CONTROL OF THE TECHNOLOGICAL PROCESS OF DRILLING

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Drilling with a rotary steerable system (RSS), the mechanical drilling speed increases by two times compared to drilling with a screw bottom-hole motor, which provides significant savings drilling-time. The effective length of the horizontal elbow increases, which enables to increase the production rate more than twice. It is found that in comparison with the bottom hole motor, RSS provides drilling smoother barrel, which reduces the risk of accidents to come out. The efficiency of RSS: improved sludge removal, as it does not create strained intervals of well trunk; increased penetration rate, as effective removal of prevents its deposition, which has a positive impact on the rock destruction; increases the drilling speed and the length of the horizontal wellbore by reducing the friction force between the column and the hall wall due to the rotation of the entire column; reduces the risk of mechanical and differential grips, as there are no fixed RSS elements in contact with casing, well control diverter system or hall bore wall.

KEYWORDS

rotary steerable system, directional well, deviation system, radius of curvature

1 INTRODUCTION

The most commonly used machining technologies include turning, milling and drilling or boring. [Pokorny 2012] [Vopat 2015] The aim is to achieve the desired quality of the machined surface with dimensional accuracy and surface roughness. [Beno 2013] [Peterka 2004] The cutting process is characterized by the accompanying phenomena: chip formation, existence of cutting forces, tool wear [Vopat 2013], surface roughness and vibrations. [Sentyakov 2020]

Components are designed in a CAD system. New techniques in CAD systems have been developed to overcome perceived limitations in conventional practice - particularly in dealing with complexity of the parts. Computer aided design enables the designer to tackle a task in the practice more quickly and accurately. Program for CNC (Computer Numerical Control) [Pokorny 2012] machine tool is generated in CAM system. Machine-tool, tools [Peterka 2020a] [Peterka 2020b] or machined surface can they be damaged, therefore the program must be simulated and debugged.

Currently, the horizontal wells technologies development is a priority way of improving efficiency in the oil and gas industry for involvement in the industrial development of hard-to-recover oil and gas reserves. [Mostovoy 2019a] [Shevchenko 2014] Horizontal drilling is one of the promising methods of intensification of oil and gas production [Akbultov 2006] [Khasanov 2004], which increases the filtering area of the reservoir fluid due to the length [Novoseltsev 2014] [Kein 2014]. The development of directional drilling so far is related to complex horizontal wells and wells with a significant deviation from the vertical [Mostovoy 2019b] [Galikeev 2018]. Rotary steerable systems (RSS) are most often used in directional drilling. [Weatherford 2017] [Schlumberger 2020] [Halliburton 2020] [BakerHughes 2020]

2 THE PRINCIPLE OF OPERATION OF THE ROTARY STEERABLE SYSTEM

Currently, RSS is actively used for the penetration of vertical, inclined and horizontal trunks, in which the destruction of rock is carried out by rotation of the drill bit with the drill column top drive of the drill rig or rotor, as well as deviation systems combining the use of screw bottom hole hydraulic motors and RSS. These systems are the most advanced, and with telemetry and geo-navigation systems have turned into a perfect unmanned remote control of directional drilling. The capabilities of these systems are impressive: with the highest accuracy (± 0.1º) and speed, these systems are capable of drilling wells of any spatial orientation up to 13 km with continuous pass more than 1000 m.

State-of-art deviation system is an unmanned electron-mechanical unit controlled remotely. Figure 1 shows the flowchart of the deviating RSS.

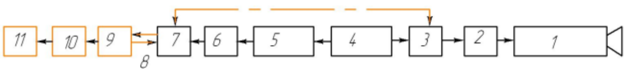

Figure 1. A System flowchart of downhole deviation drilling system
1 - a deviation gear, 2 – the drive of the deviation gear, 3 – an electronic control unit for the drive of the deviation gear, 4 – an electronic power source (hydraulic turbine or storage batteries), 5 – telemetry, 6 – an electronic telemetry unit, 7 – a transmission and reception unit of information transmitted from the surface and downhole system, 8 – a communication channel (hydraulic pulse, electromagnetic), 9 – a receiving device and signal amplifier, 10 – a computer, 11 – a device for visual monitoring of the drilling process

With an autonomous electric power source (4), the deviation systems are controlled from the surface by the operator through a computer (10), which generates a signal transmitted through the drilling fluid or by electromagnetic radiation (8) to the downhole assembly in which, by electronic unit (3) and the drive system (2) of the deviation mechanism (1), the well direction is adjusted with accordance to a given orientation. At the same time, the embedded telemetry system (5) continuously monitors the angular parameters of the borehole through the electronic unit (6) and signal conversion system (7) transmits information to the surface of the receiving and amplification unit (9), then to the computer (10) and to the device for visual inspection of the drilling on the rig (11) to the operator. As a result of this interaction, a new job is defined to correct the direction of the well, which is performed with high accuracy.

The efficiency of RSS:

- improved sludge removal, as it does not create strained intervals of well trunk;

- increased penetration rate, as effective removal of prevents its deposition, which has a positive impact on the rock destruction;
- increases the drilling speed and the length of the horizontal wellbore by reducing the friction force between the column and the hall wall due to the rotation of the entire column;
- reduces the risk of mechanical and differential grips, as there are no fixed RSS elements in contact with casing, well control diverter system or hall bore wall.

No bore bend (normal when using downhole engines) with a greater length due to the reduction of friction forces and better cleaning of the barrel from sludge being the RSS systems enable to drill low-angle borehole and horizontal well with a smooth profile. Higher penetration with constant rotation of the drill column prevents the possibility of the drill tool clamps, reduces the time to clean the barrel from the drill rock and makes available a number of additional advantages in the quality of exposing a producing horizon.
RSS facilitates drilling long for more than 10 km horizontal trunks, as drilling with the rotation of the drill column reduces the probability of slurry of the column and provides enhanced ability to push the column along the horizontal hole.
There are three types of RSS: push-the-bit systems, point-the-bit systems and the RSS combining these two mechanisms.

3 THE PRINCIPLE OF OPERATION OF PUSH-THE-BIT RSS

Push-the-bit systems involve the set of curvature by milling the well's wall under the deviation force. In a chisel deviation system, the deviation force on the chisel $P_{(defl)}$ appears as a result of the extension of blades 1, exerting pressure on the well's wall with a force $P_{(p)}$ (Figure 2, Figure 3).

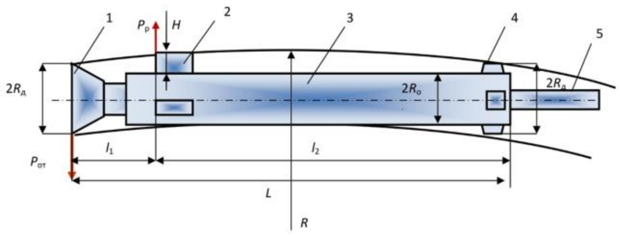

Figure 2. Scheme for calculating the radius of curvature of the RSS with a radial offset of the bit
1 – bit, 2 – retractable blades, 3 – body, 4 – upper stabilizer, 5 – pipe
D_d – the diameter of the bit, H – the blade exit from the body, D_b – diameter of the body, D_s – stabilizer diameter

The drive of blades 1 is hydraulic, carried out by a successive supply of drilling fluid to the corresponding hydraulic chambers. To increase the angle of deviation, each blade 1, turning and being in the lower part of the barrel, presses the lower side of the barrel, and to reduce the angle, each blade 1 presses the upper section of the wellbore.
The commands sent through telemetry on the hydro-impulsive and electromagnetic communication channels determine the actuation time and force of the shoe 1. A control unit 3, located above deviation block 5, activates the rotary valve 6, which closes or opens the channel for the flow of mud to the chambers with blades 1 in accordance with the rotation of the drill string. The system synchronously changes the impact interval and the force with which the blade 1 acts on the well wall, thus directing the chisel 4 in the desired direction. Bit 4 provides the borehole wander by milling the well wall by side equipment. Thus, a significant role in long dogleg processing of this type of RSS is given to the bit, which must meet certain requirements.

In accordance with the scheme depicted in Figure 2, the radius of curvature of the wellbore, realized by the RSS with the radial displacement of the bit, can be determined:

$$R = 0{,}5 l_1 l_2 / h,$$
$$h = H - (R_d - R_0) + [l_1 - (R_d - R_u)/L] \quad (1)$$

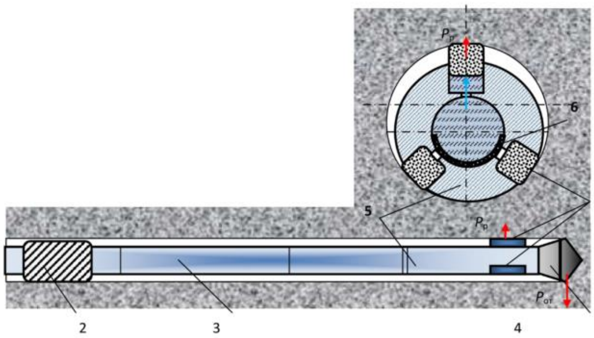

Figure 3. Layout of a rotary steerable system with a deviation of the bit
1 – retractable blades, 2 – the stabilizer, 3 – the control unit, 4 – the bit, 5 – the deviation unit, 6 – the shutter

Formula (1) is derived from the condition of the deviant fit into the curved well barrel with the non-deforming hull, so it is possible to determine the minimum value of the radius of curvature and accordingly the minimum value of the long dogleg intensity at the specified parameters.
At the same time, in milling the wall of the well a significant role plays the milling ability of the bit under the action of the deviation $P_{(df)}$. In this case, the curvature intensity and radius of curvature are determined by:

$$R = \nu_b / (\nu_f L) \quad (2)$$

where v_b is the drilling speed, v_f is the well wall milling speed.
To meet the required parameters of the set of curvature, the radius of curvature calculated by the formula (1) can only be obtained at certain milling speeds.
The deviation force acting in the direction of milling of the RSS depends on the size and pressure of the flushing fluid in the throttle circulating well control diverter system and can be determined by the formula:

$$R = \nu_b / (\nu_f L) \quad (3)$$

where ρ_f is the pressure of the washing liquid in the hydraulic chamber over the retractable shoe, MPa; S_b is the area of the retractable blade on the side of the hydraulic chamber, cm^2; L is the length of the RSS, m; l_2 is the distance from the retractable blade to the deflector stabilizer.
Calculations according to the formulas (1 - 3) for R_d = 147.65 mm, R_o = 122 mm, R_c = 140 mm, l_1 = 0.7 m, l_2 = 2.5 m enable to determine the values of the radii of curvature, which vary from 152 m to 350 m in advance blades at a distance H = 30 — 26.75 mm.

4 THE PRINCIPLE OF OPERATION OF PO IN-THE-BIT RSS

For RSS, based on point-the-bit) are used the internal bending of the shaft of the deviation to change the drift direction. In such a system, the point of curvature of the shaft is inside the body above the bit. The orientation of the shaft curvature is controlled by a servo motor, which rotates at the same speed as the drill column, but in the opposite direction. This enables the geostationary orientation of the drill end to be kept when the column is rotated.

The radius of the borehole curvature for RSS with the change of the bit distortion, in the absence of deformation of the body, is determined by following expression:

$$R = l/(2\sin(\alpha - \beta)) \qquad (4)$$

where β is the angle of inclination of the deflector to the axis of the well, deg.

$$\beta = arctg\frac{D_d - D_c}{2L_1} \qquad (5)$$

γ is a slope angle created by shaft bending, deg

$$\gamma = \frac{3\Delta(1-\eta)^2}{\alpha^3 \eta l_2} \qquad (6)$$

where Δ is the angle of deviation of the shaft at bend

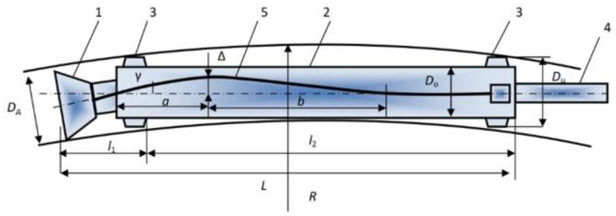

Figure 4. Scheme for calculating the radius of curvature of the RSS with a change in the direction of bias of the bit
1 – a bit, 2 – a body, 3 – a pipe, 4 – a deflector shaft
D_d – the diameter of the bit, H – the blade exit from the body, D_b – diameter of the body, D_s – stabilizer diameter

For Geopilot system with the following parameters, a = b = 2.25 m; l_1 = 0.8 m; l_2 = 4.5 m; D_o = 244 mm, the curvature radii when drilling with a chisel diameter 295.3 mm and various deviations of the deviation shaft are shown in Table 1.

Centralized diameter Dc, [mm]	244			280			
Shaftdeviation Δ, [mm]	4	5	6	2	3	4	5
Slope angle, γ, [°]	1.75	2.18	2.62	0.87	1.31	1.75	2.18
Curvature radius R, [mm]	-	438	194	475	200	126	93

Table 1. Calculated GeoPilot RSS Curvature Radius

In the RSS with changing the direction of distortion or positioning of the bit (point-the-bit) the control mechanism with eccentric sleeve is used.

The scheme of operation of this type of device is shown in Figure 5.

Eccentric bushing 1 has the ability to rotate both around its own axis in the direction η, and around the axis of the case-stator 2 of RSS in the direction τ. The rotor shaft 3 of RSS, on which the bit 5 is installed, rotates inside the eccentric bushing 1 with a frequency ω. Stator housing. RSS is fixed in the well when the plates are moved 4. The turn of the eccentric bushing 1 is carried out through a servomechanism, which is controlled by an electronic unit by commands from the controller computer. The rotation of the eccentric bushing 1 leads to the deviation of the axis of the rotor shaft 3 from the central axis of the body 2 RSS by the gap Δ and the chisel 5 is skewed in one direction or another, depending on the position bushings 1 inside the case-stator 2 RSS.

In Figure 5 a, given the scheme corresponding to the case of drilling without curvature, in which the inner hole of the eccentric bushing 1 and shaft 3 are coaxial housing 2 of RSS (Δ=0), and the bit 5 does not have distortion.

In other cases, illustrated in Figure 5, b, c, eccentric bushing 1, turning, takes a position in the body of the RSS, which provides the bending of the shaft 3, the skew of the bit 5, the change of direction drilling and curve of a borehole in the directions indicated on the diagrams (item 6).

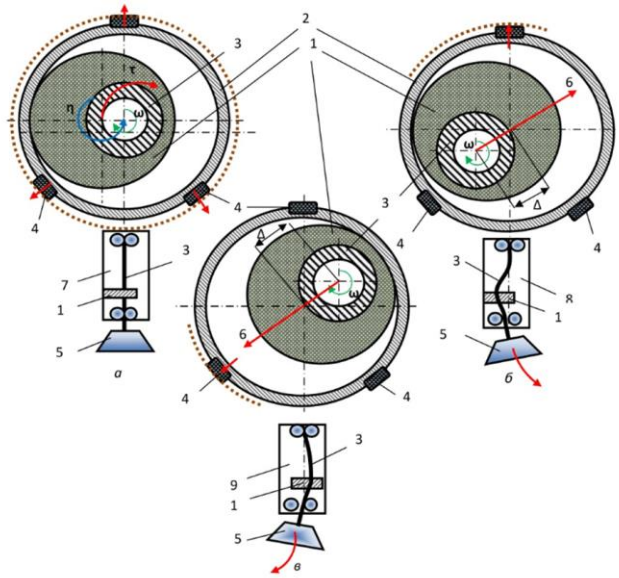

Figure 5. Operational diagram of RSS with bit positioning: a} the position of the system that determines the straight direction of drilling; b, c – the position of the system that determines changes in the direction of drilling; b) 1 – eccentric sleeve, 2 – stator housing, 3 – shaft rotor, 4 – retractable, 5 – a chisel, 6 – the direction of curvature of the well, 7 – a diagram of the RSS during straight drilling, 8, 9 – RSS-schemes when changing

Figure 6 shows a different scheme of control of the bend of the drive shaft of RSS due to the transverse deviation of the symmetrical bush packing. This option is possible but requires a different, slightly more complex drive system, which should carry out transverse force displacement of the sleeve with the shaft, which within the limits of the body the deviator is complicated.

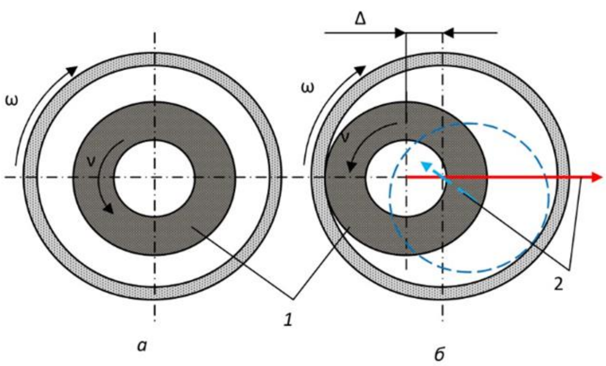

Figure 6. Diagram of the work of the deflecting unit and the crookedness increase of the RSS with positioning the location of the bit: a} the location of the shaft 1 when drilling without deviation; b) the location of the shaft 1 changes the location of the well

5 COMPARATIVE ANALYSIS OF MODERN DEVIATORS FOR THE ISSUE OF DIRECTIONAL DRILLING TO BE MET

Recently, two-directional drilling systems have become the most widespread. These are motor-driven systems and rotary driven systems. It is worth noting that systems with a controlled motor system have been used since the 1960s, and the rotary steerable system appeared relatively recently, namely in the late 1990s.

In this section, the main criteria for comparing the systems with the controlled motor and the rotary steerable system are highlighted.

Based on the practice of drilling directional wells, it is possible to distinguish the following main criteria for drilling systems to be sorted out:

- mechanical penetration rate;
- curvature to meet the project's demands;
- well quality;
- effective length of the horizontal section;
- accident-free driftage;
- the cost of the equipment.

Most boreholes with a rotary steerable system, show an increase in the mechanical drilling rate compared to the downhole engine. In other words, drilling with RSS takes on average twice as much time as drilling with a screw downhole motor.

The occurrence of geological uncertainties near the entry point sometimes requires corrective measures, for example, it is often necessary to increase the rate of curvature increasing. As a result, wells drilled with the RSS provides significant savings in drilling time. In addition, due to the quality drilling of the well, all drill strings of completion are descended with no incident. Hybrid RSS also facilitates deeper penetration into the target object, which leads to an increase in production volumes more than twice.

Evaluating the mechanical drilling speed, it is also necessary to take into account the increase in the length of the horizontal section provided by the RSS. The high sinking rate of the curved interval combined with the high speed of the curvature increasing and the smoothness of drilling of the branch hall enables to reduce drilling time compared to the screw downhole motor.

Another important indicator is the quality of the well. Controlled motor drilling is characterized by low borehole quality, wavy humps and sharp bends, and they are practically unstoppable drawbacks of the method. The reason for this is the "sliding" mode of drilling. In this mode, only the bit rotates, and the drill string simply follows the directing layout. The main difficulties in this case are caused by a lack of rotation of the drill string (Baranov 2017). In sinking, the drill string slides along the lying wall of the well, the flushing fluid moves around it unevenly, which reduces the absorptive capacity of the solution and increases the likelihood of sticking of the string. In addition, the risk of key-seating is increased. Figure 18 shows the images obtained with the caliper. They prove that drilling with a volumetric motor produces a well bore with a spiral groove (at the top in Figure 18), while the rotary steerable system creates a much smoother barrel. This is due to the fact that in the process of drilling rotary steerable system the string is rotating permanently which is conducive to high-quality washing of the borehole and the bit is directed in conjunction with the direction of well drilling.

Figure 7. Comparison of the quality of the well borehole constructed according to data obtained with the caliper: at the top there is the downhole motor with a curved translator, at the bottom, there is the rotary steerable system

It also noted the advantage of RSS for the effective length of the horizontal section, both in the domestic experience of drilling and abroad. Experts in geology and field development give the following data: RSS enables one to drill the well more effectively and place it in the most productive areas of the reservoir. At the same time, the effective length of the horizontal section is increased to 70%, while in wells drilled with the mud motor, this figure is only 30%. As a result, well flow rates are increasing.

The failure of penetration is a really hazy indicator with no capability to draw any certain conclusions. The cause of the accident, including the loss of the tool, may not be directly related to the type of equipment used. However, based on the conditions of downhole engine usage the slightly higher level of risk can be predicted. This is, first of all, due to the previously mentioned "sliding" mode of drilling. The main challenge here is gutter formation and uneven movement of the flushing fluid around the string, which enables a holding strap.

6 CONCLUSIONS

The cost criterion is the most significant obstacle to the widespread implementation of the rotary steerable system. So, if RSS is lost in the well during drilling, the cost of replacement of this equipment may exceed $1 million. A replacement of the mud motor costs about $200 thousand.

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