Technological Solutions for Slant Directional Drilling Project Challenges

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Abstract. The paper describes an experience in the field of slant directional drilling in oil industry, which is currently under pressure. The experience helping to meet drilling projects’ challenges in an effective way has been approved for a several years of work at quite a few projects in different countries. The paper includes some design and technological tricks to overcome standard problems arising during slant directional drilling of oil wells such as entering the ground, maintaining the drilling trajectory, adjusting of an axis misalignment between the rig’s central shaft and the drill line, choosing proper pumps and adjusting pumping pressure, and keeping the drill rods and casings from sliding into the hole from an inclined mast.

1. Introduction
While the oil price crisis is raging around the world, most of the oil mining companies and their drilling contractors pay serious attention to economic effectiveness of the applied drilling technologies and look for the most effective way to save financial resources and enhance their projects’ viability. Most of the new technologies enhancing effectiveness of drilling operations require considerable financial investments before the effect takes place, while progress becomes possible when a contractor can start saving at the initial stage of the process and improve this process at the same time. The purpose of this paper is to shed new light on the most tricky and interesting aspects of drilling inclined wells and applying heavy-duty rack and pinion rigs for oil and gas mining in order to save financial resources.

2. Technological solutions for the most common problems of slant directional drilling
Almost all drilling industry is used to a cable rig with a top drive. All engineering is carried out for this type of the rigs, and all costs are calculated proceeding from the fact that the rig is going to be a conventional cable rig. In 1990s several drilling contractors started one of the first SAGD (Steam-Assisted Gravity Drainage) projects in Alberta, Canada [1]. In 2006 the technology got adopted in Russia. The vertical depth of the Russian horizontal wells ranged between 70 and 250 meters. It soon
became apparent that using ordinary vertical cable tool rigs was not productive due to extremely small bending radius of the casings and mile long slotted filter pipes. The decision was taken to apply inclined rack and pinion rigs for wells with vertical depth less than 500 meters (1100 ft). Such rigs are normally used for coal bed methane [2] mining in Australia and Russia, mine dewatering, Horizontal Directional Drilling (HDD) [3], long-range horizontal offshore oil well drilling [4], underground gas storage construction [5] and in some other applications. The technology is normally referred to as Slant Directional Drilling (SDD) [6].

It has been spent several years to work out the best and the most economically viable technological solutions and overcome the difficulties on the way to successful project accomplishment. As the technology became predictable and widely used, it’s time to share the experience of overcoming most unpleasant problems on the way to high quality wells with 45 degree.

3. Technological solutions for the most common problems of slant directional drilling

As opposed to vertical drilling, where the suspended string finds its center automatically after the axial force is communicated to the drill bit by the weight of the drill string, the bit refuses to enter the ground without hydraulic hammering and special extra heavy drill collars. If the diameter of the first casing exceeds 300 mm, the best way to penetrate the ground is to use step-face bits (they can be cone, PDC or combined). One more important detail: in order to successfully accomplish an inclined drilling the contractor should be sure that the drill rig central shaft is properly aligned with the center of the well. The problems stemming from misalignment take a lot of time and effort to correct; hence precision of penetration at the right point is absolutely imperative.

![Figure 1. Adjusting of mast axis.](image)

Standard problems with drilling trajectory come from vertical drilling where pitch should change gradually and it is nearly impossible to keep the same gradient intensity at every point of drilling between inclined and horizontal sections. Most of project bureaus use conventional software for inclined wells [7, 8], which prescribes pitch per rod does not allow to achieve necessary precision.

In inclined position casings of smaller diameters fall to the bottom of a previous large diameter casing. The rig in most cases is rigidly welded to the anchors, which is required by safety regulations.

The solution, which was implemented in ADI 360 VS based on several years of field experience, is as follows. The rig can adjust the mast axis by using parallelogram under the mast to move the mast on the existing well head 300 mm left and right using powerful guides and sidelong anchors (Fig. 1).

Inclined well head makes it possible to greatly decrease residual pipe steel stress.

In HDD no pipeline can be bent to the radius greater than 1200 of its diameters, which is perfectly achievable in slant directional drilling [9]. It should be noted that the quality of a well without residual
stress in the casings is much higher than the quality of the well where the casings are bent nearly to their yield point. There is one more argument in favor of keeping the maximum possible drill curve radius: cement is evenly distributed along the walls of the casing if there is no stress making the casings press against the walls of the well and the rotation while cementing comes in easier. This leads to a reduction of a soil and groundwater contamination by reagents [10, 11]. It also helps to prevent the next problem linked with the mud losing, which is often exacerbated by the loss of formation stability in the hole. The most important issue in the process of applying inflatable packers is controlling down-hole pressure. To prevent it the next operational sequence should be followed: prepare cementing agent or polyacrylamide; pump it down the hollow in small portions until proper pressure is achieved; clean the packer by with great care and properly calculated weight of the cleaning fluid, because heavy fluid goes below the cement, light fluid goes on top; after solidification of the cementing or plugging agent try to apply maximum possible pressure of the pump that do not frack the formation; after pressurizing is complete and successful, pull out the string.

To provide slant directional drilling with the conditions listed above when drilling between 100 and 300 meters to the length of up to 1,6 km and more, two pumps with a working pressure of 80-100 bar and 100-120 bar should be used. At this, their parameters' values should have relation as it described by the following equations

\[
Q_1 = 16.944 \cdot q_{t1} - 402.7; \\
Q_2 = 14.645 \cdot q_{t2} - 360,
\]

where \(Q_1\) and \(Q_2\) are delivery of pumping liquid for the 1\(^{st}\) pump (80-100 bar) and 2\(^{nd}\) pump (100-120 bar), l/min; \(q_{t1}\) and \(q_{t2}\) are strokes per minute for the 1\(^{st}\) and 2\(^{nd}\) pumps respectively.

Another problem is keeping the drill rods and casings from sliding into the hole from an inclined mast [12]. Standard “Vertical slips” cause problems in inclined positions as the upper wedges touch the rods and casings and scratch them even in open position and the upper wedges do not get fully opened. So it is nearly impossible to center standard slips against an inclined mast. To solve the problem the calculation of drilling rods sliding forces should be made, e.g. as shown in the Table 1 for drilling rods with diameter 244.5 mm in the conditions of negative buoyancy. The weight of one pipe is 520 kg, friction factor is 0.25, number of rods at the slant section is 20, initial inclination angle is 45\(^{\circ}\), and iteration of inclination per rod is 2.3\(^{\circ}\).

| Pipe’s number | Inclination angle, \(^{\circ}\) | Friction-free sliding force, tones | Sliding force of the casing pipe into the well, tones |
|---------------|-----------------|-----------------|-----------------|
| 0             | 45              | 0.364           | 0.234           |
| 1             | 42.7            | 0.3536          | 0.2236          |
| 2             | 40.4            | 0.338           | 0.208           |
| 3             | 38.1            | 0.3224          | 0.1924          |
| 4             | 35.8            | 0.3016          | 0.1716          |
| 5             | 33.5            | 0.286           | 0.156           |
| 6             | 31.2            | 0.2704          | 0.1404          |
| 7             | 28.9            | 0.2496          | 0.1196          |
| 8             | 26.6            | 0.234           | 0.104           |
| 9             | 24.4            | 0.1976          | 0.0676          |
| 10            | 22.1            | 0.1976          | 0.0676          |
| 11            | 19.8            | 0.1768          | 0.0468          |
| 12            | 17.5            | 0.156           | 0.026           |
| 13            | 15.2            | 0.1352          | 0.0052          |
If a clean well is properly constructed, the 244.5 mm diameter casing pipe should be loaded into the well without efforts on inclined sections and on horizontal sections of short length. In the event of efforts on the casing string when it is submerged in the well, it is necessary to diagnose the well for faults and the presence of emergency situations. When lowering the pipe filled with air, the load can be reduced to 200 kg, since the force of the pipe on the lower arch of the well will be reduced by 10 times. The appearance of a pressure load is possible only after reaching 20-30 meters of the horizontal section.

4. Conclusions
The full list of challenges and related technological solutions for SDD projects is not an issue that could be discussed within a short scientific article. At this, the represented information from a field is a foundation for a construction of a new generation of rack and pinion rigs specially designed to meet the requirements of SDD projects as well as for zero-incidents technology of oil and gas drilling.

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