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Research paper

Setting the Well Path Direction with the Help of Rotary Steerable Systems

V.P. Lozhechko[1]*, A.V. Ashcheulov[1], Ya.I. Binder[2], A.L. Gutnikov[2], R.D. Zimin[2], D.A. Sokolov[2]

[1] Peter the Great St. Petersburg Polytechnic University, Saint-Petersburg, Russia
[2] Specialnoe konstruktorskoe byuro priborov podzemnoj navigacii, AO, Saint-Petersburg, Russia
**Corresponding author E-mail: vp.lozhechko@mail.ru*

Abstract

This article describes the main reasons for the emergence of directional drilling, technological advances in directional drilling and the prerequisites that led to the creation of rotary steerable systems, the history of the emergence of modern principles of curvature control of the well path, a comparative analysis of existing implementations of these principles and the main results of the development of the RUS220 rotary steerable system prototype. Based on the materials studied, the main configurable parameters are identified that define a specific concept, the tasks are formulated, choosing and justifying further research directions for developing the principles of trajectory curvature vector when drilling small diameter wells using rotary steerable systems.

Keywords: *Directional drilling, Rotary steerable systems, "Push-the-Bit" technology, "Point-the-Bit" technology.*

1. Introduction

The priority direction ensuring the stable growth of the economy is the modernization of the oil and gas industry as part of the strategy for the innovative development of the energy sector. This development involves the solution of the primary task aimed at improving the efficiency: exploration, drilling, facilities construction and development of new fields, as well as additional development of oil and gas provinces, developed in 70-80 years of the last century, the introduction of high-tech, intelligent integrated systems in the field.

Multilateral drilling and completion is a well-known method of increasing oil and gas production, which is widely used today. A well bore with several branches – sidetracks – reduces total costs, increases productivity and improves drainage of the reservoir [1]. This type of drilling is associated with sidetracking and penetration of inclined sections in the direction from the casing string to the producing layer with subsequent entry into the formation with a predetermined angle specified individually for each case. As a result, directional drilling has long become the main type of drilling both onshore and offshore when drilling wells from platforms of various types. To date, the highest level of directional drilling development is reflected in complex horizontal wells and extended reach drilling wells.

Deliberate deviation of the well bore from the vertical came into practice in the late 1920s, when operators were looking for the ways to sidetrack past various obstacles. The emergence of the possibility of drilling directional wells was partly due to the development of rotary drilling and the development of rolling-cutter bits. By virtue of their design, such bits go aside with certain values of the parameters of a formation or a drilling mode. It was also found that by changing the design of the rotary bottom-hole assembly (RBHA), you can change the angle of inclination of the drill string. Changing the location of the stabilizer allowed to affect the equilibrium state of the bottom-hole assembly, making it increase, maintain or reduce the angle of deviation of the well bore from the vertical. The rate at which the rotary bottom-hole assembly increases or decreases the angle is determined by such variables as the distance between the stabilizers, the diameter and rigidity of the drill collars (DC), the formation dip angle, the speed of rotation, the load on the bit, the formation hardness and the type of a bit.

Early 1960s were marked by a significant breakthrough in the field of directional drilling, when a bottom-hole assembly with a fixed angle of inclination of around 0.5° was combined with a bottom-hole motor to drive the drill bit. The orientation of the assembly takes place with the help of rotation of the drill string and bottom-hole tools of inclinometry, which inform the driller in real time of the current deviation angle and azimuth. This is not an easy task, considering that a drill string can behave like a spring at long intervals and absorb the torque [2].

2. Research objective

The wear and tear of rock cutting tools (rolling-cutter bits) throughout the history of the development of directional drilling has been the main factor determining its effectiveness. The need to replace worn bits determined the frequency of run-in-hole/put-out-of-hole operations (RIH/POOH), during which it was possible to vary the angle of inclination of the bottom-hole motor spindle, which determines, in turn, the intensity of the set of the curvature of the well. With the appearance, and then with the widespread introduction of the bits with polycrystalline diamond arms - PDC (Polycrystalline Diamond Cutter), their significantly greater resource has ceased to determine the frequency of the RIH/POOH. Practice shows that when drilling deep wells, PDC bits provide headway to the tool for more than 1000 m with an average mechanical drilling speed of up to 35...40 m/h. Therefore, at present in the Siberian region, the volume of penetration using PDC-class bits reaches 85...90% of the total volume of industrial drilling [3].

3. Theory

Many of the disadvantages of directional drilling were eliminated or minimized by using the rotary steering systems (RSS), invented in 1990, using which the drilling bit moves in a predetermined path along with the continuous rotation of the drill string, which significantly improves the cleaning of the well bore and reduces the likelihood of sticking and also allows continuous geophysical measurements in the process of penetration [4]. Modern RSS systems are divided into two types:

- RSS – Rotary steerable systems

The RSS system is a special controlled drilling tool, ending in a drilling bit and replacing the downhole drilling motor (DDM). As a rule, these systems are pre-programmed and function automatically (being activated in one way or another from the "daylight surface") or controlled, if there is a duplex communication channel, by an operator who directs the drilling tool in the right direction. Obviously, these systems are able to control drilling using only rotary rotation without additional RIH/POOH;

- RSM – Rotary steerable motors.

RSM is a system that includes RSS in combination with an additional "motor section" located above it [5] – DDM – designed to increase the rock-destroying effect on the drilling bit due to the addition of rotor and turbine rotation torques. Despite the seemingly obvious synergistic effect, RSM has not found wide application in practice, and is developing, at present, only by the APS company and a number of other companies supporting their development (Gyrodata, etc.). This is due to the fact that the kinetic energy of the DDM, in this case, is consumed not only for rock cutting, but also for the generation of electro-hydraulic control energy, which, with the main, used today variant of the implementation of the principle of "Push-the-bit", takes a very large share, at the same time limiting the permissible difference in the angular velocity of the string and the DDM.

RSS – technologically sophisticated innovative devices that control the change of the trajectory of the well during rotary drilling, and combining elements of mechanical engineering, precision instrument making and electronics. In earlier versions, retractable drillshoes or stabilizers put in motion by the drilling liquid were used to change the direction. They pulled the assembly from the wellbore wall but since the control of the curvature of the borehole depends on the area of contact with the wall, the erosion or roughness of the walls can sometimes affect the performance of these tools. In this regard, later versions provided for a design in which changes in the angle of the end plane of the drilling tool were caused by bending, which reduced the influence of the characteristics of the borehole on the tool operation. Thus, since its inception, the RSS have undergone many changes and, ultimately, technological development has led to the emergence of two basic concepts of building the RSS (Fig. 1):

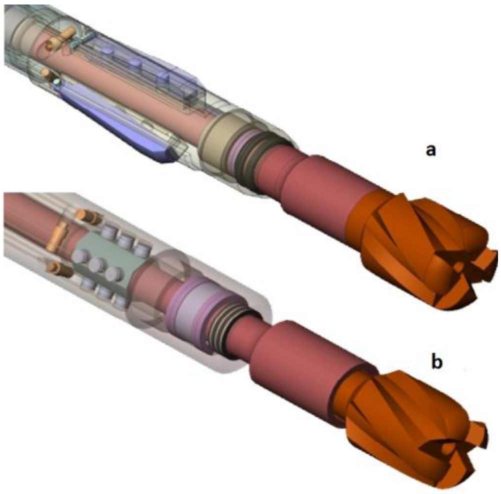

Fig. 1: RSS concepts: a – Push-the-bit; b – Point-the-bit

a) with a drilling bit deviation (Push-the-bit technology, Fig. 1a);

In a system with a bit deviation, the guidance of the drill string in the desired direction is performed by pressing the wellbore wall. The system synchronously changes the position and contact pressure of the shoes when each of them passes a certain orientation point.

b) with the bit direction (technology Point-the-bit, Fig. 1b).

In the system with the direction of the bit, the internal shaft bend is used to deflect the axis of the assembly from the current axis of the well and change the direction of drilling. Systems with the direction of the bit change the trajectory of the well by changing the angle of the end plane of the drilling tool. The well trajectory changes in the direction of bending [6].

Structurally, all existing RSS can be represented in the form of several main blocks:

1) Snatch block.

In the snatch block, as a rule, the deflecting and actuating RSS mechanisms are located. The further implementation of the chosen concept of building the RSS is often completely dependent on the design of the snatch block, since it can be made in the form of a geostationary part, isolated from the rotation of the drill string with the help of bearing blocks, or be directly part of the drill string.

2) Control unit.

The control unit contains navigation, control systems, as well as batteries and/or turbine generator. It can be executed as an independent unit, or as an integral part of a snatch block.

3) Drill string shaft.

The shaft transmits the torque and the axial load on the drilling bit and at the same time is the load-bearing part of the RSS. In this regard, the requirements for the mechanical properties of the materials used for its manufacture are always very strict.

Separately, it is necessary to highlight the pressure compensation system used in the RSS constructions, which use oil as the working fluid of the hydraulic system. To overcome the pressure difference in the internal hydraulic system and the annular flow, and, consequently, to reduce energy consumption, one or more air-oil actuators in the form of elastic hoses separating these fluids are built into the hydraulic system.

Thus, main structural and functional differences of the RSS should be divided into several categories:

– The principle of constructing the assembly (with or without the geostationary part);

– Type of the working fluid of the hydraulic system (drilling mud / hydraulic fluid);

– Used energy sources (replaceable elements/self-contained power supply);

– Concepts of a vector control of the curvature of the well trajectory (Push-the-Bit / Point-the-Bit).

Any implementation involves the configuration of the parameters described above and, consequently, the basis for creating any RSS is a constant search for a compromise between the technical requirements and technological difficulties of production. If we consider the intensity of the curvature as a criterion for setting the well trajectory, one should pay attention to the Schlumberger company's Power Drive system and the Baker Hughes company's Auto Trak system (see Table 1).

Table 1: RSS comparative characteristics

System name	Drilling bit control principle	Snatch block assembly	Type of working fluid of a hydraulic system	Add. energy sources	Max. Curvature Intensity
Power drive	Push-the-bit	Rotating	Drilling mud	no	0.26
Auto Trak 6.75 Curve	Push-the-bit	Geostationary	Hydraulic fluid	present	0.5

The essential differences between these two systems are the hydraulic system working fluid used and a snatch block assembly type. It is obvious that the placement of the deflecting elements on the rotating part of the assembly has a completely natural speed limit, and this approach is extremely difficult in terms of further development. It should be noted that in the Power Drive system, a geostationary mechanism is implemented in the snatch block, which rotates at the same speed as the drill string, but in the opposite direction, and directs the drilling fluid to the required deflecting element.

The geostationarity of the snatch block allows to reduce the system performance and, consequently, the power consumption by dozens of times, while maintaining the effectiveness of the well trajectory control. In this regard, the development of modern systems follows the path of implementing design solutions built on the basis of the geostationary scheme.

From this point of view, the joint development of the Koncern CNII Elektropribor AO and Specialnoe konstruktorskoe byuro priborov podzemnoj navigacii AO, namely the prototype RUK-8.75BS of the rotary controlled system RUS220 (Fig. 2), intended for drilling with the bits of 220,7-222 mm, is very interesting.

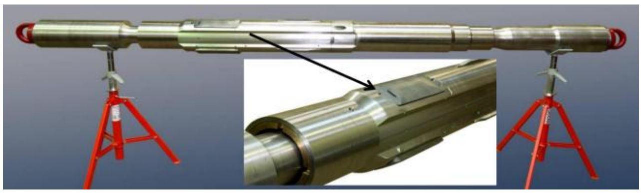

Fig. 2: RUS220 rotary steerable system prototype

The implemented Push-the-Bit concept is based on a geostationary snatch block containing control electronics and actuators. This approach made it possible to place the deflecting elements as close as possible to the drilling bit and thereby more efficiently manage the well trajectory. The prototype uses hydraulic oil as the working fluid of the hydraulic system, the pressure of which is created by linear drive units that do not require additional power to maintain a given configuration of shoes. This allowed the developers to abandon the power source in the form of a turbo-generator and, as a result, requirements for the quality of drilling mud and circulation parameters. Along with the above features of the constructive implementation of the prototype, the geostationarity of the snatch block due to the abandonment of the fast-rotating kinematic pairs and hydraulic connectors made it possible to reduce the requirements for materials, components, precision of the mechanical assembly operations, improve operational reliability and ease of maintenance, greatly simplify the design in general.

According to the results of pilot tests, the implemented assembly solution showed its viability (tests were carried out on the wells of Vyngapurovskoye field, Noyabrsk). The average mechanical speed of penetration was 29 m/h, the maximum – 60 m/h [7].

4. Summary and conclusions

The concept chosen for the implementation of the prototype RUS220 has the potential for further development to create a full-fledged range of standard sizes. However, reducing the outer diameter of the layout will not allow the direct scaling method to be applied to most structural elements (linear drive units, batteries) and will inevitably require developers to conduct serious research and development, as well as to test and implement new construction solutions.

Acknowledgement

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