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The fastest way to the bottom: Straighthole drilling device - drilling concept, design considerations and field experience

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ABSTRACT

A straight top hole section in many cases is a strict requirement to be able to drill deeper sections with complex well trajectories. Especially when geological parameters tend to deviate the course, and if the hole stability is a risk, drilling of a straight surface portion of hole is a must. Conventionally, this will be achieved with steerable motors, and changing between sliding and rotary mode. The Straighthole Drilling Device, 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. This concept had first been deployed on a more developmental basis in the KTB ultra deep scientific wellbore in Germany, thereby exceeding the 9,000 meter target. Today, the basic technology has been converted into a highly durable drilling tool for commercial oil wells. After a description of technical concept, details and performance features of SDD, the paper will focus AGIP's drilling experiences from critical fields in southern Italy.

KEYWORDS

Drilling technology, drilling tool, vertical drilling, oil well, Italy

Introduction

Early devices for providing a vertical borehole were large-diameter, ultra-heavy drill collars, utilizing the earth's gravity force. Since, in many cases, the formation dip could not be overcome this way, the idea of active steering devices was investigated. Results were limited to shallow wells, until a very rapid development for the "Continental **Deep** Drilling Program" (KTB) resulted by the end of 1990 in the first "Vertical Drilling System" (VDS) for application in deep wells [1] .

The VDS was used in 100 runs down to 7,200 m, maintaining the borehole vertical and straight, which was drilled in 1994 to a depth in excess of 9,000 m without major hole problems [2]. Soon afterwards, AGIP had identified this concept as a strategy to overcome major drilling problems in specific areas, and to gain major operating benefits. In a joint industry project, a completely new generation of an automated Straighthole Drilling Device (SDD) was developed, to fit much more to the requirements of a commercial drilling operation.

Technical requirements

Some of the basic development requirements have been:

- Continuous measurement of any deviation from vertical direction,
- Instantaneous compensation for any such small deviation,
- Steering operation in sliding,
- Downhole autonomous steering,
- Surface monitoring,
- Durability exceeding the bit life.

The continuous assessment of momentary directional data has been identified as an essential feature to provide a permanent steering. This can not be achieved with a steerable motor assembly, when the MWD with directional sensors is rotated in the straighthole mode.

Equally, operating steerable motors means switching between sliding mode to change the hole, and rotary mode when drilling ahead. A much smoother borehole path, also with a lower degree of change rate, is achieved if the steering is performed on a continuous basis.

Through automated adjustment as with SDD, the delay between signal occurrence and corrective steering action will be minimized. Although the steering control has to be fully autonomous, the tool's performance must be monitored on the surface. As regards durability, a service life of one drill bit is the minimum objective. Among others, the concept of minimizing the tool components has been identified as a valuable approach to optimize durability.

Functional concept

The idea of the Straighthole Drilling Device was originally conceived within a research project on ultra deep drilling. The concept there was to optimize the wellbore course in the upper section of the hole through drilling a constantly straight and vertical path. Results of such strategy are:

- Less friction and torque during drilling,
- Improved penetration rate,
- Improved hole stability,

- Less requirement for reaming,
- Better course control,
- Less efforts and risk to run casing,
- Reduced torque and drag when drilling deeper sections of horizontal or multi-lateral legs.

SDD basically represents a downhole motor with a modified bearing assembly and computerized instrumentation, plus a hydraulic system. A variable-gauge stabilizer controls the inclination, a mud-pulse system transmits data back to surface. For a correct steering, the SDD is operated in the sliding mode. If not steering, rotation from the surface is possible.

Upon any deviation from the vertical, a compensating command will be generated. Hydraulic forces are then selectively applied to one or more of the expandable ribs. This correcting force will work in the required toolface 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 positioning of the bit, expandable stabilizer and top stabilizer and the eccentricity of the steering ribs. By moving the position of the upper string stabilizer, the actual drop rate of the tool may be influenced.

In case of the 16" hole size, when positioning a 15 3/4" stabilizer directly above the tool, the SDD will drop at a rate of approximately 0.8 °/10 m.

Technology enhancement

The overall goal was to enhance the width of application opportunities and at the same time simplify the design for optimum durability and economics. Among the things kept were:

- Motor integration and type
- Expandable steering pads
- Positive pulse transmission
- Automated control algorithm.

With VDS, the hydraulic energy to power the expandable pads was directly taken fiom the mud pressure drop as generated through bit and motor. Major shortcomings with this previous concept were:

- Direct relationship between bit pressure drop and steering force leads to limitations in operating flexibility.
- Mud hydraulic elements require high maintenance efforts.
- Precise adjustment of mud hydraulics is problematic.

Based on the original Vertical Drilling System, first the SDD-6, and then the current version, SDD-7, have been made. While SDD-6 was still qualified as being a prototype tool, SDD-7 now provides the opportunity to be applied under commercial conditions.

Some of the more important principal changes in the new tool generation have been:

- Oil hydraulic force generation instead of mud hydraulics,
- Alternator to provide electrical power instead of batteries,
- Latest downhole electronics.

Oil hydraulic pressure generation provides a pre-defined pressure to feed the pistons, independent fiom bit hydraulics. The hydraulic circuit can be designed such that a constant steering force is provided under varying operating conditions.

All elements of the oil hydraulic circuit are readily available on the market, or may be adopted with very few modifications. **Also** a better accuracy of flow parameters can be achieved with industrially-made oil hydraulic elements. Practically no erosional wear will occur. Limitations of battery power supply as used in previous systems were the finiteness of operating life, the space required, temperature constraints, and environmental aspects. **As** a consequence, all SDD new generation tools now have a mud driven alternator.

SDD-7 technical data

The SDD-7 has been developed to provide a durable tool for a regular commercial application. This has basically been achieved through a complete redesign of both the electronic and hydraulic modules, taking into consideration the past field and maintenance experience available.

Among the new attributes are:

- Simplified electronics
- More compact oil hydraulics
- Standard top string stabilizer

By reducing the maximum electronics operating temperature fiom 200°C to 150°C, the electronics could be minimized in size. They were placed within a sub wall pocket close to the hydraulics.

The hydraulic compensation system was modified and the filtering considerably improved. For easy maintenance and adjustment of hydraulic pressure the complete control unit of the oil hydraulics is now located within a sub wall pocket.

With the top stabilizer directly above the SDD the theoretical maximum drop rate will be 0.6°/10 m (1.8°/100 ft) for the 12 1/4" hole size tools and 0.8°/10 m (2.4°/100 ft) for the 16" hole size tools. **A** higher position in the drill string decreases the drop rate. However, a drop rate below 0.3°/10 m is not appropriate.

The SDD's are currently supplied with a 9 1/2" Mach 1P/HF motor for the 12 1/4" hole size and with a 11 1/4" Mach 1C motor for the 16" hole size. The tool is available for the 16" and 12 1/4" hole size, but can be modified for the 14 3/4", 17 1/2" and larger hole sizes. With a length of about 10 m the SDD is only 2 m longer than a normal steerable motor w/o the MWD.

Field results with latest generation tools

In a first test on the AGIP well Case Pinelli 1 in Po Valley no major problems in controlling the vertical direction were encountered. Further tests were planned in two areas where the formations showed a larger tendency to build angle: The Agri Valley, located in the Basilicata region, and an onshore region in Sicily. Furthermore, another important point of concern for these two areas was formation instability.

Case #1 - SDD-6 @ Monte Alpi 5 OR (Agri Valley)

The test started on July, 1995 during the 16" drilling phase. The SDD was run in hole at an inclination of 3" at 836 m. At 1,025 m, the inclination of the well was dropped to 0°,resulting in a drop-off-rate (DOR) of about 0.5°/30 m. The tool kept drilling down to 1,201 m controlling the verticality of the well at 0". At 1,249 m, the tool was pulled out of hole because of a failure. The section was completed with a conventional BHA, with a final inclination of 7". The average ROP while using the SDD was 6.4 m/h.

The caliper log, made after the drilling phase, showed a good quality of the hole in the section were the SDD was used, both in terms of hole geometry and inclination. No hole enlargements occurred. The tool for the 12 1/4" hole was run in hole at 1,508 m, dropping the inclination down to 0" at 1,660 m, with a resulting DOR of 1.4°/30 m. The tool kept inclination at 0" down to 1,850 m where inclination started increasing.. At 1,972 m, the tool was pulled out of hole due to a failure. The average ROP obtained with the SDD was 4.2 m/h. The section was then completed with standard assemblies.

The test proved the ability of the tool to control inclination while drilling formations with a high tendency to deviate from the vertical direction. The drilling performance (ROP) was generally good. On the other hand, SDD could not fully express its capacities because of the lack of reliability. Design changes regarding the oil hydraulics and the electronics were made, in order to improve the reliability of the tool.

Case #2 - SDD-7 @ Monte Alpi 1 EAST (Agri Valley)

Before Monte Alpi 1 EAST, the improvements initiated after the experience at Monte Alpi 5 OR were introduced, into version 7 of SDD. In the early 16" phase the new tool showed some problems related to unstable performance of the revised electronics. After long term laboratory testing a communication problem on board level was found. Changes were made to software and hardware.

In the 12 1/4" hole the SDD was operated from an initial inclination of 1.8" @ 1967 m; it dropped the angle down to 0" after about 30 m. In total, 454 m were drilled with different formations, having an averaged ROP of 3.8 m/h, some 30% more with respect to ROP's values from offset wells. Throughout the 12 1/4" drilling phase, no major problems regarding overpull or reaming occurred during trips. The logs made afterwards were run in hole and executed with no problems. Wellbore instability problems, often present in this area, were not an issue during application of the SDD. An explanation is as follows.

The tool reduces both exposure times (faster ROP) and mechanical shocks to the hole (no drill string rotation). Both are key factors for formations that tend to instability [3]. Furthermore, a vertical trajectory helps to hole cleaning, thus permitting to avoid short **trips,** also identified as a potential source of wellbore instability.

Afterwards some shortcomings were identified with the tools: Wear on pistons of the oil pump and peak power demand affecting the magneto coupling operation were the issues to focus on before the next tests on Timponivoli.

Case #3 - SDD-7 @ Timponivoli

Timponivoli is an explorative well, located some 100 km North-West of Catania, Sicily. From offset major problems regarding verticality control and formation stability were known.

The test started in May 1996, with the 16" drilling phase. At a depth of 424 m, the SDD had to face an inclination of 4.5° that was easily dropped to 0" with the first run, where an outstanding ROP of 11.7 m/h was obtained. Since the beginning, the tool was expressing an ROP never seen before in the same area. At a certain time of the program, it was some 17 days ahead of the schedule. Afterwards, due to very serious formation instability problems, several efforts were necessary to establish good hole conditions. Yet because of the time saved previously it was still possible to stay ahead of schedule. In the following runs the SDD kept drilling with high ROP's, giving its best performance, also in terms of reliability.

A glance at reliability

The changes in the design implemented in SDD-7 proved to be helpful in increasing reliability. While the SDD-6 had a Mean-Time-Between-Failure (MTBF) of 44.8 hours, the SDD-7 showed an MTBF of 84.8 hours. However, for a more sophisticated comparison between the two versions, we can use the probability plots based on the Blom algorithm [4]. Obviously there are big improvement in terms of reliability after the first 20 hours of operations, where the SDD 6 had a decrease in reliability down to about 55% and the SDD 7 still had more than 90 %. Also, if we consider the average bit life for the case under question (50 hours), the SDD 7 has almost 90% reliability and 40% more chances to reach this target than SDD-6.

New operative perspectives with SDD

The SDD demonstrated in the field that it could maintain the vertical direction very accurately, assuring high standards in terms of ROP and reliability. 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. Now, the SDD can give some extra value added by providing solutions to operative problems. To cite some examples, we can still refer to the Agri Valley. In this area, thanks to the SDD, it is possible to consider clusterization of well locations and slimmer well profiles as main beneficial operating options.

Clusterization

This is particularly important in onshore areas, where the environmental impact has to be reduced. Clusterizing wells can dramatically decrease the number of well locations. However, in the Agri Valley the environmental impact is of overwhelming importance and therefore clusterization is considered a "must". Typically **2-3** wells will be run down vertically to a depth of at least 1,000 m. Unfortunately the formations in the area show a high tendency to deviate from the vertical. For example, considering the Monte Alpi field in the Agri Valley, the difficulties in controlling the verticality of well boreholes using the conventional drilling technique (i.e., stiff BHAs) leads to vertical trends. The probability of having collision between two wells can be very high, unless we consider a minimum cellar distance so high to make clusterization not reasonable. The SDD, by providing the possibility of drilling a practically perfectly vertical hole, permits consideration of clusterization, thus reducing the environmental impact in the area.

Slim well profiles

Today, for the explorative wells of the Agri Valley it is necessary to run an additional intermediate casing unlike other "standard" wells of the area. It is necessary to drill a **23**" hole down to 1,200 m. The formation to be drilled has a very low drillability and a high tendency to deviate from the vertical direction. Here, the use of steerable systems is not convenient and, for certain aspects, also not practicable. The typical operating scenario is then stiff BHA's and high WOB. In many cases a satisfactory operating performance can not be achieved. A change in the drilling technique is necessary to move forward. Such possibility is offered by the SDD which, by permitting practically perfect vertical hole drilling, allows for casing runs with small hole-casing clearances[4].

So, by using the SDD it is possible to consider an alternative well profile. The main advantage with the slimmer profile is a reduction in well cost, due to the smaller hole sizes. Furthermore other expectations are higher ROP, less disposal for waste drilling materials, and less cost for materials (casing, fluids, cement, etc.). Also, this way of operating in contingency situations permits running of a further intermediate casing without jeopardizing completion possibilities.

Conclusions

The SDD, through a series of design improvements has been brought to a commercial stage, assuring both good reliability and performance. After the application in the field, it is possible to state the following conclusions:

- The SDD allows for drilling very accurate vertical trajectories, even in formations that have a high tendency to deviate from the vertical.

- The SDD provides better ROP's relative to standard assemblies.
- The "quality" of the hole drilled by the SDD permits to leave the hole to subsequent operations (logs, casing running, cementing, etc.) in good shape.
- The tool helps to reduce wellbore instability problems.

The Straighthole Drilling Device is the basis for the application of a vertical drilling strategy which proved to be effective in specific operating conditions. Now, it is possible to extend the tool's advantages, in order to achieve important operating results such as clusterization in critical onshore areas and slimmer well profiles, with the additional benefits of less environmental impact and operating costs.

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Metric conversion factors

cp x 1.0* E - 03 = Pa. s
ft x 3.048* E - 01 = m
ft2 x 9.290 304* E - 02 = m^2
ft3 x 2.831 685 E - 02 = m^3
in. X 2.54* E + 00 = cm
lbf x 4.448 222 E + 00 = N
md x 9.869 233 E - 04 = μm^2
psi x 6.894 757 E + 00 = kPa

*Conversion factor is exact.