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Distribution of an Axial Load along the Teeth Rows of Rolling Cutters of Drill Bits (Test Results)

[1]Vladimir A. Pyalchenkov, Vladimir V. Dolgushin[2] and Irina A. Purtova[3], Lyubov I. Nikitina[4]

[1,2]Irina A. Purtova Industrial University of Tyumen Volodarskogo, 38, Tyumen 625000, Russia.
[1]Orcid: 0000-0002-3867-4700

Abstract.

The durability of cutting elements and bearings of roller cutter drill bits depend on load level of their components. A considerable number of analytical and experimental studies are devoted to the study of regularities of distribution of efforts along the teeth of the cutting elements and roller bearing supports of drill bits. For experimental measurement of value of efforts, acting on separate teeth of each rolling cutter of the drill bit in the process of overrolling of drill bit under the load on metal bore-hole bottom, there was constructed the measuring device and special stand. This stand provides the possibility of testing of the drill bits of various standard types and sizes with a minimum expenditure of time and materials. The choice of the standard types of the drill bits is justified to conduct the research and of the testing methodology. The results of the research are suggested of distribution of axial load amoung the teeth rows of rolling cutters of drill bits with hard-alloy and milled inserts. The results obtained made it possible to establish that the load on the teeth rows of rolling cutters distributes quite unevenly, and the intermediate teeth rows of rolling cutters are most loaded. At this, this unevenness remains unchanged at different constructive design of cutting elements. The distribution of axial load along the rolling cutters of drill bits is also uneven, the maximum axial load is taken by the first roller cutter, the minimum - by the third. However, the degree of unevenness of distribution of an axial load along the rolling cutters depend largely on constructive design and mainly on the location of teeth rows on rolling cutters alond the radius of the drill bit, which is especially significant for drill bits with hard-alloy inserts. It is established that the nature of the distribution of the axial loads along the teeth rows is related to the design of the rolling cutter support assembly. To reduce the unevenness of the distribution of an axial load between the teeth rows and the rolling cutters, it is necessary to change the scheme of interaction with the bore-hole bottom.

Keywords: drilling, roller cutter drill bit, rolling cutter, cutting elements, bearing, load.

INTRODUCTION

Reliability and durability of drilling bits depend on the value of forces, acting on the teeth of rolling cutters, directly contacting the rock [1]. A considerable number of both analytical and experimental studies have been devoted to investigations of the patterns of the interaction of the rolling cutters teeth with a bore-hole bottom. The model of the interaction of the rolling cutters teeth with a rock is proposed in [2]. The tooth of the drilling bit affects the rock, making a complex movement, depending on the parameters of rotation of the rolling cutter and the drilling bit, slippage of the rolling cutter along the bore-hole bottom Experimental studies of the interaction of separate elements of the rolling cutters of the drilling bit with the rock are performed according to the scheme of drilling with a single tooth. The results of an experimental study of the interaction of a drilling bit with a rock are presented in [3,4]. In [5], the axial force acting on the drilling bit from the fractured rock side is determined. In [5, 7] analytical dependencies are proposed for determining the velocities of collision and movement in contact with the bore-hole bottom of cutting elements of teeth row of rolling cutter, as well as nonlinear dependences between the rotation angles of teeth row around its axis and around the axis of the drilling bit when working on a deformable bore-hole bottom. Using wear resistance as a criterion of optimization in this model, the author [8] determines their optimal ratio, varying the geometric parameters. In [7] the model is considered, which is a set of interconnected modules for calculating the kinematics and dynamics of the bit, the drill string bouncing, as well as formation and bottom-hole deepening during drilling. The model allows for a given combination of design parameters of the drilling bit and the drill string, drilling mode and drilling conditions to determine for any time of drilling the distribution of forces and movements of any point of the drill tool, starting from the upper end of the drill string and to the tops of teeth of roller cutters of drilling bit [6]. Various mathematical models of roller cutter drill bits for the analytical determination of the forces acting on roller bearing supports are proposed in [9,10]. In [11], a methodology and an ensemble of devices and measuring equipment were proposed for the experimental determination of the loads, taken by each rolling cutter during their operation at the bore-hole bottom. The methodology consists in the experimental determination of the load, acting on each section of the roller cutter drill bit model, followed by analytical assessment of the distribution of these loads between the journal bearings.

METHODS

We have developed a device that makes it possible to measure the forces perceived by each tooth of each rolling cutter of a real drilling bit when it interacts with an indestructible bore-hole bottom [12,13]. For separate registration of the forces acting on teeth rows of each rolling cutter, the bore-hole bottom is divided into two sectors, a working (measuring) sector I and a non-working section II (Fig. 1). When the drilling bit rotates along the bore-hole bottom, the rolling cutters are contacting in series with the ring inserts of the working sector of the bore-hole bottom I.

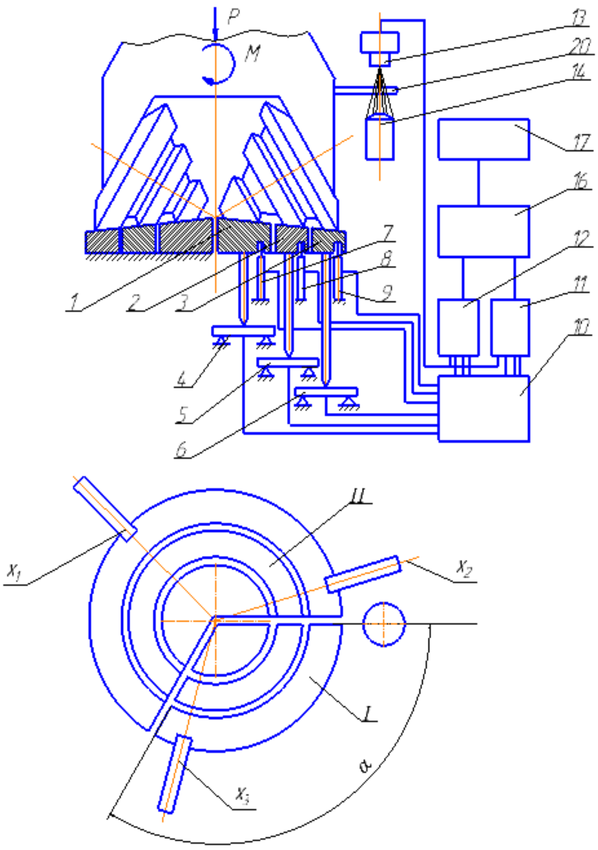

Figure. 1: Principle scheme of measuring and registration of forces, acting on the teeth of cutters: 1,2,3- concentric bottom of operating sector; 4,5,6,7,- strain-gauge beams; 7,8,9- bushings; 10-amplifier; 11,12-oscilloscopes; 16,17- converting equipment; X_1, X_2, X_3 – rolling cutter axis.

To implement this method, a special stand has been designed and manufactured, which makes it possible to rotate the tested drilling bit along the bore-hole bottom of the measuring device. The axial load on the drilling bit can vary smoothly within the range from 0 to 200 kN, which makes it possible to test the drilling bits of different standard sizes for axial loads close to or equal to the workloads, depending on the size of the drilling bit being studied. The drive of the stand provides a change in the angular velocity of the drilling bit from 0.16 to 11.34 s-1, therby simulating the conditions of rotary drilling. The vertical components of the interaction reactions of the rolling cutter teeth with a bore-hole bottom, parallel to the axis of rotation of the drilling bit, deform the strain-gauge beams 4, 5, 6. Sensing elements for recording the tangential components are the bushings 7, 8, 9. The deformations of the beams and the bushings are converted by sensors into electrical signals proportional to the values of the axial and tangential reactions of interaction between the teeth of the rolling cutters of the drilling bit with the bore-hole bottom, which are registered by the oscilloscopes 11, 12 and processed through the special equipment.

RESULTS

To study the influence of the design of cutting elements on the distribution of the axial load along the teeth rows of the rolling cutters the tests were conducted of the drill bits V-ACS74Y-R1190-6 (SH215.9K-PV) and SH215.9TKZ-CV-Z, which have different location of teeth rows on rolling cutters, and also different shape and number of hard-alloy inserts. The methodology of the research of load distribution on the cutting elements of drill bits and the choice of test modes are justified by the results of special studies. The tests were carried out at an axial load on the drill bit P = 80 kN and the angular velocity of the drill bit $\omega\_g = 3{,}3\ s^{-1}$. The given results of studies of the distribution of an axial load between the teeth rows of each rolling cutter of the drill bit V-ACS74Y-R1190-6 (SH 215.9K-PV) make it possible to conclude that an average load level of teeth rows of different rolling cutters is significantly different from each other (Table 1). The largest share of the entire axial load acting on the drill bit is received by the intermediate teeth row of the first rolling cutter. The relative load level of this teeth row, at a load on the drilling bit of 80 kN and an angular bit velocity of 3.3 s^{-1}, is 19.1% of the total axial load on the drill bit. This significantly exceeds the relative load level of adjacent to it peripheral and top teeth rows, taking respectively 10.6% and 13.4% of the total axial load on the drill bit. A similar pattern is observed also for other rolling cutters of the studied drill bit (Table 1).

Table 1: Results of tests of drill bits V-ACS74Y-R1190-6 (SH 215.9K-PV) at an axial load on the drill bit R=80 kN and an angular bit velocity ω_g=3.3 s $^{-1}$

Indicators of teeth row load level	Number of the teeth row in order								
	1	2	3	4	5	6	7	8	9
The average value of effort, kN	9.9	18.1	12.5	8.3	11.3	8.8	10.0	5.2	5.4
The average value of effort, %	10.6	19.1	13.4	8.7	12.2	9.5	10.8	9.9	5.8
The average maximum of effort, kN	13.6	25.0	21.2	12.6	16.0	14.8	12.7	16.6	8.7
The average minimum of effort, kN	6.4	10.8	3.5	4.1	6.4	2.6	7.5	3.8	1.8
The amplitude of effort, kN	7.2	14.2	17.7	8.5	9.6	12.2	5.2	12.8	6.9

For convenience, all the teeth rows of rolling cutters are numbered in order from the peripheral teeth row of the first rolling cutter (teeth row 1), to the top teeth row of the third rolling cuter (teeth row 9). Summing up the relative loads acting on the teeth rows of one rolling cutter, it can be established that the most loaded is the first rolling cutter, which receives 43.1% of the total load on the drill bit, the second place is occupied by the second rolling cutter (30.4%) and the least loaded is the third rolling cutter (26.5%). The results of tests of the drill bits SH215.9TKZ-CV-Z are given in Table 2. For the drill bits of this standard type, the intermediate teeth row of the second rolling cutter is the most loaded teeth row. The average value of the force on this teeth row is 17.67 kN, which is 19% of the total axial load on the drill bit. For the drill bit SH215.9TKZ-CV-3, the load of the intermediate teeth row of each rolling cutter is also higher than that load level of the top and peripheral teeth rows, and the difference in the load level of the intermediate and adjacent to them teeth rows for the drill bits of this standard type is more significant than for the drill bits of the K -PV standart type.

Table 2 Results of tests of drill bits SH215.9TKZ-CV-Z at an axial load on the drill bit R=80 kN and an angular bit velocity ω_g=3.3 s $^{-1}$

Indicators of teeth row load level	Number of the teeth row in order								
	1	2	3	4	5	6	7	8	9
The average value of effort, kN	8.2	14.3	11.3	8.0	17.7	6.6	10.0	13.7	3.3
The average value of effort, %	8.8	15.4	12.1	8.6	19.0	7.1	10.7	14.7	3.6
The average maximum of effort, kN	10.3	20.6	17.8	10.9	27.0	10.3	11.9	21.6	5.2
The average minimum of effort, kN	5.8	7.6	4.6	5.2	8.3	2.6	8.2	5.3	1.1
The amplitude of effort, kN	4.5	13.0	13.2	5.7	18.7	7.7	3.7	16.3	4.1

Discussion. When comparing the relative load level of the rolling cutters of drill bit of this standard size it can be seen, that the most loaded rolling cutter in this drill bit, as well as in the drill bit V-ACS74Y-R1190-6 (SH 215.9K-PV), is the frist rolling cutter, taking 36.3% of total axial load. The second place on the level of load takes the second rolling cutter, perceiving 34.7% of total load, and the least loaded is the third rolling cutter – 29.0%. From these results it is evident that the unevenness of the distribution of the axial load along the teeth rows of drill bit is observed in both standard sizes of drill bits. However, the distribution of the load along the rolling cutters of drill bit SH215.9TKZ-CV-Z is significantly more even, then along the rolling cutters of drill bit V-ACS74Y-R1190-6 (SH215.9K-PV). If we take the value of the load acting on the least loaded third rolling cutter of the drill bit V-ACS74Y-R1190-6 (SH215.9K-PV) as unit, then the load on the first and second rolling cutters will be 1.63 and 1.15, respectively. At the same time for the drill bit SH215.9TKZ-CV-Z the relation of an axial load, taken by first and second rolling cutters, to the load, taken by the least loaded third rolling cutter, will be respectively only 1.25 and 1.20. Because the number of the teeth on particular teeth tows of different rolling cutters is not the same, then the assessment the load level of the cutting elements of particular teeth rows only by the value of average axial load on the teeth row is apparently unsufficient. In Fig.2. and Fig.3. the diagrams of the distribution of forces for each teeth row of all rolling cutters of drill bits V-ACS74Y-R1190-6 (SH215.9K-PV) and SH215.9TKZ-CV-3 are given, combined with the schemes of the cutting elements of the rolling cutters and the schemes of differentiation of the bore-hole bottom by the teeth rows.

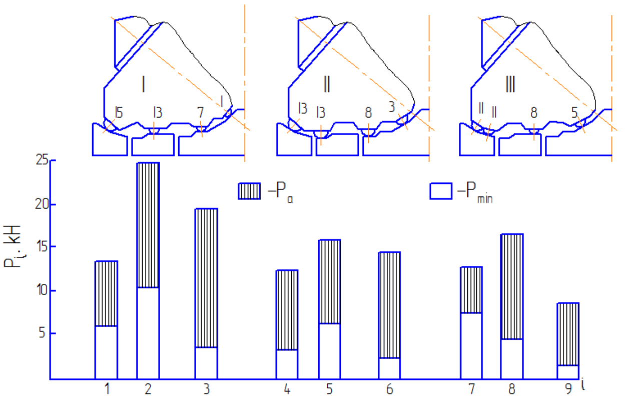

Figure.2: Diagram of distribution of axial load along the teeth rows of rolling cutters of the drill bit V-ACS74Y-R1190-6 (SH215.9K-PV) (I,II,III- number of the rolling cutter; 15,13,7,…- number of teeth on the teeth row; Pi- force on the teeth row; i- number of the teeth row; P_{a}- amplitude of force; Pmin- minimum of force)

The diagram shows the average values of the axial forces amplitudes acting on the teeth rows, as well as the average minimum values of the axial forces. The results were obtained when testing the drill bits with an axial load P = 80 kN and an angular velocity of 3.3 s^{-1}.

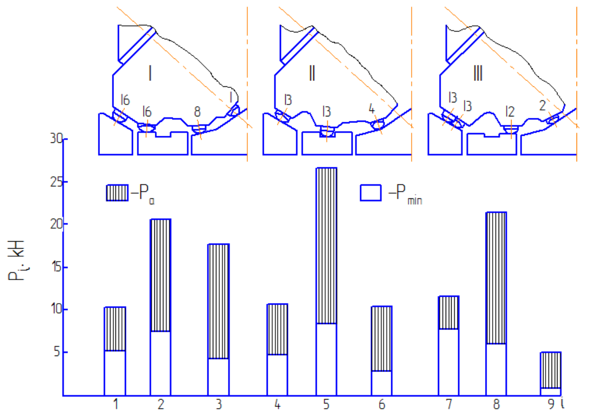

Figure.3: Diagram of distribution of axial load along the teeth rows of rolling cutters of the drill bit SH215.9TKZ-CV-3(I,II,III- number of the rolling cutter; 16,16,8,…- number of teeth on the teeth row; Pi- force on the teeth row; i- number of the teeth row; P_{a}- amplitude of force; Pmin- minimum of force)

The nature of the distribution of maximum of forces along the teeth rows of particular rolling cutters approximately corresponds to the nature of the distribution of the average values of the forces, but the difference in the value of the forces acting on the intermediate teeth row and adjacent to it teeth rows at this is even more significant. The maximum in value axial forces act on the second teeth row of the drill bit V-ACS74Y-R1190-6 (SH215.9K-PV) and the fifth teeth row of the drill bit SH215.9TKZ-CV-3 and are 25.03 kN and 26.96 kN, respectively. The design of the bearing assemblies of rolling cutters of drill bits of standard type K and TKZ is practically the same, and these drill bits differ from each other, mainly by the constructive design of cutting elements and by the location of teeth rows on the rolling cutters.

Conclusions. In this regard, it seems necessary to establish the dependence of the change in the value of the maximum axial force acting on the teeth row from the radius of the drill bit on which this teeth row is located. This dependence, combined with the scheme of the bearing assembly of the rolling cutter, is shown in Fig. 4

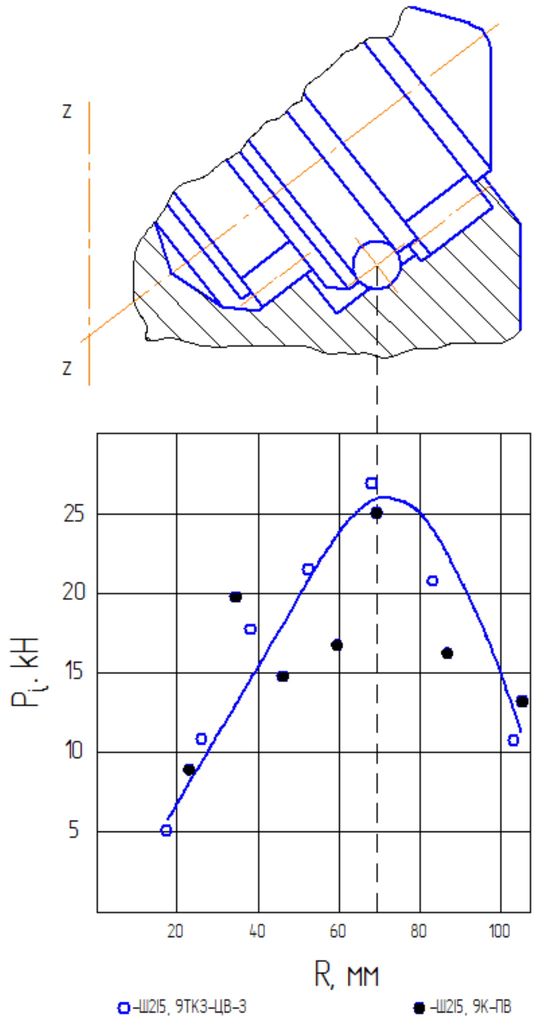

Figure.4: The influence of the position of the teeth rows on their load level (Z-Z - axis of the drill bit, Pi - force at the teeth row, R - radius of the location of the teeth row)

As can be seen from the above figure, the distribution of points characterizing the load level of particular teeth rows is quite significant, however, a qualitative regularity is yet traced. It is that the dependence has a maximum, being close to the middle of the drill bit radius, moving away from which both to the drill bit axis and to the periphery, the average value of the maximum force, acting on the teeth row, decreases. At that, the greatest axial force for both standard types of the studied drill bits act on the teeth rows, a radius of location of which is about 70 mm. This agrees with the results of our analytical and experimental studies [3,4,10]. On this radius the center of the lower ball of the ball-lock cone retention is located. When applying an axial load to these teeth rows, the support assembly of the rolling cutter has a maximum vertical stiffness, since the load is distributed along all three bearings of the support. When the radius of the application of the load is changed, the rolling cutter rolls on the pin and the vertical stiffness of the support assembly decreases. In order to check whether the obtained regularity of the distribution of an axial load along the teeth rows remains for the drill bits with milled cutting elements, the tests of the drill bits SH215.9T-CV were carried out. For the drill bits SH215.9T-CV the most loaded is the second rolling cutter, perceiving about 40% of the total axial load. The most loaded teeth rows of all rolling cutters of the drill bit of this standard type are, as well as for the drill bits with hard-alloy inserts, the intermediate teeth rows. However, this maximum is not so visible and the load level of the top teeth rows for the drill bit with the milled teeth is close to the load level of the intermediate teeth row. For example, the average value of the maximum force acting on the intermediate teeth row of the second rolling cutter is 16.8kN, and on the top teeth row of the second rolling cutter is 15.7kN. This can be explained by the following reasons. As established by our researches [2,6,7,10], the stiffness of the supporting assemblies of the rolling cutters has a significant influence on the distribution of the axial load along the cutting elements. For the drill bits, equipped with hard-alloy inserts, the areas of contact with the bore-hole bottom of the teeth located on different teeth rows are approximately the same, because the diameters of the teeth differ insignificantly (8 ... 10 mm on the top teeth rows and 10 ... 12 mm on the peripheral and intermediate teeth rows). That is why the stiffness of the system “tooth-rock” for different teeth rows in this case can be considered practically the same and not having a significant influence on the nature of the distribution of the load along the teeth rows of rolling cutters. In the drill bits with milled cutting elements, the size and shape of the blunting areas of the teeth, located on different teeth rows, vary quite significantly. Therefore, the stiffness of the "tooth-rock" system exerts a significant influence on the distribution of the load along the teeth rows of the rolling cutters as well as the stiffness of the support assembly.

The results of the above studies of the distribution of an axial load along the teeth rows of the drill bits made it possible to establish that the load is distributed along the teeth rows of the rolling cutters very unevenly, and the intermediate teeth rows of the rolling cutters are the most loaded. At that, this unevenness remains unchanged for different constructive design of cutting elements. The distribution of an axial load along the rolling cutters of the drill bits is also uneven, the maximum axial load is perceived by the first rolling cutter, the minimum - by the third one. However, the degree of unevenness in the distribution of an axial load along the rolling cutters of the drill bits depends to a large extent on the constructive design of the cutting elements, and mainly on the nature of the location of the teeth rows on the rolling cutters along the radius of the drill bit, which is especially significant in drill bits with hard-alloy inserts cutting elements. To reduce the unevenness of the distribution of an axial load between the teeth rows of rolling cutters, it is necessary to change the scheme of the location, placing the teeth rows in such a way that, for the drill bits of the standard types being studied, they would be located as far as possible from the radius of the drill bit equal to 70 mm.

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