Designing a High Performance Rock Cutting Tool

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Abstract. The design parameters of a rock cutting tool reinforced with diamond hard-alloy plates of PDC type are described in the article. A core bit with mechanical fastening PDC is described. The description of the bit work on the drift is given. The economic efficiency of the bit is achieved due to the fact that worn PDC plates are easily replaced with new ones, and multidirectional water courses allow creating an efficient turbulent flow on the drift, which increases the mechanical drilling speed. A stabilizing drill bit, reinforced with PDC, having calibrated PDC plates located along the helix, is described, which gives it additional roll stability at the drift. A description of a stabilizing two-level bit of a cutting type is given. On the axis of the bit there are long lines having a different frequency and counter-rotation. The design of the bit helps to reduce the torque on the drilling structure, which prevents the occurrence of torsional vibrations that cause PDC breakdown. A description of the stabilizing cutting-shearing type two-level bit with a permanent magnet mounted inside the upper drill string is given. Magnetization helps to improve the quality of the drilling agent. The proposed rock cutting tool allows to increase the mechanical drilling speed by 1.8 times for the core bit and 2.1 times for the bit.

1. Introduction

The expansion of drilling operations’ production volumes largely depends on the efficiency of the rock destruction process. Creating effective types of drilling tools is determined by the modern requirements and conditions of the existing market relations. It is known that significant material costs in the process of well-boring concern the instrument, hence the creation of new and improvement of existing structures and technologies of their application are our top-priority goals. It follows that having properly chosen tool structure, linked to the technological requirements, we can obtain an optimal design and effective interaction of the tool with the drift, i.e. greatly increase the speed of mechanical rock drilling and rock cutting tools operating time.

Design of bits reinforced with PDC the cutting tool reliability largely depends on its design features, wear resistance and strength [1-7]. On the basis of previously developed characteristic features of the rock-destroying tool parametric series, taking into account the impact of processes occurring in the face and the possibility of their regulation, and also with the aim of increasing the efficiency of rock destruction, removing the products of failure, cooling the working end and increasing the wear resistance of the tool’s working surface, the authors determined the geometrical parameters of the bit design. The working end of the tool is created with the use of diamond hard-alloy
plates (PDC). The flush system is designed in such a way that in the process of work active heat removal is done from the working end of the tool as well as the effective sludge disposal from the face of the well. The use of this bit design will increase the technical and economic indicators of drilling wells.

Crowns reinforced with PDC effectively drill rocks of VI-IX categories. This is of fundamental importance, especially for conditions where the interlayers of rocks of VI-IX categories frequently occur in the section. The advantage is the PDC plates presence, which do not change the contact area of the cutting tool (cutter) with a face in the process of work, they are self-sharpening and have a 100% working off of the diamond layer. When drilling with the PDC bits equipped, in soft and medium rocks they work as a cutting tool, cutting the rock. In the presence of solid rocks of VIII-IX categories, the bits begin to work in the mode of microcutting (abrasion). Such bits are designed primarily to increase the mechanical speed of drilling, increase the volume of drilling on the bit, improve the quality of bottomhole cleaning from the sludge, reduce the section modulus and feeding pressure.

Circulation system of the drill bit, reinforced with PDC plates, should ensure maximum penetration of the buffer fluid into the structure of the drilled rock, facilitating the realization of the Rehbinder effect, i.e. decrease in the strength of the drilled rock under the influence of the buffer fluid capillary energy inside the rock. Circulation system of the diamond bit is a set of channels for the movement of the cleaning agent, which allows full washing of all cutting part elements of the bit matrix with the purpose of cleaning them from the sludge and reliable cooling, as well as cleaning the face of the drilled well to remove the sludge and transport it to the mouth of the well by ascending flow. This system facilitates the penetration of the cleaning agent, primarily liquid, into channels, voids, pores and cracks in the drilled rock, both in the compression-collapse zone in front of the cutters and behind them in the zone stretched from the released energy of the elastic deformation of the rock.

![Figure 1. Core bit with mechanical fastening of PDC.](image)

The authors carried out experimental studies to establish the optimal design of the drill bit's water courses, which provides the most effective fluid impact on the face of the well and the removal of sludge from the drill bit end. Based on these studies, a drilling bit reinforced with PDC plates was proposed [5-7]. A core bit of cutting type with a mechanical fastening of PDC plates with cylindrical wedges with clamp screws is shown in Fig. 1. The bit comprises a body 1 with a connecting thread 2, divided by waterways into sectors 3 fitted with cutters 4 reinforced with PDC 5. In the body 1 in a cylindrical groove having a diameter equal to the diameter of the PDC, there is a cylindrical wedge 6
having a limited degree of freedom in moving along the axes X and Z, but capable of moving along the Y axis. Inserted into the cylindrical groove PDC 5 rests against its rear surface in the end surface of the cylindrical groove and is pressed to it by the cutting force F and the axial force PZ. A cylindrical wedge 6 fixed with a clamp screw 7 of diameter d keeps PDC 5 from moving along the Y axis. The clamp screw 7 keeps the cylindrical wedge 6 from rotating.

For the purpose of improving the design of the drill bit it is proposed to make flushing grooves on the bit multidirectional angle wise. Multidirectional flushing grooves allow to create an effective turbulent flow of the buffer fluid at the face, which contributes to the increase of the drilling rate of rocks, since the bottom scavenging is improving, i.e. large particles of sludge do not penetrate to a cutting bit and are not destroyed for the second time.

The core bit works as follows. Rotating from the flight of the drilling rig, the bit contacting the bottom hole destroys it due to the fact that the advancing cutting member 5 is mounted with a negative front rake $\beta_3$, cuts a channel with the depth h. Lagging cutter 6, which is set with the negative front rakes $\beta_2, \beta_1$ in a centreplane, handles the core and the wall of the well, respectively. When cutting hard rocks, cutting elements 5, 6 are worn; at the same time the wear of the hard-alloy base exceeds the wear of diamond layer in dozens of times, thereby forming a clearance angle, the cutter remains sharp and may continue rock cutting with the swarf thickness h. However, drilling speed depends largely on the removal of wellbore cuttings from the face (bottom hole degradation products). In order to increase the rate of breakdown products removal from the bottom of the well, the flushing channels at the well-forming cutting elements 5 are made counter-angled, and the desired result is achieved.

The authors were given the task to reduce the curvature of the wellbore and increase the mechanical speed of drilling and footage per bit by creating a bit with a distinctive design. The task was solved by means of a stabilizing core bit comprising a body with connecting thread divided by main waterways into sectors that are provided with diamond hard-alloy plates from the end face having negative front rakes in plan to the side inner and outer surfaces of cutting and negative front races to of the bottom face of the well. The bit body is elongated, the main and additional external waterways are inclined at an angle to the right in the direction of rotation. In the form of a screw line, two or more diamond-carbide calibration plates are placed in the additional waterways, each of which is an element of a separate screw line and fixed to the body by soldering at a negative angle from -5 to -15 ° relative to the cutting surface. The screw line of the main and additional waterways has a step depending on the height of the bit. The installation of calibration PDCs in each additional waterway at a negative angle of -5 to -15 ° in a helical spiral facilitates the qualitative calibration of the wellbore, improves the quality of washing by enhancing the flow turbulence regime; thus the removal of sludge is improved, vibration is reduced, the smoothness of the drilling path is made, and as a result, the bending of the bore is reduced, the drilling penetration rates and the amount of hole per bit are increased.

Fig. 2a shows the general view of the crown. The stabilizing core bit comprises a body 1 with a connecting thread 2 separated by main waterways 3 into sectors that are provided with diamond-carbide plates 4 on the end face having negative front races in plan to the side inner and outer surfaces of cutting and negative front races to of the bottom face of the well. The bit body 1 is elongated, the main 3 and additional 5 external waterways are inclined at an angle to the right in the direction of rotation. In the form of a screw line, two or more diamond-carbide calibration plates 6 are placed in the additional 5 waterways, each of which is an element of a separate screw line and fixed to the body 1 by soldering at a negative angle from -5 to -15 ° relative to the cutting surface. The screw line of the main 3 and additional 5 waterways has a step, depending on the height of the bit. The screw line of the calibrating diamond-carbide plates 6 has a step, also depending on the height of the bit.

Diamond-carbide plates processing the face are fixed to the bit with a negative front race $\beta_0$ in the longitudinal plane and with a negative front race $\gamma_c$ in the diametric plane when the well’s wall is formed; (most often $D_{PDC} = 13.5$ mm, front race $\beta_0 = -(10\div20)^\circ$, front race $\gamma_c = -(5\div15)^\circ$).

Small diameter cutters d are fixed in the longitudinal grooves intended for removing drill cuttings from the face during washing the well. These cutters calibrate the well’s wall and impart additional
lateral stability to the bit at the face. Most often, 8 mm diameter cutting elements are used to calibrate the walls of the well, which are installed with a negative front race in the diametric plane $\gamma_c = -(5\div15)^\circ$.

Figure 2. The general form of the drill bit stabilizer (a) and bits with cutting fragment and the calibrating elements (b).

Fig. 2b shows a fragment of a bit with cutting calibrating elements 6 of 8 mm in diameter fixed in additional channel 5, along which the drill fines are removed from the bottom of the well; the PDC forming the wall of the well is designated as 8.

Studies performed at the department of "Drilling of oil and gas wells" in SRSTU (NPI) have shown, that in the process of exploration and production wells drilling with rock cutting tool (RCT), mechanical drilling speed throughout the range of operating frequencies is not dependent on the rotational speed of RCT, but it depends only on the axial load. This means that tiers can be fixed on one of the bit axis, having a different frequency of rotation, but the mechanical drilling speeds, by each of them, will be the same. This development is designed in the form of two patents: No. 2310732 "Multi-level bit of cutting type" and No. 92900 "Stabilizing two-level bit of cutting type" (Fig. 3).

Stabilizing two-level bit (figure 3) of cutting type includes a shank, an inner channel, lower spudding and upper drilling parts with stabilizers, which consist of a number of symmetrically arranged cutting blades which, in their turn, include a radially disposed cutting elements, the bit is divided into tiers, each of which is executed in the form of independent body of revolution located coaxially, and the cutting speeds of the farthest from the longitudinal axis cutting elements of the spudding and drilling layers do not exceed critical values, the stabilizers, equipped with highly resistant pins have calibrating performance.

The drawback of this bit is the impossibility of the drilling agent magnetization, which leads to a deterioration of the solution remote capacity. And also the occurrence of large torsional oscillations when drilling inlam rocks, which lead to the breakage of the bit cutting elements.

The technical result of the invention is to reduce the torque at the drill string and to prevent the occurrence of torsional vibrations during drilling, causing breakage of the cutting elements, to improve the parameters of the buffer fluid, and save chemical reagents.

This goal is achieved by the fact, that the stabilizing two-level bit of cutting and shearing type, including a lower spudding tier, stabilizers of lower spudding tier and the cutting blades of the lower spudding tier, upper drilling tier, including a shank, an internal bit channel, stabilizers of upper spudding tier and cutting blades of the upper spudding tier, the cutting blades of the lower and upper
spudding tiers are symmetrically arranged with radially disposed cutting elements, stabilizers of the upper drilling tier are equipped with highly resistant stabilizers pins having calibrating performance, the number of cutting elements on the blades of the lower spudding tier is equal to the number of cutting elements on the blades of the upper drilling tier, inside which a permanent ring magnet is located coaxially to the bit axis. Cutting elements on the blades of the lower spudding and upper drilling tiers can be made in the form of comb-shaped cutting PDC elements at a negative angle of 10° to 35°.

Figure 3. The stabilizing two-level cutting-type drilling bit. I - planetary gearbox; II - two-level cutting-type drilling bit; 1, 2 - shank and stabilizer of the drilling layer; 3 - cutting blades of the drilling layer; 4 - PDC cutting elements; 5.6 - stabilizer and cutting blades of the spudding layer; 7 - cutting elements of the spudding layer; 8, 9, 10, 11 - center shaft, spider, central wheel and gear ring of the reducer, respectively; 12 - satellites of the planetary gearbox.

Downhole motor and planetary gearbox, that transmit counter rotation to the lower spudding tier with an angular velocity ω1 and to an upper drilling tier with an angular velocity ω2, are used to operate the proposed bit.

The bit works in the following way: when the lower spudding tier 1 rotates with the angular speed ω1 and upper drilling tier 2 rotates with an angular velocity ω2, during axial displacement of the bit, the cutting blades 3 of the lower spudding tier 1 are spudded into the face, expanding as they move the well to a diameter d, which is determined by the position of the outside cutting elements 4 of the lower spudding tier 1 located in the upper parts of the cutting blades 3 of the lower spudding stage 1, and the cutting blades 5 of the upper drilling tier 2 with cutting elements 6 of an upper tier 2, they expand the well as they move to a diameter D, determined by the outside position of the cutting element 6 of the upper drilling tier 2, stabilizers 7 of the lower spudding tier 1 and the stabilizers 8 of the upper drilling tier 2 increase the area of contact with the borehole walls. The torques on the lower spudding and
upper drilling tiers are directed counter-clockwise and are equal in absolute value. This will prevent the occurrence of torsional vibrations, which are one of the main causes of PDC breakdowns.

The drilling agent moving through the internal channel of the bit 13 in the upper drilling tier 2, serving to move the drilling agent from the shank 10 in the upper drilling tier 2 to the circulating openings 11 in the lower spudding tier 1 of bit, flowing through the inner channel of the bit 13 via the circular permanent magnet 12 installed in upper drilling tier 2 annular and is magnetized by it, that leads to an improvement in the quality of the drilling agent, i.e. its basic parameters (viscosity, density, water yield, static shear stress).

To prevent the occurrence of torsional vibrations, it is necessary to free the drilling string from the transmission of torque from the bit. This is possible if the torque on the lower spudding tier and on the upper drilling tier is equal in absolute value but opposite in direction; the number of cutting elements on the lower spudding tier should be equal to the number of cutting elements on the upper drilling tier. By approximating the modulo of the torque values on the spudding and drilling tiers, torsional vibrations on the drilling string can be prevented and the number of PDC breakages from shocks generated by torsional vibrations can be reduced.

The external magnetic field changes the distribution of electron clouds of ions and polarizes the electron clouds of water molecules. In this case, the energy of ions interaction with the nearest water molecules and polarization by ions of nearby water volumes change, which leads to a change in the structure of the solution. The macromolecules of the polymers used are high-molecular compounds and have a linear structure. When the solution is treated with a magnetic field, the length of the
macromolecule increases. As a result, more free water is adsorbed, thereby increasing viscosity and decreasing fluid loss, increasing density and static shear stress, i.e., improving the quality of the drilling agent.

Innovative new generation comb-shaped cutting tools PDC significantly increase the impact resistance of the bit and the mechanical penetration rate. The comb-shape of the PDC cutter increases the efficiency of the cutting force and heat transfer at a higher resistance to the front load on the cutter, which is achieved by increasing the thickness of the diamond layer on the crest by 70%, compared to the standard PDC cutter. Reducing the stress on the cutter to achieve the same penetration rate leads to a more stable and less torque, and improved control of the bit orientation with directional drilling. This advantage allows to increase the intensity of the angle buildup at a higher mechanical penetration rate, thereby increasing the interval of the productive zone and minimizing the unproductive time while maintaining a more accurate well trajectory.

Tests of comb-shaped bits reinforced with PDC, allowed to increase the mechanical speed of penetration compared to the bits reinforced by standard PDC with the same bit designs, which allows to reduce the drilling time and reduce the cost of well construction.

It should be noted that the efficiency of the proposed stabilizing two-level bit of the cutting-shearing type is calculated as the arithmetic mean of the main technological parameters - drilling speed, bit-work-up to total wear, bit cost, PDC wear, bit wear on the diameter, loss of PDC.

2. Conclusion
1. Optimization of the crown structure and bit allows to drill with the optimum values of the axial force and rational values of the specific contact pressure on the face, while reducing lateral movement of the rock cutting tool on the basis of the well.
2. Based on the studies of fracture rock mechanics of medium and higher average category of drillability is grounded at the base level of cutter tool design inventions, enhances the effectiveness of wells structures.
3. Optimal schemes of the rock-cutting tool working ends have been developed, differing in their various functional capabilities.
4. As a result of bench tests, the developed destructive tool showed a high efficiency when drilling rocks of medium and higher grade in terms of drilling.
5. Implementation of the developed rock cutting tools and technology of its application in practice of drilling operations would lead to increase in ROP of the drill bits by 1.8 and 2.1 times.

3. References
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