International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 22 (2017) pp. 11901-11906

Methodology of Experimental Measurement of Loads, Acting on Rock Cutting Elements of Drilling Bit

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

Industrial University of Tyumen Volodarskogo, 38, Tyumen, 625000, Russia.
ORCID 0000-0002-3867-4700

Abstract
To assess the reliability and durability of the cutting elements of roller cutter drill bits and bearing assemblies of rolling cutters, it is necessary to know the values of the forces acting on the rock cutting elements of a rolling cutter. A fundamentally new measuring device is known that allows measuring the value of force acting on each tooth of each rolling cutter when interacting with an indestructible bore-hole bottom, consisting of concentric steel rings divided into two sectors. To implement this method, a stand was designed for rolling the drilling bit under load on the bore-hole bottom of the measuring device. A methodology for measuring the forces acting on the cutting elements of a roller cutter drill bit is developed. The substantiation of the choice of the object of research is given and based on the results of the conducted methodical experiments and their statistical processing the minimum required duration of one test and the number of repetitions of each test are determined to obtain reliable results at a given level of confidence probability and permissible measurement error. The analysis of the scheme of interaction of cutting elements of one rolling cutter with the bore-hole bottom is made, on the basis of which it was concluded that the axial components of the forces have a greater influence on the useful life of the cutting elements than the tangential ones. Therefore, when selecting the test regimes, only axial components were evaluated. Optimal intervals of axial loads on the drill bit and bit rotation frequencies are determined, which allow to obtain an actual model of the distribution of forces on the cutting elements the drill bit. The developed methodology with the use of a computer makes it possible to obtain very quickly a large amount of reliable information about the loading of all cutting elements of roller cutter drill bits of various standard sizes for the purpose of optimizing the design of their cutting elements and bearings.

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. 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 [1]. 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 [2,3]. In [4], the axial force acting on the drilling bit from the fractured rock side is determined. In [1, 5] 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 [6] determines their optimal ratio, varying the geometric parameters. In [5] 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. Various mathematical models of roller cutter drill bits for the analytical determination of the forces acting on roller bearing supports are proposed in [7,8,9]. In [10,11], 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. An analysis of the results of known experimental and analytical methods for determining the load on the cutting elements of the drilling bit shows insufficient knowledge of this issue.

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.

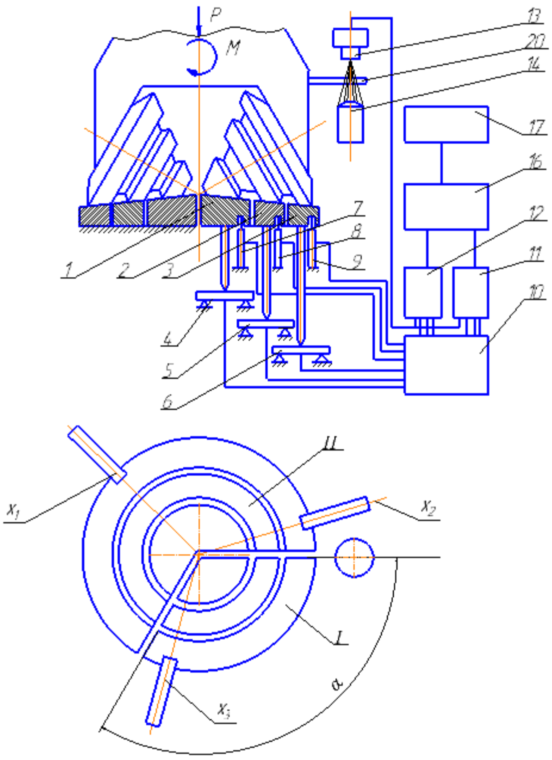

Figure 1: Principle scheme of measuring and registration of forces, acting on the teeth of cutters: 1,2,3- concentric bottom of operating sector; 4,5,6,7,- strain-gauge beams; 7,8,9- bushings; 10-amplifier; 11,12-oscilloscopes; 16,17- converting equipment; X_1.X_2,X_3 – rolling cutter axis.

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

As the object of the test, 215.9 mm diameter drilling bits with hard-alloy inserts as cutting elements, widely used for drilling of exploration and production wells for oil and gas, as well as blast holes in quarries, were selected. The main volume of the research was carried out on drilling bits V-ACS74Y-R1190-6 (SH215.9K-PV), intended for drilling in hard rocks with the cleaning of the bore-hole bottom with compressed air or air-water mixture. The safe axial load capacity on the drilling bit is 250 kN, the recommended angular velocity of the drilling bit is from 0.8 to 1.2 s^{-1}. The choice of this type of the drilling bit as the main object of the study is due to the fact that the cutting elements of the rolling cutters of this drilling bit are made of hard-alloy round headed inserts of the same type, which allows to exclude the possible influence of the shape of the teeth on the parameters under study. Besides that, the bearing assembles of rolling cutters of these drilling bit are made according to a widely used scheme: large roller bearing, ball-lock cone retention, small roller bearing. This makes it possible to extend the results of the study of given drilling bits to bits of other types having the same scheme of bearing assemblies. Fig. 2 shows the scheme of cutting elements of rolling cutters of studied drilling bit and the scheme of differentiation of the bore-hole bottom by teeth row.

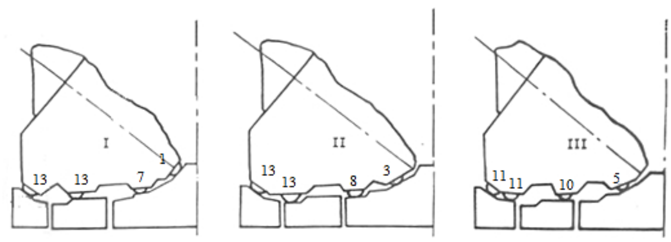

Figure 2: Scheme of cutting elements of drilling bit V-ACS74Y-R1190-6 (SH215.9K-PV) and a scheme of differentiation of the bore-hole bottom by the teeth rows (I, II, III - number of rolling cutters, 13, 13, 7, 1 ... - number of teeth on the teeth rows).

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 22 (2017) pp. 11901-11906

Studies were carried out on a metal bore-hole bottom made of low-carbon structural steel. The patterns of the distribution of forces on the cutting elements, obtained during research on the metal bore-hole bottom, will, in our opinion, persist even when drilling in hard and very hard rocks. In order to reduce the drilling bit running-in time, the metal bore-hole bottom was manufactured with a profile simulating the profile of the run-in bore-hole bottom. Before recording, the drilling bit was worked to the bore-hole bottom within 10 ... 20 revolutions of the drilling bit with an axial load of 80 kN and an angular velocity of the drilling bit 1.31 s^{-1} until the lines of 1 ... 2 mm depth were formed on the bore-hole bottom. Such running-in mode ensures contact with the bore-hole bottom of the teeth of all rolling cutters and excludes the possibility of contact with the bore-hole bottom of the shells of the rolling cutters. Fig. 3 shows a photograph of the bore-hole bottom, runed-in by a V-ACS74Y-R1190-6 (SH215.9K-PV) drilling bit. Each experience was conducted on a new bore-hole bottom.

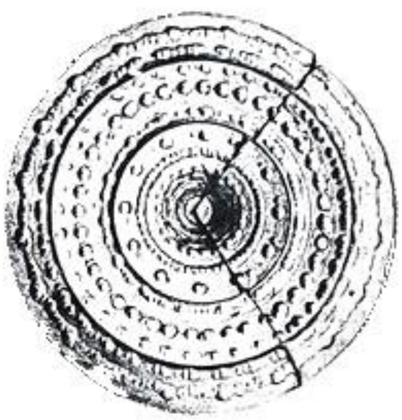

Figure 3: View of run-in bore-hole bottom

For the stand conditions, to obtain information about the load distribution on the cutting elements, obviously, there is no need to load the drilling bit with it's maximum permissible load. At the same time, it should be sufficient so that it is possible to obtain absolute values of the load with the required accuracy. In this regard, the axial load on the drilling bit during the research did not exceed 160 kN. Drilling bit rotations per minute were chosen depending on purpose of conducted study and was within the limits of 0.16…11.34 s^{-1}. Analyzing the oscillograms of the time variation of the axial components of interaction reactions of the teeth of rolling cutters of drill bit with the bore-hole bottom (Fig. 4), it can be established that, the processes of reaction variation are random stationary periodic. The average level of the process can be estimated by the mathematical expectation of the amount of force for a certain period of time. The amplitude of the process of changing of the reactions can be characterized by the average values of the maxima and minima of the reactions over a certain time interval.

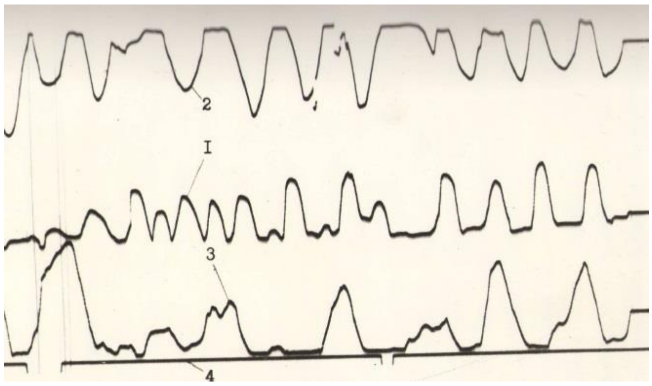

Figure.4: Oscillogram of changes in axial components of the forces:

1 – force on the peripheral rolling cutter teeth row; 2 - force on the intermediate rolling cutter teeth row; 3 - force on the top rolling cutter teeth row; 4 – boundary line of sectors of separate rolling cutters.

Statistical processing of the measurement results, converted into digital information, was carried out on a computer by a special program. The program allows to obtain the value of the mathematical expectation of the force on the rolling cutter teeth row, its dispersion and standard deviation. In addition, the program provides for smoothing the original digital array (low-frequency filtering) with a variable length of the smoothing operator, which makes it possible to exclude intermediate values of extrema from consideration and to schematize the actual process. The smoothed array is used to select maxima and minima, and standard deviations. To determine the duration of one experiment, the processes of changing of the axial components of the forces at each teeth row of each rolling cutter were recorded during ten drilling bit turns with an axial load of 80 kN and a bit angular velocity of 3.3 s^{-1}. The mathematical expectations of the forces on each teeth row of each rolling cutter were determined for each revolution of the bit. For each teeth row, the mathematical expectations of the force for ten turns of the drilling bit $\overline{X}$, also their dispersions S_x^2, standard deviations S_x and the values of coefficients of variation W_x are determined. The test results are shown in Table 1.

Table 1

Mathematical expectations of forces on teeth rows of rolling cutters for each revolution of the drilling bit V-ACS74Y-R1190-6 (SH215.9K-PV) (R=80 kN, ω=3,3 s^{-1})

No. of revolution	Forces on teeth rows of rolling cutters for 1 revolution, kN								
	Rolling cutter I			Rolling cutter II			Rolling cutter III		
	Peripheral teeth row	Intermediate teeth row	Top teeth row	Peripheral teeth row	Intermediate teeth row	Top teeth row	Peripheral teeth row	Intermediate teeth row	Top teeth row
1	6.62	17.16	8.37	11.48	9.49	7.20	13.27	8.87	4.35
2	8.63	14.30	11.80	11.82	10.98	8.15	13.55	6.27	3.36
3	6.70	18.13	7.92	12.20	10.25	6.20	13.04	8.80	4.73
4	9.00	15.00	11.66	10.89	10.95	8.92	13.75	6.11	3.66
5	6.38	17.66	8.35	10.70	10.36	6.58	13.12	8.20	3.54
6	9.27	15.14	11.87	11.67	11.58	8.14	13.56	6.27	5.03
7	7.38	17.00	8.65	10.38	10.91	7.93	12.92	9.31	4.15
8	8.20	14.62	11.77	12.20	10.83	8.15	12.82	6.86	4.78
9	7.10	17.91	8.97	11.67	11.08	6.72	12.87	9.44	4.39
10	7.80	15.00	12.19	11.00	11.90	7.56	13.25	6.66	4.90
$\overline{X}$	7.71	16.19	10.16	11.41	10.83	7.55	13.22	7.68	4.29
S_x^2	1.08	2.28	3.31	0.39	0.45	0.74	0.10	1.87	0.36
S_x	1.04	1.51	1.82	0.63	0.67	0.86	0.32	1.37	0.60
W_x	13.00	9.00	17.90	5.00	6.00	11.00	2.00	17.80	14.00

DISCUSSION.

From given results it follows that the greatest variations during one experiment are observed in the force on the top teeth row of the first rolling cutter. For this teeth row, the minimum number of drilling bit revolutions is determined during the time of one experiment, which is necessary to obtain the average value of the force on the teeth row with a specified accuracy with the chosen confidence probability γ . As a result of calculations it was established that the number of drilling bit revolutions during one experiment should not be less than six. In order to check the repeatability of the results of the experiment, five experiments were carried out on one drilling bit. The conditions in each experiment remained the same, the axial load on the drill bit was 60 kN, the bit angular velocity was 3.3 s^{-1}. Each experiment, as indicated above, was carried out on a new bore-hole bottom. In order to exclude the influence on the test results of the mutual position of rolling cutters relative to the bore-hole bottom, on which the dynamics of the drill bit may depend, each experiment was carried out with a new random position of the rolling cutters relative to the bore-hole bottom. The recording time of each experiment was six revolutions of the drill bit. It was found that the greatest coefficient of variation, equal to 12%, is observed in the axial component of the force on the peripheral teeth row of the first roller cutter. As a result of the conducted methodical experiments and their statistical processing it is determined that to obtain reliable results of measurements of the average values of the axial components with an error not exceeding 10% at a confidence level $\gamma = 0{,}9$, each experiment must be repeated at least three times. On the oscillogram (Fig. 4), peaks of axial forces acting on the teeth rows are periodically repeated, and the periods of the processes depend on the number of teeth on the teeth rows. Let's consider the scheme of interaction of cutting elements of one teeth row with a bore-hole bottom (Fig. 5). There are two possible extreme cases of interaction between the cutting elements of the teeth row and the bore-hole bottom. At time t_1, the teeth row occupies position 1, when the vertical axis of symmetry of the teeth row divides the angle between adjacent teeth almost in half. At this moment, one tooth stops contacting the bore-hole bottom and the next one begins contacting with the bore-hole bottom, while the axial component of the force P acting on the teeth row has a minimum value and can be equal to zero if one tooth has already finished contacting the bore-hole bottom, and the next tooth has not yet come into contact. At time t_2, the teeth row occupies position 2 when the vertical axis of symmetry of the teeth row coincides with the axis of one tooth of cutting elements. At this moment, the maximum axial load, perceived by one tooth, acts on the teeth row. In addition to the axial components of the interaction reactions of the teeth with the bore-hole bottom, there are also tangential components **F**, lying in a plane, perpendicular to the axis of rotation of the drilling bit.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 22 (2017) pp. 11901-11906
© Research India Publications. http://www.ripublication.com

In carrying out of experimental studies of the loading level of the hard-alloy cutting elements, the main attention was paid to the study of the distribution of the axial force acting on the drilling bit among the cutting elements of the rolling cutters. The study of the distribution of rotative moment between the cutting elements of the drilling bit was carried out only when determining the forces acting on each tooth of the cutting elements of rolling cutters. This is due to the fact that the value of rotative moment acting on the drilling bit depends, other factors being equal, on the value of the axial force acting on the drilling bit. Therefore, it can be assumed that the values of the tangential components of the forces acting on the teeth rows and the separate teeth of the teeth rows of the rolling cutters depend on the values of the axial forces. In addition, when drilling hard rocks with drilling bits made without displacement of the axis of rolling cutters in plane, the rotative moments on the drilling bit are relatively small, and the effect of the tangential components of the forces on the durability of the teeth of cutting elements is considerably lower than of the axial components.

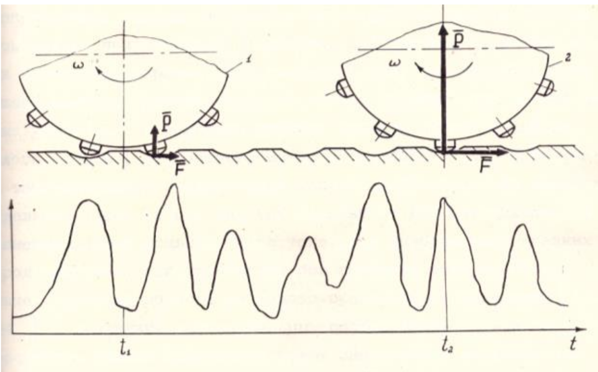

Figure. 5: Scheme of interaction of cutting elements of a teeth row with a bore-hole bottom

To determine the influence of the test modes on the nature of the distribution of the axial load among the cutting elements, tests were carried out for various axial loads and angular velocities of the drilling bit. The axial load on the drilling bit was assumed to be 20, 40, 80, 120 and 160 kN. For each value of the axial load, tests were carried out at angular velocities of the drilling bit of 1.31 s^{-1}, 3.30 s^{-1}, 5.65 s^{-1}, 11.31 s^{-1}. As a result of the tests, it was found that with increasing the load on the drilling bit, the axial force on each teeth row of each rolling cutter increases proportionally, and the proportionality factors for all the teeth rows in the studied range of forces are close to the coefficient of proportionality of the increase in the drilling bit load. However, the rate of increase of the axial load on the different teeth rows is somewhat different, that is when the axial load on the drilling bit increases, it is redistributed between the teeth rows of the rolling cutters. To determine the nature of this redistribution we determined the relative workload of all the teeth rows of rolling cutters in percent. The relative loading of the teeth rows changes when the axial load on the drilling bit changes. Especially significant are these changes at small (up to 40 ... 60 kN) loads on the drilling bit. With a further increase in the axial load on the drill bit, the change in the relative loading level of the teeth rows of rolling cutters slows down and, with an axial load of more than 80 ... 100 kN, there is no redistribution of it between the teeth rows of the rolling cutters practically observed. From the above analysis it follows that in order to obtain reliable data on the distribution of the axial load on each teeth row of each rolling cutter of drilling bit of this size, the tests should be carried out with an axial load on the drilling bit of at least 80 ... 100 kN.

To determine the influence of the angular velocity of the drilling bit on the nature of load distribution, tests were carried out with an axial load on drilling bit of 80 kN and drilling bit angular velocities of 1.31 s -1, 3.30 s -1, 5.65 s -1, 11.31 s -1. With an almost tenfold change in the angular velocity of the drilling bit, the change in loading level of teeth rows of rolling cutters is insignificant and does not exceed the experimental error. There are no regularities in these changes found, so it can be concluded that the change in the angular velocity of the drill bit in the studied range has practically no effect on the distribution of the axial load between the teeth rows of the rolling cutters of the drilling bit. Therefore, it is possible to choose most convenient test mode for carrying out certain researches without significant restrictions.

CONCLUSIONS

The given above results of studies of the distribution of the axial load between the teeth rows of each rolling cutter of the drilling bit V-ACS74Y-R1190-6 (SH215.9K-PV) under various test modes make it possible to conclude that the loading level of cutting elements is very different. The largest share of the entire axial load acting on the drilling bit is received by the intermediate teeth row of the first rolling cutter. The relative loading level of this teeth row, with 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 drilling bit, which significantly exceeds the relative load of adjacent peripheral and top teeth rows, taking respectively 10,6% and 13.4% of the total axial load on the drilling bit. A similar pattern is observed for other rolling cutters of the studied drilling bit. Summing up the relative loads acting on the teeth rows of one rolling cutter, it can be established that the first rolling cutter is the most loaded (43.1% of the total load on the drilling bit), the second rolling cutter is the second in loading level (30.4%) and the third rolling cutter is the least loaded (26.5%). Experimental studies of the force interaction of the V-ACS74Y-R1190-6 (SH215.9K-PV) drilling bit cutting elements with a metal bore-hole bottom showed a high degree of reliability and repeatability of the results obtained during the transition from experiment to experiment, which indicates the correctness of the chosen methodology and its reliability. The developed methodology with the use of a computer allows very quickly to obtain a large amount of information about the loading of all elements of the drilling bit. The obtained results confirm the assumption about the uneven distribution of the load on the cutting elements and bearing assembles of rolling cutters and correlate with the studies of failures and damages of cutting elements and bearings of rolling drilling bits.

REFERENCE

[1] Spivak A.I., Popov A.N. Destruction of rocks during drilling of wells: tutorial - M.: Nedra, 1994. – 261 p.

[2] Geoffroy H., Nguyen Miah D., Putot C. Study on Interaction Between Rocks and Worn PDC's Cutters // Int. J. of Rock Mechanics and Mining Sciences. - 1997. - Vol. 34, № 314. – P. 611.

[3] Rao K. U. M., Bhatnagar A., Misra B. Laboratory investigations on rotary diamond drilling // Geotechnical and Geological Engineering. – 2002. – Vol. 20. – P. 1-16.

[4] Elsayed M. A., Washington L. E. Drillstring Stability Based on Variable Material Specific Force and Using a Sharp Three-Insert Polycrystalline Diamond Compact (PDC) Coring Bit // J. Of Energy Resources Technology. - 2001. – Vol. 123. – P. 138-143.

[5] Eigeles R.M., Levian A.B., Lubyanyi D.A. Modeling kinematics and dynamics of roller cutter drill bits// Construction of oil and gas wells on land and at sea. – 1993. - Issue 1-2. – P. 41-43.

[6] Bilanenko N.A. Establishment of optimal kinetic characteristics of roller cutter drill bits to improve the efficiency of drilling wells: diss…Cand. Of Tech. Sc. – Tashkent, 1994. – 219 p.

[7] Postash S.A. On calculation of bearings of tricone drilling bits // // Higher Educational Institutions News. Neft' I Gaz. – Baku, 1959. - Issue 8. – P. 91 – 98.

[8] Pyalchenkov V.A. Analytical determination of responses in cone bit bearings // Higher Educational Institutions News. Neft' I Gaz. – 2014. - Issue 3. – P. 66-72.

[9] Pyalchenkov, V.A., Dolgushin, V.V., Kulyabin, G.A. The model for studies of load for the roller bit support bearings. – 2017. - ARPN Journal of Engineering and Applied Sciences. - 12 (19), pp. 5548-5553.

[10] Komm E.L., Perlov G.F., Mokshin A.S. Study of weighting sections of rolling cutter bit // Proceedings VNIIBT.- V. 36. - P. 27-36.

[11] Grechin, E.G., Dolgushin, V.V., Pyalchenkov, V.A., Kuznetsov, V.G., Bastrikov, S.N. Designing the downhole drill string assembly with motor-deflector with four-point pattern of its interaction with borehole walls. – 2017. - Neftyanoe Khozyaystvo - Oil Industry. - (9), pp. 82-85.

[12] Pyalchenkov V.A., Pyalchenkov D.V., Dolgushin V.V., Kulyabin G.A. Experimental Method for Measuring the Forces Acting On the Cutters of the Rolling Cutter Bit // Research Journal of Pharmaceutical, Biological and Chemical Sciences. - 2016. - September-Octobebr. - RJPBCS 7(5).- P.663-669.

[13] Pyalchenkov, V.A., Pyalchenkov, D.V., Dolgushin, V.V., Danilov, O.F., Kurbanov, Ya.M. Method of experimental determination of forces, acting on the cutting elements and the bearings of rolling cutter bit // Oil Industry. – 2016. - Issue 8. – P. 112-115.