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Experimental Method for Measuring the Forces Acting On the Cutters of the Rolling Cutter Bit

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ABSTRACT

To assess the reliability and durability of separate elements of drill bits cutting structure and rolling cutter support nodes as well as the whole bit rolling cutter, it is necessary to know the force values acting on the cutting structure elements of the rolling cutter bit during its interaction with the down hole. Analysis of existing experimental investigation methods for weight distribution on the rolling cutting structure elements indicates the insufficient knowledge of this issue. The paper presents a method of direct measuring of these forces. A radically new measuring device was developed and manufactured. It allows to measure the force values acting on each tooth of each rolling cutter in cooperation with indestructible downhole, consisting of concentric steel rings, divided into two sectors, a working one in which the measurement is made, and a non-working one. Measurement is performed using the strain-gage sensors glued on special beams. The sensor signals amplify, are recorded and processed using the special equipment. For implementation of this method a stand is made, intended for the bit rolling under a load along the bottom of the measuring device. The stand makes it possible to perform testing of various standard bit size, changing the axial load on the bit from 0 to 200 kN and the bit angular speed from between 0.16 to 11.34 s^{-1}, which corresponds to real conditions of rotary drilling. The given stand allows bits testing with different standard sizes expeditiously and at minimal cost, in order to optimize the cutting structure design and rolling cutter bit bearings, including those at their design stage.

Keywords: bearing, drilling, rolling cutter bit, rolling cutter, rolling cutting structure, weight on bit

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INTRODUCTION

The reliability and durability of the drilling equipment and tools depend on many factors. One of those is the force values acting on the working elements. Rolling cutter teeth are such elements for drilling bits, directly affecting the breakable rock. Significant number of both analytical and experimental studies [1, 2] is devoted to researches of interaction regularities of rolling cutter bits cutting structure with the downhole. In the papers [3, 4] the results of an experimental study of the bit interaction with the rock are presented. In the paper [5] the axial force acting on the bit from the side of the crushed rock is determined. The result analysis of the known experimental methods for weight determining on elements of the bit cutting structure show the insufficient knowledge of this issue. It is related to the complexity of the studied process. The weight on bit acting on the rolling cutter teeth during drilling are determined most simply by direct measurement using strain-gage sensors glued on the side teeth surface [6]. The main disadvantage of this process is that the teeth have small sizes and the rolling cutters rotate with glued sensors. The method of experimental determination of the axial forces acting on the rolling cutter teeth with a carbide bit cutting structure in a static position is known [7]. Rotary drilling bit, which rolling cutter teeth bear on special dynamometers, has been weighted by an axial force. Various options have been investigated when the rolling cutter could bear on one, two or three teeth located on different crowns. But the obtained results hardly reflect the real picture because the rolling cutters are welded to the drilling bit legs to prevent the rotation of the rolling cutters. This additional rolling cutters fastening had significantly changed the structure rigidity, which lead to the results distortion. The methodology for the experimental determining of the weight on bit, acting on each model section of the rolling cutter bit during its work on the downhole, followed by the analytical assessment of the distribution of these weights on bit between the support bearings [8, 9], is interesting. The bit model is composed of three rolling cutter units, each mounted on a cylindrical measuring beam rigidly fixed on base plate. The rotating downhole bearings are on the top of the bit model. The vertical weight on the section, torsion and bending moments are determined by using the strain-gage sensors. Then, with the assistance of hypotheses and assumptions the calculation of weights on bit acting on the bit cutting structure and bearings is performed. This method allows determining of the weight on bit acting on each bit section, to simulate the bits manufacturing errors very well and assess their impact on the weight distribution according to sections.The advantages of the method may include the ability to test performing at the downhole, made of the real rock. However, the need to perform the complex calculations reduces the results reliability.

METHODS

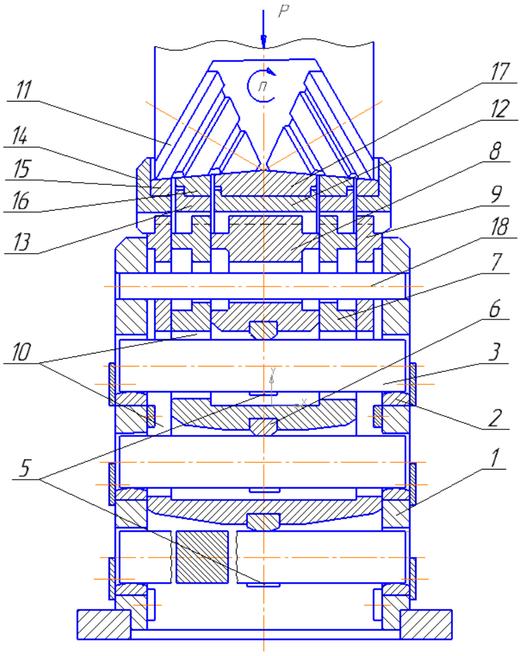

Fig.1 General view of the measuring device:
1 –base; 2 – bearings; 3 – beams; 5 – sensors; 6 – bushings; 7, 8, 9, 10 – plungers; 11 – bit; 12, 13, 14 – plates; 15, 16, 17 inserts; 18 – axis

In our opinion, the method of the downhole differentiation, used in the operating, is a promising one for the direct experimental measurement of forces, acting on the cutting structure elements of the rolling cutter bit [10]. The downhole is made of three concentric steel rings mounted on the plungers of the special hydraulic telescopic measuring device. The total axial weights and torque values acting on the analogous crowns of all bit rolling cutters can be measured by this device. A significant disadvantage of this device is a possible fluid leakage which can lead to the picture distortion of the force distribution. In addition, only the downhole ring differentiation does not provide a complete picture of the weights distribution according to the rolling bit cutting structure. A way to measure the efforts perceived by each tooth of each rolling cutter of the real bit in its interaction with non-destructive downhole has been developed. The principle of the downhole differentiation was accepted for the construction design of a measuring device of axial and tangential components efforts of the rolling cutter bit teeth interaction with the downhole. But to avoid the disadvantages of the hydraulic telescopic device the strain-gage beams were selected as sensitive elements. In fig. 1 a perspective view of the measuring device is presented.

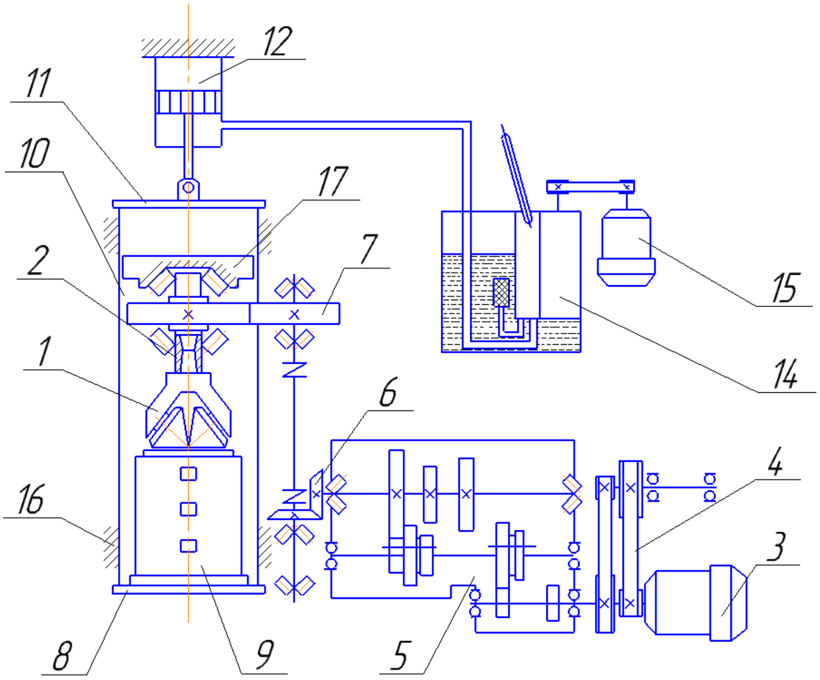

Fig. 2 Flow-sheet of the test stand:
1 – bit; 2 – spindle; 3 – motor; 4, 5, 6, 7 – transmissions; 8 – lower yoke assembly; 9 – measuring device; 10 – pulling; 11 – upper yoke assembly; 12 – hydraulic cylinder; 13 – pipeline; 14 – pump; 15 – engine; 16 – guides; 17 – housing

It consists of a base 1 in which strain-gauge beams are freely mounted on the replaceable bearings 3. Plungers 7, 8, 9 are bearing on each beam. The number of plungers is determined by the crowns number of the tested bit 11. Replaceable ring bushings 15, 16, 17 are mounted to plungers. They are made of rock simulating material, and forming the down hole, on which the rolling cutters roll. Each bushing is exposed to the force effects of only its crown, which is determined by the bushing diameter corresponding to the geometric crown dimensions. To prevent rotation of the downhole, the axis 18 is provided, fixed in the housing 1. When the bit rotates along the replaceable bushings simulating the downhole, the perceived force is transmitted to the strain-gauge beams with sensors 5. Then it is converted into an electrical signal and recorded by the appropriate equipment. Beams made of spring steel of the high hardness, bear on support 2 mounted in the device housing. High hardness of details of the strain-gage part of the bushing-beam-bearing system is necessary for its long-term operation without changing the contact shape of the work surfaces. Contact of the beams with bearings and plungers occurs along a line that provides stable measurement results. Strain-gauge beams of the devices have high sensitivity and sufficient rigidity. Thus, bend of one beam under the action on it of the force 100 kN is only 0.1 mm. The absence of an intermediate working fluid (liquid) improves the reliability of the device when testing the rolling cutter bits of any standard sizes. Using as a gage the double-bear rectangular beams with strain-gauges sensors increases the measurement accuracy and reduces the preparation and research complexity. Using the unsealed plungers reduces their manufacturing costs, simplifies the device construction and operation. Results of numerous studies of weight distribution rules on the elements of rolling cutter structure are hardly comparable and often contradict each other. The reasons for this, in our opinion, are the high interaction complexity of the bits with the downhole, as well as using of not sufficiently perfected research means and methods. In particular, as the primary actuating mechanism for creating the weight on bit (or model), and its rotation along the downhole (or the downhole one along the bit), the rig of a particular model had been used in most cases. However, the drilling rig use has its disadvantages related to the need of bits cooling when testing, significant beats of its spindle and the crossover sub related to the rotation axis, the lack of testing performing capabilities at low rotating speeds, resulting in significant errors in the measured parameters, as well as limitations in the test modes choice. A special stand was designed and manufactured to eliminate the given disadvantages and to provide a deeper investigation of the interaction process between the bit cutting structure and the downhole. The flow-sheet of the stand is shown in Fig. 2.

The research probes in the bit rotation under the weight along the metal downhole of the measuring device. The tested bit 1 is fixed in the spindle 2 installed in the angular contact bearings. The overhang of the spindle supporting end over the bottom support is only 40 mm, which allows the bit radial beam minimizing. The torque-on-bit is transmitted from the electric motor 3 through a two-stage belt transmission 4, or passing it directly through a gearbox 5, conical and cylindrical transmission 6 and 7. The drive provides change in the angular speed of bit from 0.16 to 11.34 sec^{-1}, thereby reproducing rotary drilling conditions. A cylindrical transmission housing 17 with installed therein two spindles is rigidly fixed to the fixed upper joke assembly of the testing machine, and the measuring device 9 is installed on the lower joke assembly 8. The movable joke assembly 8 is connected by pulling 10 to the upper movable joke assembly 11 which is attached to the rod of the power hydraulic cylinder 12 connected by the piping system 13 with the plunger high pressure pump 14, with as modulating capacity. The pump is driven by the electric motor 15. Under the action of the hydraulic cylinder rod, the joke assembly 8, moving in guides 16, is pressing the measuring device 9 to the tested bit 1, thereby weighing it with necessary axial force. Axial load can smoothly vary from 0 to 200 kN, which allows testing of various bit standard sizes when axial weights close or equal to operating weighs, depending on the size of the tested bit.

RESULTS

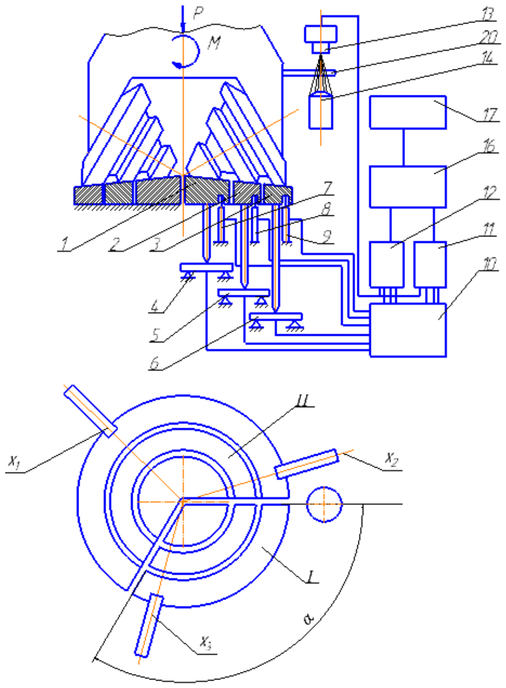

Fig. 3 Flow-sheet of measuring and recording the forces acting on the rolling cutter teeth: 1, 2, 3 – ring down hole of the working sector; 4, 5, 6, 7– strain-gage beams; 7, 8, 9 – bushings; 10 – amplifier; 11, 12 –oscilloscopes; 16, 17 – transforming equipment; X_1, X_2, X_3 - rolling cutter axle

The design of the ring downhole device shown in fig.1 allows only measuring of the total force on the appropriate crown of all rolling cutters. The additional downhole differentiation into two sectors, a working (measuring) sector I and a non-working sector II (Fig. 3) is necessary for separate registration of forces, acting on each rolling cutter crown. The rolling cutters consistently contact with ring bushings of the downhole working sector I when bit rotating about the downhole.

The working sector angle is chosen according to the condition that only one bit rolling cutter could be in the working sector at the given time moment. Other bit rolling cutters are in non-working downhole sector II at the given time moment fixedly mounted to the measuring device. Each rolling cutter crown bears on its ring portion 1, 2, 3 in the working sector. Vertical reaction components of rolling cutter teeth interaction with the downhole parallel to bit rotation axis, deform the strain-gauge beams 4, 5, 6. Sensing elements for recording of the tangential reactions components of rolling cutter teeth interaction with the downhole directed perpendicularly to the bit rotation axis, are special bushing 7, 8, 9 cantilever fixed in the housing of measuring device. The strain-gage sensors are glued on the side faces of the bushings too. The free end of each bushing is connected with one of the ring portions of the downhole working sector. The beam deformations and elastic bushings are converted by sensors into electrical signals that are proportional to the values of axial and tangential reactions of rolling cutter teeth interaction with the downhole, which are recorded and processed using the special equipment.Wire strain-gages resistors of general purpose with a single-element loop grid on a paper basis with a resistance rating of 200 ohm, and the active base of 20 mm were used as sensors. Two sensors were glued on each beam and bushing, the active and the compensation ones, connected in half-bridge circuit.

Such a circuit allows the possible errors compensation due to variations in ambient temperature. The active sensors were glued strictly along the symmetry axes on lower edges, the compensating sensors were glued on the free surfaces of the beam ends, not subjected to deformation. For bushings, having been sensors for registering the tangential efforts, sensors were glued on opposite faces, which allowed not only to compensate the temperature errors, but also to increase the sensitivity. In order to enhance the electrical signals, an eight strain-gage amplifier 8АНЧ-7М was used. The process registration was carried out using the light-beam oscilloscopes K12-22 on paper photo tape with the wide of 120 mm. The photo tape speed of the oscilloscope can vary from 0.8 to 1000 mm/s, which allows recording the processes with a frequency from 0 to 500 Hz. The oscilloscope allows recording simultaneously up to 12 processes. However, the reading error of the oscilloscope trace ordinate depends primarily on the value of the reading ordinates and the ordinate values should not be less than 25 mm so the read error does not exceed 2%. In addition, the presence of frequent recording line crossings makes it difficult to process the oscilloscope traces. In connection with this, the recording was carried out simultaneously by two oscilloscopes. Three process changes of the axial reactions component of the bit interaction with the downhole were recorded by one oscilloscope, three change processes of the tangential components were recorded on the second one. It is possible to register the total axial force on the bit using the sensors glued onto the rod of the power hydraulic cylinder 12 (fig. 2). In fig. 4 a sample of oscilloscope trace for axial force component is shown.

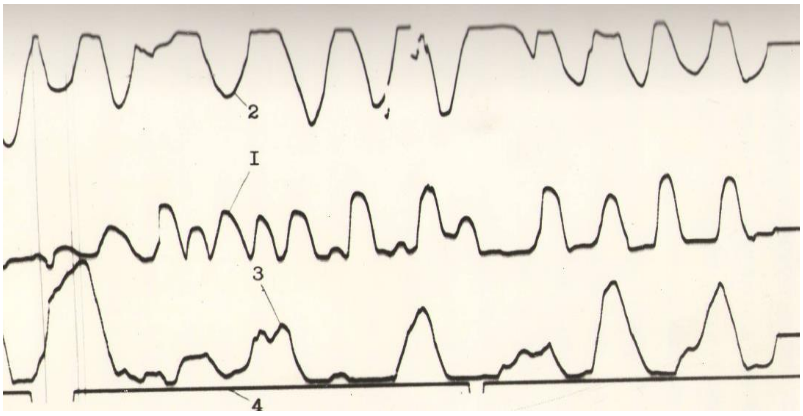

Fig. 4 Oscilloscope trace of changes in axial force components:
1 – force on the peripheral crown; 2 – force on the middle crown; 3 – force on the crown top; 4–line of demarcation for separate rolling cutters portions

The recorder scales of the ordinate and time axis are chosen so that the reading error had minimal effect on the measurement results, and the oscilloscope traces were suitable for both manually processing and one by means of special devices. Since the rolling cutters have contact with the working down hole sectors sequentially, it was necessary to identify the record portions relating to each rolling cutter, on the oscilloscope trace recorded during a single bit rotation, that is, it was necessary to determine which oscilloscope trace portions the force interaction with the downhole of the 1st, 2nd and 3rd rolling cutters had been recorded in. For this a photocell 13 and a lighting lamp 14 are installed at the beginning of the measuring sector. The photocell and lamp power is supplied by the semiconductor counter of piece products. The photocell has parallel connection to one galvanometer of both oscilloscopes. Blades of different widths are fixed in the tested bit in front of each rolling cutter, which sequentially overlap the luminous flux incident on the photocell thereby changing the signal on the oscilloscope galvanometers. At the same time, on the oscilloscope trace, peaks of varying length (line 4, fig. 4.) form the portion demarcation of particular rolling cutter interaction with the downhole measuring sector. Electronic counter allows furthermore controlling the number of revolutions executed by bit when testing and, upon reaching a number of revolutions predetermined by program automatic disconnection of the bit rotation drive and the photo tape mechanisms of both oscilloscopes interlocked with it. This is especially important when performing the tests with significant bit rotation frequencies as it greatly simplifies maintenance and reduces the photo tape consumption. A general view of the measuring device mounted on the stand in the operating position is shown in fig. 5.

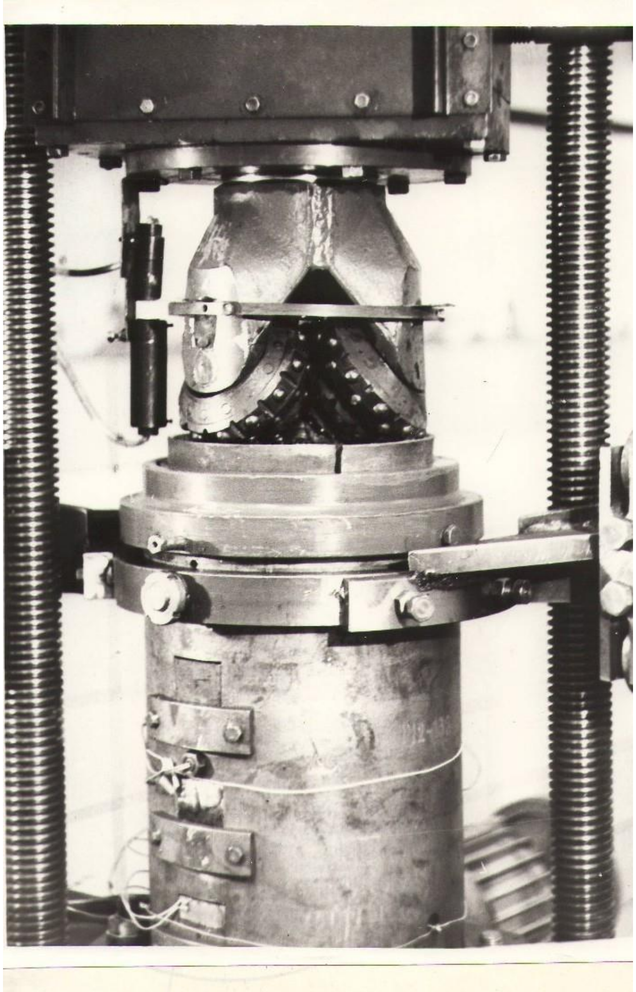

Fig. 5 General view of the measuring device in the operating position

Processing of the obtained oscilloscope traces was performed using the graphs converter for reading graphic information off the oscilloscope traces and converting the read data into the code easy to input into the computer.

DISCUSSION

A significant disadvantage of the proposed method for forces measurement is using not a natural rock as the downhole material, but indestructible metal rings. However, from our point of view, the use of such downhole material is quite acceptable. Using of natural rock makes impossible a direct measurement of forces acting on the bit teeth. The downhole divided into rings and sectors will be uploaded rapidly during drilling, which would result in distortion of the real pattern of cutting structure load. Furthermore, when drilling hard and extra hard rocks, the downhole destruction occurs very slowly. In this case, representation of the real downhole by the metal one does not make substantial changes in the nature of the load distribution on the cutting structure elements and of the rolling cutter bearings, due to the peculiarities of its construction.

CONCLUSION

The developed measuring device allows performing the direct measurement of the axial and tangential force value acting on each tooth of each cutter bit during its rotation under the load along the indestructible downhole. This makes it possible to evaluate the nature of the load distribution on the cutters, crowns and individual bit teeth, to identify the most loaded elements and make changes in the bit design in order to ensure a more balanced load of cutting structure and leg bearings. A more balanced load of cutting structure and bearing elements would increase the headway per bit and improve the performance of the drilling process. This stand and technique allow testing of rolling cutter bits with both milled and pin carbide cutting structure quickly, at low cost and with high accuracy. The diameter of the drill bits can be up to 269 mm, the axial load on the drill bit can be up to 200 kN. This stand can be used for serial as well as experimental bit tests in order to optimize their design and verification of the analytical studies results of cutting structure loads and leg bearings of rolling cutter bits.

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