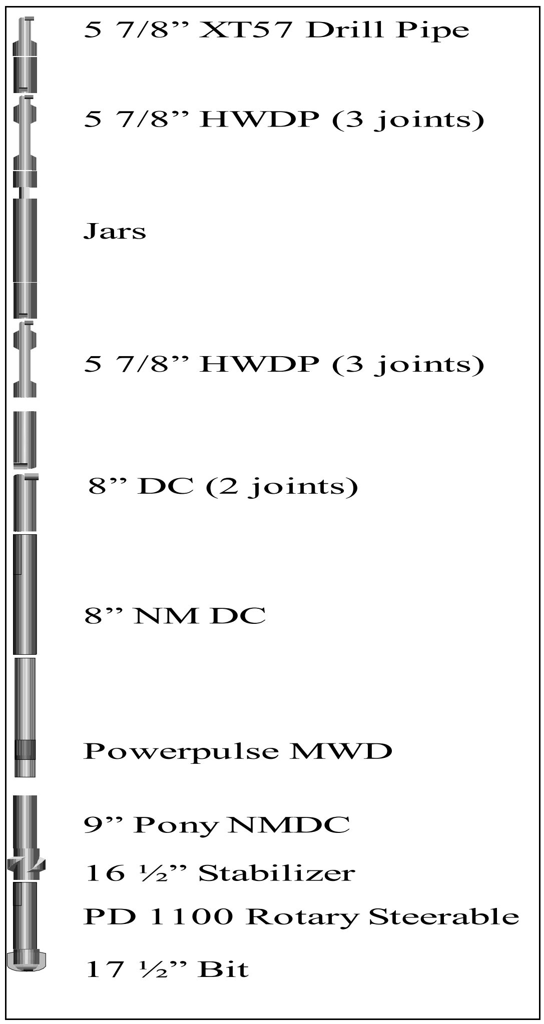

Figure 2 - Sample well trajectory – Vertical, Build and Hold in 17 ½" Hole size