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A Method for Optimizing the Structure of the Roller Cone Bit Assembly

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ABSTRACT

The conducted studies show that the axial load applied to the bit is distributed unevenly among the roller cone crowns. Middle crowns are the most loaded. The value of the axial load on an individual crown is connected with the deformation of the drilling-bit assembly. We can optimize the structure of the bit to balance the load of its crowns by offsetting them on the cone along the bit radius. They should be placed in such a way that the vertical line crossing the center of the bottom ball of the retaining bearing would pass through the middle of the clearance gap between the crowns of the neighboring roller cones. Bits with the new type of tooth placement were tested on the bench and in production. Such bits had the axial load distributed among the crowns more evenly, which improved their performance indicators.

Key words : bit, drilling, load, roller cone cutting structure, support.

1. INTRODUCTION

When drilling oil and gas wells (deep), blast mining holes (shallow) and other wells, assorted drilling tools are used. Depending on the shape of the drilled bottom hole, a drilling tool can be either a drilling bit or a cutting head. Drilling bits are used for full-hole drilling and cutting heads – for core drilling. The latter is done to extract a column of rock – a core sample. According to the mechanism of rock destruction, rotary drilling bits can be of cutting or cutting-scraping action type and percussion or percussion-shearing bits [1]. This classification is rather conditional, however, since bits of the same type can exert different impact on rocks. Cutting or cutting-scraping bits include blade bits, milling bits, diamond bits, PDC bits, as well as one-cutter and two-cutter drilling bits with spherical heads whose teeth are in a continuous contact with the bottom. Percussion or percussion-shearing bits include roller-cutter bits with cone cutters. Despite the ever-expanding field of application of PDC bits, the roller cone bit has been one of the most common tools for drilling various wells so far. These bits perform the largest volume of well drilling in most countries. Roller cone bits are the most complex of all drill bits. The technology of their manufacture is also very complex and specific. Also very high requirements are imposed on the material of the parts of roller cone bits. Rock-breaking elements are located on the surface of the cone body. They can be steel, milled directly on the protruding annular section of the cone body called the crown. Such elements are called teeth. Rock-breaking elements can also be made in the form of rods made by sintering from tungsten carbide powder (hard alloy), pressed into holes drilled on the crowns of the cones. Such elements are called cutters (or bits). The aggregate of rock-cutting elements is usually called the roller cone or bit cutting structure. In this regard, a distinction is made between bits with milled cutters or carbide cutters. The roller cones are mounted on supports consisting of several different bearings.

The support during the rotation of the cone ensures the transmission of the axial load and torque applied to the bit through the bearings to the bit cutting structure elements that are in direct contact with the bottom rock. Now we consider the diagram of forces acting on the cone from the side of the bottom hole (Fig. 1) [1].

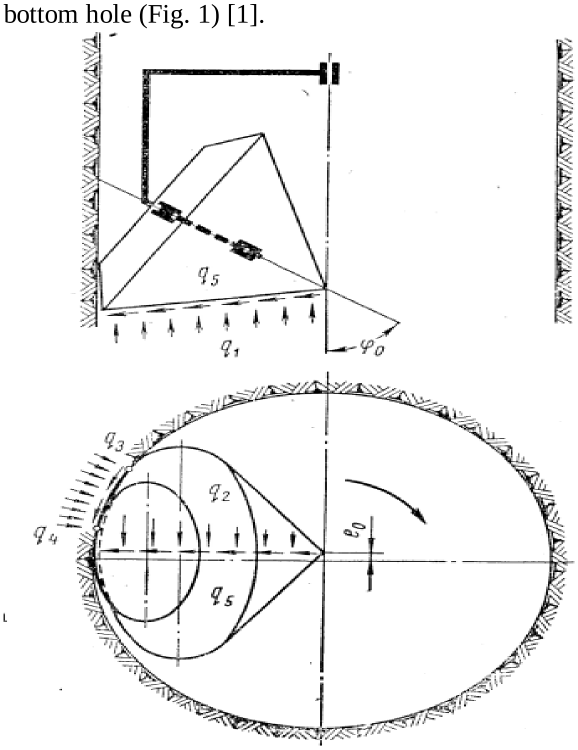

Figure1: Loads acting on the roller cone body from the side of the destroyed rock

From the side of the bottom hole, the cone experiences the impact of the vertical component of the specific reaction of the bottom hole q1, the specific loads q2 and q3 caused by the lateral sliding of the teeth along the bottom and the walls of the borehole in the direction of rotation of the bit, the specific normal reaction of the borehole wall q4 on the occipital part of the cone, and the specific load q5 associated with the sliding of the cone teeth in the radial direction caused by the displacement of the cone axis in the plane e0. It should be noted that the presented diagram of forces acting on the cutting structure and support of the cone is rather arbitrary. In view of the high complexity of the process of interaction of the cutting cones with the rock and the complexity of the design of the roller cone bits, the question of the value and sources of loads in the support of the cone is still insufficiently studied and is debatable. [1,2,3,4,5,6,7,8]. In particular, there are conflicting data on the load of parts of the cutting structure and bearings. Direct measurement of the forces acting on individual elements of the structure (cutters) of the Sh215,9K-PV drilling bit from the side of the bottomhole material was carried out using a special device [9,10,11,12,13]. These measurements showed that the values of forces acting on the cutters of different crowns and different cones differ from each other. The most loaded cutters in the tested drilling bits are the cutters located on the middle crowns of all cones. Statistical processing of the measurement results presented in the form of digital information carried out according to a special program made it possible to establish that the mathematical expectation of the axial force for six revolutions of the drilling bit, acting on the middle crown of the first cone, can be about twenty percent of the total axial force applied to the drilling bit. This significantly exceeds the value of the forces on the cutters of the peripheral and apex crowns of this cone. The mathematical expectations of axial forces acting on the middle crowns of other cones also exceed similar forces acting on the cutters of the peripheral and apex crowns. The measurement results showed that individual cutters of the middle crown of the first roller cone the Sh215,9K-PV drilling bit can take up to 50% of the total axial load.

2. METHODS

One of the factors that determine the unevenness of the loading of the cutters located on different crowns of the cones is the different rigidity of the "cone-bottom" system, when interacting with the bottom of the crowns of the cones located at different radii of the drilling bit. We can make this conclusion by considering the plane model of the interaction of the bit cones loaded with axial force and torque with the bottom hole material in the case when each roller cone rests on one crown cutter (Fig. 2).

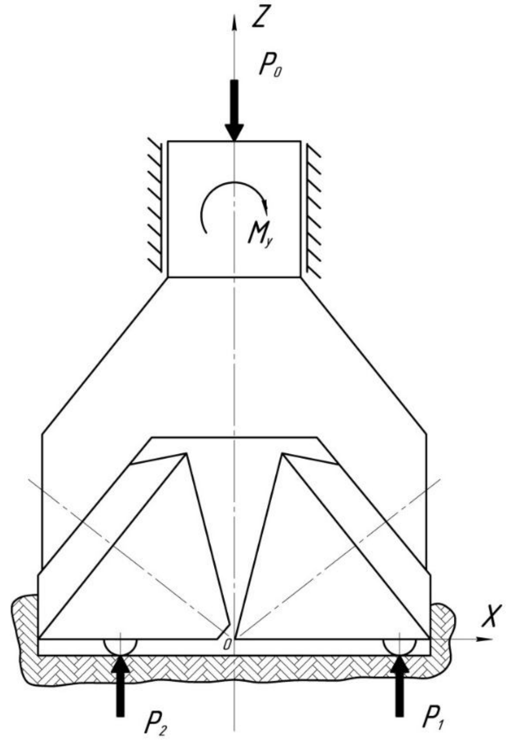

Figure 2: Flat model of a roller cone bit.

If we assume that the bit body can only move strictly vertically, without distortions, then such a system will be statically indeterminate once. To solve it, it is necessary, in addition to static equations, to draw up additional equations for the joint deformation of the bit parts. Thus, the values of the forces P1 and P2 will be inversely proportional to the rigidity of the roller cone assembly upon contact with the bottom of the corresponding crown bits. To test this assumption, analytical and experimental studies of the vertical rigidity of the roller cone assembly were carried out depending on the radius of application of the axial load to the roller cone. On the basis of this assumption, an experimental-theoretical method was developed for calculating the value of the forces acting on the roller cone cutting structure [14]. The direct measurement of the values of the axial force acting on the individual crowns of the bit cones when working on a non-destructible bottom was carried out on a special bench using an original measuring device [12]. The results of measuring the average axial forces in kN acting on each crown of each cone at an axial load on a bit of 80 kN and an angular velocity of a bit of 3.31 s-1 are given in [14]. Here, for clarity, the average values of these forces are given in percent, the average maxima, minima and amplitude of forces - in kN.

Comparison of the calculation results with experimental data allows us to conclude that this method can be used for both a qualitative and quantitative assessment of the loads acting on the roller cone crowns, especially at the design stage when choosing the optimal arrangement of the cone cutting structure.

3. RESULTS

The analysis of the measurement results made it possible to establish that the mathematical expectation of the value of the axial force acting on a particular crown of the bit cones depends on the distance the given crown is from the axis of the bit. The value of the vertical movement of the crown, which occurs as a result of deformation of the bearings of the support unit, the bearing pin, the selection of clearances in the bearings, occurring under the action of the axial load applied to the crown, also depends on the distance from the axis of the bit to this crown. Fig. 3 shows these dependences obtained as a result of measurements [12, 15]. It also shows the design of the bearings on which the cones of the test Sh215.9K-PV bit are secured.

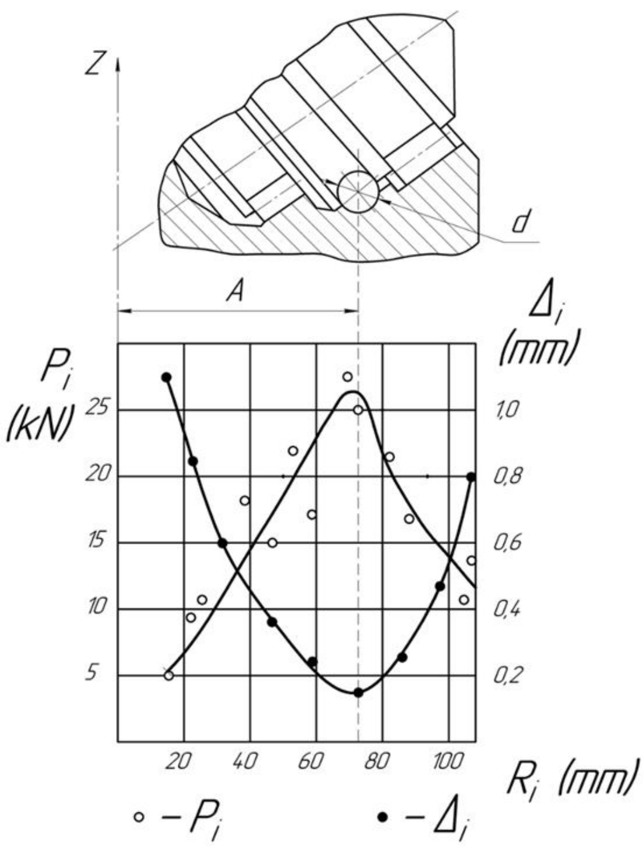

Figure 3: Dependence of the axial force on the crown Pi and the vertical displacement of the crown Δi on the distance to the bit axis Ri for the Sh215,9K-PV bit

Analyzing the dependences shown in Fig. 3, we can easily conclude that the mathematical expectation of the force acting on the crown is inversely proportional to its displacement. The stiffer the crown, the more axial load it takes. Moreover, both curves have an extremum located at the same distance A from the bit axis. Comparing these curves with the design of the roller cone bearing unit, one can make sure that the center of the lower rolling body of the ball bearing is located at the same distance from the bit axis. Different movement of the crowns and their different load can be caused by a change in the stress state of the bit parts when changing the point of application of the force acting on the crown from the side of the destroyed rock [16,17]. The above analysis allows us to propose a new approach to the selection of the arrangement of the cutters of the cutting structure on the body of the bit cones. The essence of this new approach to the design of the cone cutting structure is to eliminate the placement of the cone crowns at a distance A (see Fig. 3) from the bit axis. This approach is protected by the inventor's certificate [18], obtained for the structure "Roller cone bit", characterized in that in order to increase the durability of the bit by more evenly distributing the load over individual bearings and roller cone crowns, all crowns are located on cones according to the ratio:

$$\left|A - R_i\right| \geq d / 2 \qquad (1)$$

where A – maximum distance from the bit axis to the center of the ball of the lock bearing;

R_i - maximum distance from the bit axis to the point of intersection of the crown symmetry axis with the roller cone generatrix;

d – diameter of the ball of the lock bearing.

Analysis of serial designs of roller cone bits Sh215,9K-PV and Sh215,9TKZ-CV-3, on which the studies were carried out, showed that the above condition (1) is not met for both types of bits. The middle crowns of the first cones of these bits are located at radii R_i , equal to distance A. As our studies have shown [19, 20], it is on the cutters of these crowns that the greatest axial force acts.

4. DISCUSSION

Guided by the formula of invention proposed in [18], changes were made to the design of the Sh215,9K-PV bit, consisting in placing the cutters on the cone bodies in accordance with expression (1). Fig. 4 shows the new arrangement of the crowns on the roller cones of the Sh215,9K-PV bit. The figure also shows the design of the bearings on which the cones are fixed.

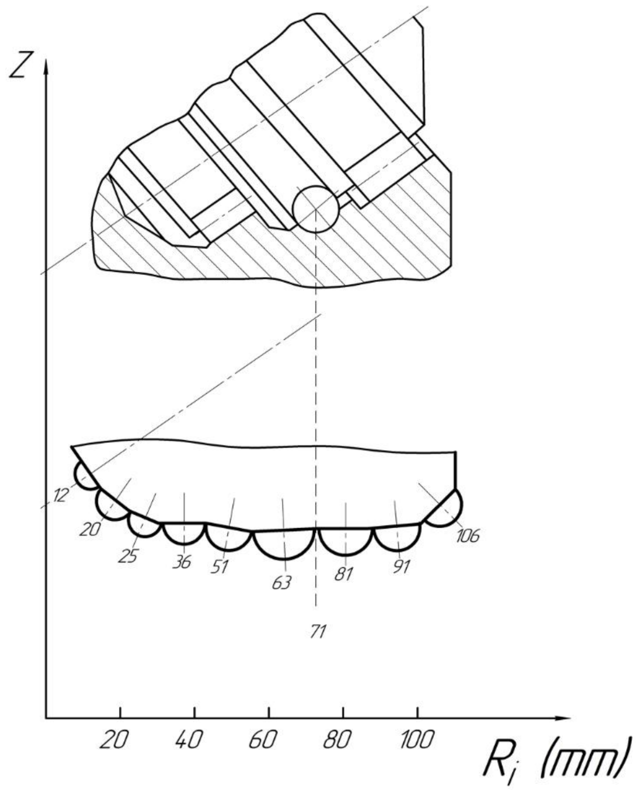

Figure 4: New arrangement of crowns on roller cones of the SH215,9K-PV bit

Before manufacturing a bit with a new arrangement of the crowns on the cones, according to the method that we developed [14], the values of the mathematical expectations of the axial forces that will act on the cone crowns from the side of the bottom hole were determined. The calculation results confirmed that for a bit with a new arrangement of crowns along the cones, the calculated mathematical expectations of axial forces should be distributed over the crowns more evenly than for serial bits. After analytical verification of the proposed arrangement of the cutting structure, it was decided to manufacture full-scale samples of bits.

All manufactured bits were carefully checked for compliance with the accuracy parameters established by the regulatory documentation. As a result of measurements, a bit was selected the height difference of the cones of which was minimal. This was done in order to minimize the effect of manufacturing accuracy on the research results [19, 20]. For the selected bit on the bench [10, 11, 12], the values of the mathematical expectations of the axial forces acting on the roller cone crowns from the bottom hole under bench conditions were measured. The results of experimental bench tests also showed that for a bit with a new arrangement of crowns on cones, the mathematical expectations of axial forces are distributed over the crowns more evenly than in serial bits. So, for example, the most loaded middle crowns of the first, second and third cones of a serial bit perceive respectively 19.1%, 12.2% and 9.9% of the total axial load on the bit. For a bit with a new crown arrangement, the corresponding values are 15.5%, 14.1% and 13.3%. Thus, the most loaded middle crown of the first roller cone of the serial bit perceives the axial load 1.93 times more than the least loaded middle crown of the third roller cone. A bit with a new arrangement of crowns on cones has a similar figure of only 1.17. The load is also distributed more evenly among the individual cutters of the new bits.

5. CONCLUSION

Based on the results of analytical studies and bench tests, it is still impossible to draw reliable conclusions about the advantages of a new product design. These advantages can only be confirmed by testing the product, including the drill bit, in production conditions. Similar tests for bits of the proposed design were carried out while drilling blast holes in a mining open pit. Drilling was carried out in hard formations such as dolomite and magnesite, for which this type of drill is intended. One of the main indicators of drill bit performance is the average ROP. Tests have shown that bits with a new arrangement of crowns on cones made it possible to obtain an average ROP of 1.24 - 1.3 times the average penetration rate per one bit of a serial design. Inspection of broken bits of new design and serial ones showed that the performance of almost all bits was limited by the durability of the bearing units of the cones. The cutting structure in most cases remained operational. The higher performance of bits with a new arrangement of cutters on the cones is due to the fact that approximately the same axial load acts on different cones and, as a result, approximately the same wear of the bearing assemblies occurs. Thus, the equal strength of all parts of the bit is ensured.

The performed analytical, experimental and industrial studies of roller cone bits with a new arrangement of cutters on cones have confirmed the possibility of increasing the efficiency of the drilling bits with minimal costs. When designing new bits and improving existing structures, it is necessary to use the possibility of leveling the load of individual bit parts and, thereby, ensuring their uniform strength.

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