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Automated steering systems applied to complex horizontal well in South Italy

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ABSTRACT

Automated directional drilling systems were amongst the key deliverables in a recently concluded joint development program between an oil company and an oilfield service provider. The two automated directional drilling systems as developed in the project have a certain degree of commonalty, however, there are also major differences in the way they work. The field experience described here was the first opportunity to run both tools together in the same well. Each of them was able to demonstrate it's specific and unique capabilities. The drilling strategy for Monte Enoc 9 required the use of a straighthole drilling system, SDD, in the upper hole sections and the rotary steering system, AutoTrak, in the 8 1/2" hole size. By synergistically using the new automated tools, Monte Enoc 9 was drilled in a much more efficiently than offset wells, producing substantial time savings, a smoother hole trajectory, and less friction. The concluding ***6***" hole section of the well could be drilled and steered in a much easier fashion than expected because of the good conditions created in the vertical and curved hole sections. The drilling strategy as practised in ME9OR will be further optiinised to allow for even greater savings.

KEYWORDS

Directional drilling, drilling technology, automated drilling tools, oil well, Italy

Introduction

Improving the efficiency of the drilling process will cause a substantial reduction in capital expenditure for an oil company through the time savings alone. One additional goal in many cases is to improve the quality of the bore hole trajectory, thereby saving even more time and reducing the **risk** of catastrophic failures with bottom hole assemblies. As will be outlined in more detail below, the Monte Enoc 9 OR well was planned and drilled in a revolutionary way, that with a high probability that it will change the method of deepening wells in a whole geographical area.

This new concept of drilling could only become a reality because of the excellent results achieved in a joint development project between a major oil company and a service company. Through providing a breakthrough technology in directional steering systems the accuracy of borehole steering has been considerably improved. Moreover the improved quality of the wellbore in a geologically complex set of formations as found in the Val d'Agri. The complete range of different automated directional drilling systems which were used together in a well for the first time, Monte Enoc 9 OR, will be described below.

Automated drilling tools

Within a joint development project, "Ultra Deep Horizontal Drilling'' (UDHD), between the two companies, very different novel drilling technology was developed and brought to the market. Most importantly two automatic drilling systems resulted from this effort, namely the Straighthole Drilling Device (SDD) and the Autotrak™ Rotary Closed Loop System. Both systems, the technical functionality of which are characterised below, have seen their first combined field application on the Monte Enoc cluster in the Val D'Agri area of Southern Italy. In this environment the tools were part of an innovative development drilling strategy. The main concept was to produce the upper hole sections as straight and vertical as possible. This was in order to reduce to a minimum the torque and drag effects later in the well. The positive outcome of such strategy would be to provide the optimal environment for drilling the deeper sections of the well, which in this case had to be horizontal. The following is a description of the above drillings systems as utilised on the Monte Enoc Cluster.

Straighthole Drilling Device (SDD)

A straight top hole section in many cases is a strict requirement to be able to drill deeper hole sections with complex well trajectories. Especially when geological forces tend to deviate the wellbore's course, and if the hole stability is a risk, drilling of a straight surface sections of the hole becomes a must. Conventionally, this will be achieved with steerable motor systems requiring frequent changes between sliding and rotary mode. The SDD has been developed as a fully automated instrumented downhole motor with integral expandable ribs. Through permanent steering, a vertical well path is generated without any supervision required from the surface operator.

FUNCTIONAL CONCEPT OF SDD

The SDD basically represents a downhole motor with a modified bearing assembly, housing computerised instrumentation, plus a hydraulic system. A hydraulically controlled variable-gauge stabiliser maintains the inclination, and a mud-pulse system transmits directional data back to surface. For corrective steering, the SDD is operated in the sliding mode. If not in the steering mode rotation from the surface is possible.

Upon any deviation from the vertical, a compensating command is generated. Hydraulic forces are then selectively applied to one or more of the expandable ribs in a fully automated down hole based process. This correcting force will work in the required tool face direction as long as the deviation from the vertical is measured. If the borehole is vertical when running in hole, the tool will maintain that course. The drop rate of the SDD is controlled by the relative position of the bit, expandable stabiliser, upper stabiliser and the-eccentricity of the steering ribs. By moving the position of the upper string stabiliser before running the BHA down hole, the actual drop rate of the tool can be influenced.

In case of the 16" hole section, when positioning a 15 3/4" stabiliser directly above the tool, the SDD will drop at a rate of approximately 0.8 °/10 m. One additional feature that has been established very recently with the SDD is the ability to disable the hydraulic power steerable ribs on command from the surface. Through variations of flow rate a simple and reliable method was introduced that allowed the deactivation of the hydraulic pressure build up in the steerable stabiliser whenever desired. Such situation may occur if extensive reaming or working up and down of the drill string is anticipated under full circulation and/or rotation of the BHA. As long as the tool is operated in the "ribs off" mode, the stabiliser pads will retract, thereby providing a ininimised undergauge diameter of the steerable stabiliser.

BENEFITS WITH SDD

The proved benefits of the SDD are:

- Reduced friction and torque during drilling
- Improved penetration rates
- Improved hole stability
- Better wellbore course control
- Less efforts and risk whilst running casing.

These features make this tool particularly useful in specific operating conditions where the existing technology to maintain the vertical direction (i.e., steering or stiff assemblies) has the drawback of limited ROP and poor final hole quality.

The SDD is also the basis for the reduction of the annular clearance between casing and open hole, which leads to a slimmer well profile called the "lean profile", which is described in the following paragraphs.

AutoTrak™ Rotary Closed Loop System

The AutoTrak™ Rotary Closed Loop Drilling System was developed with the main objectives of providing a Directional Drilling Rotary System with steering efficiency, easing cuttings removal and a providing enhanced hole quality. In order too achieve this, the following most important functional criteria were set for the AutoTrak system: Ability to change hole direction without stopping the drill string rotation, integrated tool design, eliminating both conventional MWD and Mud Motors, provide a surface-to-tool and tool-to-surface communication and ability to change direction ftom the surface on the basis of real-time downhole information without pulling the Bottom Hole assembly to make changes.

FUNCTIONAL CONCEPT OF AUTOTRAK

The details of the tool function and design characteristics are summarised as follows. A non-rotating steering sleeve that is uncoupled from the rotating drive on the tool, controls hole inclination and azimuth as the drill string rotates. The near bit inclinometer, control electronics and control valves which are located inside the steering sleeve. The steering direction is defined by the selective distribution of hydraulic pressures to each of the three expandable steering pads, producing a force vector against the hole wall. In controlling the eccentricity of the steering sleeve, the RCLS maintains the force vector needed to steer the BHA along the planned wellbore trajectory.

Dogleg severity is determined by the resultant amount of hydraulic pressure on the pads. This force vector is adjusted by a combination of downhole electronic control and commands pulsed hydraulically ftom the surface. Deviations ftom the programmed inclination are automatically compensated for and controlled through a downhole closed loop. New commands to adjust the wellpath can be downlinked without interrupting the drilling progress.

Real time inclination at-bit sensors, gamma ray, and Multiple Propagation Resistivity measurements close to bit, give the tool enhanced geosteering capabilities. In addition, standard directional measurements which are transmitted to surface real time following pipe connections (Toolface, Azimuth and Inclination).

The system can be set to two different steering modes while drilling:

- "Hold mode", which is associated with three parameters: Build or drop force, left or right walk force, and target inclination. When the programmed inclination is reached the system will automatically enter into a hold position to maintain the objective until programmed to do otherwise. The programmed build or drop force will control the dogleg severity until the desired inclination is reached. A walk compensation force can be set in order to counteract formation or BHA influences on azimuth hold, or for the purpose of turning laterally. Build/drop and walk forces can be applied simultaneously.
- "Steer mode", which is an alternative method of steering the wellpath by programming the steering force and steering direction, i.e. the steering vector. This is a way to navigate wellpaths more similar to the conventional steerable motor.

BENEFITS WITH AUTOTRAK

Even on conventional wells the benefits of a tool capable of steering while rotating are immense, and in some cases wells with challenging profiles may only be made possible with a rotary steerable system. Conventional slide-drilling rates of penetration are generally 40% less than those achieved during rotary drilling, so a rotary steering system can deliver substantially higher overall ROP than conventional steerable systems that require slide-drilling during wellbore course corrections. By eliminating the necessity to steer by orienting and sliding, drag on the drillstring can be significantly reduced. This allows a more constant application of WOB, reduces axial shock and vibration, and improves overall drilling dynamics.

Studies have shown that drillstring rotation helps keep cuttings suspended, positively effecting hole cleaning and minimising drillpipe-to-borehole friction. This results in fewer wiper trips and circulating operations, fewer stuck pipe incidents, fewer washout conditions and a lower, more constant ECD (Equivalent Circulating Density). In conventional directional drilling, bit selection is often dictated by the need to slide drill, usually this results in a choice of a less aggressive PDC bit, hence reducing ROP, or in the worst case, a roller cone bit, increasing the number of bit trips required.

A steering while rotating tool has two main features:

- A steering unit that can control the wellpath trajectory during drill string rotation. The ability to change the wellpath trajectory by either following a wellpath pre-programmed at surface on an internal downhole closed loop or by following the planned wellpath as directed by surface-to-downhole commands (in this case a surface-to-downhole closed loop). Based on these features, a steering while rotating tool is referred to as a Rotary Closed Loop System [RCLS].
- The second main feature of a RCLS is the ability to automatically control the wellpath independently of the drilling process. A basic RCLS without depth tracking will follow the wellpath programmed at surface and must be pulled to adjust for any wellpath corrections. To allow for a greater influence fiom surface, a communication from surface to downhole -the so called downlink- is required. The AutoTrak responds to a flow rate variation process at surface where the binary code embedded in higher and lower flowrates is decoded by the downhole tool. For basic steering, the steering direction and the build up rate (the magnitude of the steering force) will be transmitted downhole. As a further step, specific sections of the wellpath will in the future be transmitted from surface.

The Lean Profile well

The "Lean Profile" concept has been specifically identified and established by ENI-AGIP to support their demand of drilling clustered wells under difficult geological conditions. This application is very important to the Val d'Agri location in the South of Italy, where there are extreme difficulties in controlling the verticality of bore holes using the conventional drilling techniques. As will be shown later in this paper, this novel concept of drilling wells is heavily dependent upon the availability of drilling systems that can deliver a straight, vertical, borehole trajectory.

The "Lean Profile" concept

In the meaning of the word "lean" lies at the heart of the application of this innovative drilling technique. Referred to an operation, lean means economical, wherever if referred to something, it means cut to the bone, or if you like, reduced to the essential.

In our case, where the "lean" term is applied to a well, the "Lean Profile" is practically a redefinition of the well profile that is based on a drastic reduction of the existing annular clearance between casing and borehole wall. This leads to a "slimmer" casing profile hence providing for a reduction of the drilling CAPEX, as a result of a series of beneficial effects. Obviously, it is intended that all this is to be achieved without jeopardising safety and performance.

The application of the lean concept is then based on the following requirements:

- Absolute control of well vertical trajectory, achieved with a drilling system like the SDD.
- Use of flush (or near-flush) casing joint connections, because of the very small clearances between casing and open hole.

Drilling and completion experience from Monte Alpi cluster

The development well Monte Enoc 9 OR was located in the Monte Enoc NW1 Concession (Southern Apennine, Province of Potenza), in the Val d'Agri area in Southern Italy. The oil target was identified in the carbonates of the inner Piattaforma Apula layer.

Correlation wells considered for the drilling plan were Monte Enoc 1 and Monte Enoc NW1; therefore the expected stratigraphy from top to bottom was: Unita' Irpine (Langhian-Tortonian) to about 500 m, Unita' Lagonegresi (Trias-Lower Cretaceous) to about 2,500 m, Unita' Irpine (Miocene) to about 3,100 m and Piattaforma Apula (Lower Pliocene: siliciclastic and Upper Cretaceous: carbonates from about 3,900 m). Planned T.D. for ME 9 OR was prognosed at 3,662 m TVD (4,790 m of measured depth).

In the whole area, as was discovered with these offset wells, has a tendency to deviate due to formation dips, especially within the upper and medium depth zones. In addition there are typically severe formation stability problems occurring.

Drilling the Monte Enoc 9 OR

ME 9 OR was planned as one of three wells within a cluster site. The Monte Alpi cluster is composed by Monte Enoc NW1, Monte Enoc 2 and Monte Enoc 9 OR, the last two being horizontal wells. The cluster was planned to develop the lean profile concept in conjunction with the clusterization proposal. An absolute requirement for being able to drill a lean profile is the ability to avoid any collision of neighbouring wells, or at least quantify and then minimise the risk of collision. Therefore in advance of the planning for the cluster a theoretical investigation was made to evaluate the probability of collision between the wells in the upper, straight and vertical, section of well. All investigations was based on existing information about the performance capabilities of the SDD. The mathematical-statistical analysis has shown the collision risk to be low even with the worst case assumptions if the wells are drilled using an SDD system. According to the mathematics the recommended distance between the spud points is **5** m or more.

In reality then the decision was made to place the three wells only 8 m depart from each other. Of course under these circumstance a very precise steering in the upper hole sections of ME 9 OR was easily identified as being mandatory.

In order to achieve the challenging directional and hole stability goals, the innovative drilling/steering systems SDD and AutoTrak as developed in the UDHD project were applied in ME 9 OR.. The SDD (Straighthole Drilling Device) was used in the 16" (later opened to 23"), 17 1/2" and 14 3/4" hole sections to maintain the hole vertical, and to conserve the wellbore stability. At the beginning of the 12 1/4" phase directional only MWD service was started. This was then complemented with MPR (Multiple Propagation Resistivity), which provides eight quantitative resistivities and a gamma measurement.

Then in the 8 1/2" phase the AutoTrak tool was used to provide automatic steering and a smooth well path. This tool incorporated an RNT (Reservoir Navigation Tool) sub which provided four compensated resistivity curves and a dual gamma ray detector. The AutoTrak technology has already been described earlier in this article. After a 7" liner had been set, a 6" diameter hole was continued with conventional steerable motor and MWD technology to 5,069 m. Because a logging tool became stuck after the original hole was finished, a sidetrack had finally to be made with the AutoTrak tool in order to bypass the fish.

OPERATION AND PERFORMANCE OF SDD

In order to utilise the innovative "lean profile" drilling technique for the first time, the upper sections of the ME 9 OR were drilled with the Straighthole Drilling Device, SDD. More specifically a total of 13 runs were made using three sizes of SDD tools.

The operation started with the first section of hole drilled from 39 m to 413 m (SDD used to 346 m) in the 16" diameter hole section. The first BHA drilled out of the shoe in rotary mode, because this revised design of SDD allows the closing of the blades on command from the surface. The drilling then commenced with the system being operated in the sliding mode, where an inclination of 0.75 degree was gently corrected to the vertical at 128 m. The ROP was 15-20 m/hr. After drilling 152 m the tool failed to transmit from down hole and it was replaced with the back up system. It kept the borehole vertical to a depth of 346 m, when at this depth the hole developed total losses and eventually the BHA got stuck. It was necessary to perform a back off and thereon fish some equipment. Subsequent runs to the end of the phase, did not involve the use of the SDD. The 16" phase finished at 413 m and the hole was then open to 22" to 411 m and cased to 410 m.

SDD for the 14 3/4" size then drilled out the 16" casing shoe in rotary mode, i.e., with all four ribs retracted by command from the surface. Drilled commenced in sliding mode from 1,497 m. The inclination was initially 0.25 degree., but by 1,512 m the SDD tool had brought the inclination to vertical (0.0 degree.). The inclination remained at 0.0 degree to the end of the run, at 1,760m. In the following run SDD drilled ahead in sliding mode all the way to 1,931 m, which was the casing point. The inclination was kept at 0 degree all the time. ROP was in the range of 5-6 m/hr.

The very high precision of achieved with SDD in terms of well path accuracy can clearly be demonstrated by comparing the horizontal deviations from the starting point between ME 9 OR (with SDD) and offset wells ME 2 OR and ME NW 1. The application of SDD in the Monte Alpi Cluster, and specifically in Monte Enoc 9 OR, can serve as a clear proof of the economic viability of the "natural coherence" of the "Lean Drilling Concept" and the use of the "Straighthole Drilling Device". The time vs. depth graph for the Monte Enoc cluster, clearly demonstrating the dramatic time compression obtained with the lean profile relative to conventional procedures.

OPERATION AND PERFORMANCE OF AUTOTRAK

After having completed the 12 1/4" build section by using conventional drilling technology, the AutoTrak system drilled the **8** 1/2" phase of Monte Enoc 9 OR. At the time of this operation an AutoTrak for the 12 1/4" hole size was not yet available.

The **8** 1/2" phase of the ME 9 OR was drilled with the AutoTrak from an initial inclination of 20" up to 63" . The final ROP average was **of** 3.1 m/hour. The section took from 3,295-3,711 m **of** MD. The last of the 4 runs brought the well to TD. This time a specially designed AT bit helped to optimise the ROP.

From 3,711 m onwards a 7" liner was set and drilling continued to the horizontal using conventional steerable motor equipment. After the hole had successfully been drilled to T.D. at 5,069 m, a logging tool was lost at about 3,500 m, and could not be retrieved.

AutoTrak was then again mobilised to sidetrack the stuck tool and redrill part of the **8** 1/2" section. A total section from 3,333 m to 3,716 m were drilled. The hole was sidetracked successfully from highside and the well passed over the fish with +/- 2m clearance. The hole was steered to an intersection point at +/- 3,600 m where the sidetrack was placed within 0.1m of the original hole. However no intersection occurred, most likely due to the survey errors that had accumulated over the 180 m sidetrack interval. The well was then drilled to target intersection while avoiding the original hole. A total of three runs were made, two with rock bits and rotary assembly and one with the AutoTrak PDC bit and tool run below a motor. The section was completed successfully with no lost time due to tool failure. New experience from the sidetrack was the ability to sidetrack from the top of a cement plug in hard formation, and also to place a well within 0.1m of planned location.

In terms of the AutoTrak system performance the following observations were made through the whole application in ME 9 OR:

- Ability to steer with even greater than the theoretical build rate capability.
- Reliability of steering system **of** well over 50 hrs in harsh formation. All of the AutoTrak runs allowed to steer and stay on bottom as desired (no premature POOH).

- Improved steerability and ROP achieved with special AutoTrak bit over that of rock bits.
- AutoTrak proved safe and effective operation both with and w/o down hole motor.
- Less high frequency vibration and lower sleeve rotation were seen when using PDC and motor than with rotary assembly and rock bit.
- Outstanding effectiveness and reliability of the whole system also included the surface located bypass actuator with adjustable nozzle sub combination.

As regards the operational gains from AutoTrak the following excellent results were achieved on the Monte Enoc **9** OR. They clearly demonstrated the pay-out of this technology in the 8 112" hole section. Among others these achievements were as follows:

- Improved hole cleaning due to continuous rotation.
- Reduced frequency of stuck pipe and tight hole conditions.
- Minimised torque and drag and well bore tortuosity due to automated closed-loop control of directional changes.
- Increased ROP's 35% if compared with the other deviated well (Monte Enoc 2 or).
- Increased reach capability and more complex designer well profiles due to reduce wellbore tortuosity and minimised torque and drag.
- Increased operationalltool flexibility utilising surface-to-downhole communication.
- The increased ROP directly translates into saved rig time and better economics. In this case the time savings attributed to the rotary steerable system was three days.

6" HOLE HORIZONTAL SECTION

The 6" Monte Enoc **9** horizontal section has been drilled with conventional steerable motors. From the initial inclination of 63°, the inclination was built up to 80". After a slant section of 450 m the inclination was increased until 90" for the final horizontal section of 500 m with azimuth turning in direction north-west. To drill all the 6" phase (1,358 m) occurred **40** days.

Thanks to the extremely good hole shape gained with the automated drilling technologies, were reached savings in terms of time and cost estimated in six days (compared with the **ME** 2 OR) and an economical impact calculated in 220.000 US$. As a total the automated drilling systems and the lean profile enabled to save 40 days of rig time. The economic impact of this novel techniques for ME **9** OR is estimated to be 1.6 Mill. US$.

Conclusions

Novel well steering technology resulting from a 5 years joint development program, Ultra Deep Horizontal Drilling, between an oil company and a oilfield service provider made a tremendous change to how wells are drilled. Monte Enoc 9 OR (horizontal) has been the first well world-wide which saw the two of the three major goals of this project being applied in one well.

The Straighthole Drilling Device (SDD) made a true vertical upper hole, and at the same time allowed to realise what is called the "Lean Profile" casing concept. Both gave reason for substantial economic savings. Deeper sections of hole were then drilled with the automated rotary steerable AutoTrak directional drilling device. Excellent performance both in terms of hole quality and drilling economics proved the validity of this tool, which is especially useful under complex drilling conditions.

Using both the SDD and AutoTrak provided an optimum basis to drill the last section of hole in the **6"** diameter. Because of the excellent hole quality provided in the upper sections, drilling with conventional equipment in the final hole was made much easier. Most positive experience of the novel technology as described above has already initialised several similar drilling activities in Italy and elsewhere.

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