UDC 622.226
DOI: 10.15587/1729-4061.2022.263532

IMPROVING THE TECHNIQUE FOR ASSESSING THE CONDITION AND PREDICTING THE WEAR OF THE ROCK DESTRUCTION TOOL EQUIPMENT

To ensure the trouble-free operation of the rock-destroying tool, the peculiarities of its interaction with the rock at different stages of work must be additionally studied. Still unexplored in full is the relationship between the state of the equipment of the rock-destroying tool and the oscillatory processes during the operation of the drilling tool. The basic dependences for determining the wear indicators of the equipment of the rock-destroying tool have been proposed. The scheme for implementing the method of assessing the condition and predicting the wear of equipment, taking into account the peculiarities of its interaction with the rock, has been improved. Underlying its implementation is the presence of a law of change of at least one generalized coordinate of an arbitrary cross-section of a drilling tool. Bench experimental studies were carried out, according to the results of which the dependence of the depth of the face deepening on the mode parameters of drilling and the geometry of the equipment was established. It was found that the wear of the cutter by 1 mm causes a decrease in the amplitude of longitudinal oscillations by an average of 1.4 times. The obtained functions of deepening the face were used to determine the energy indicators of the process of rock destruction. Given the peculiarities of the implementation of the experiment, the work and power of the axial load for the destruction of the rocks of the pit were used for such indicators. It should also be noted that the construction of numerical models is necessary for a complete assessment and prediction of the wear of rock-destructive tools. They should reflect the mechanical system and provide the ability to obtain the values of parameters that are not determined by the results of a laboratory experiment

Keywords: rock destruction, vibration of drilling tool, rock-destroying tool, wear of equipment

Jaroslav Grydzhuk
Doctor of Technical Sciences, Associate Professor
Department of Engineering Mechanics*
Andriy Dzhus
Corresponding author
Doctor of Technical Sciences, Associate Professor
Department of Oil and Gas Field Machinery and Equipment*
E-mail: andriy_dzhus@i.ua
Andriy Yurych
PhD, Associate Professor
Department of Oil and Gas Well Drilling*
Lidiia Yurych
PhD
Department of Oil and Gas Well Drilling*
Maksym Dorokhov
PhD, Chief Technology Officer
LLC DTEK Oil&Gas
Dorohozhitska str., 3a, Kyiv, Ukraine, 04119
Andrii Livinskyi
PhD, Technical Director
LLC Endevour
Lidova str., 10, Poltava, Ukraine, 36000
*Ivano-Frankivsk National Technical University of Oil and Gas
Karpatska str., 15, Ivano-Frankivsk, Ukraine, 76019

Received date 24.06.2022
Accepted date 18.08.2022
Published date 31.08.2022

How to Cite: *Grydzhuk, J., Dzhus, A., Yurych, A., Yurych, L., Dorokhov, M., Livinskyi, A. (2022). Improving the technique for assessing the condition and predicting the wear of the rock destruction tool equipment. Eastern-European Journal of Enterprise Technologies, 4 (1 (118)), 103–109. doi: https://doi.org/10.15587/1729-4061.2022.263532*

1. Introduction

The current state of oil and gas production necessitates drilling operations at considerable depths [1]. Because of this, it is necessary to solve problems related to ensuring the design trajectory of wells [2–4], the quality of the barrel [5], the reliability of drilling equipment [6], etc. One of the main tasks that is solved when planning work is the choice of rational (optimal) types, size of bits, and drilling modes, taking into consideration the physical and mechanical properties of drilled rocks. This, along with the optimization of drilling processes and costs, predetermines the introduction of new types and designs of drilling bits [7–11]. The use of PDC-type bits makes it possible to reduce accidents, increase the mechanical drilling speed, improve trajectory controllability and, as a result, reduce the time for the construction of wells in general. However, most types of PDC bits can effectively destroy only medium-hard rocks. To expand the scope and improve the efficiency of PDS bits, various techniques have been considered. Among them are increasing the strength of the materials used, optimizing the profile, preventing wear and failure, predicting the force reaction, monitoring and dynamic process management in the field. Despite the wide range of research, a number of issues are still relevant and require further study. In particular, attention should be paid to investigating the issue of effective destruction of rocks through research using modern methods and equipment.

2. Literature review and problem statement

Many researchers pay special attention to the study of the power interaction of a rock-destroying tool with rock as the most direct method for determining the productivity of PDC bits or the limitations of drilling processes. Reproduction of these processes on single PDC cutters makes it possible to better study and understand the mechanism of interaction with the rock. Possession of information on force reactions under different cutting conditions is an important prerequisite for improving the efficiency of the cutter and the destruction process as a whole. The authors of [12] designed a test bench, based on the turning center, for measuring mechanical and thermal reactions in the interaction of a cylindrical PDC cutter with rock in real time. During the experiment, the effect exerted on the force interaction by the size of the front angle and cutting depth, as well as the feed rate of the cutter, was investigated. A phenomenological model of the relationship between force factors and the front cutting angle has been formulated. Similar studies were conducted by the authors of [13, 14] using PDC on samples of Carthaginian marble rock, with cutters 13 mm and 16 mm in diameter with structural chamfers 0.01 inches and 0.016 inches long. It was found that the size of the cutter does not affect the reaction from friction but the size of the chamfer has a significant effect on the friction and aggressiveness of the cutter. Unlike the normal component force, the cutting force proved insensitive to the chamfer size for the same cutting depth under test conditions. Based on the analysis of the obtained data, an empirical ratio between the anterior posterior angle of the cutter and the friction angle was introduced. An expression was also derived to determine the equivalent rear cutting angle as a function of the cutting depth. The results are important for the development of the design of elements of the rock-crushing tool in order to improve its efficiency. However, the cited works [12–14] do not take into consideration the wear of the cutter in the course of its work.

The authors of [15] carried out experimental studies into the influence of the degree of wear of a single cutter on the change in the force and energy parameters of the rock cutting process. A significant influence of the degree of wear of the cutting elements on the growth of the force parameters of the process has been established. With an increase in the degree of wear, a component directed at cutting the rock decreases within the resulting force. This increases the component aimed at pressing the cutting element. The authors proposed to evaluate the degree of wear of equipment according to the indicators of changes in the instantaneous values of force, changes in power, or parameters of the oscillatory processes of the drilling tool. However, the above studies were carried out in the laboratory using a rigid scheme of loading elements of a rock-destroying tool. That does not take into consideration the peculiarities of oscillatory processes characteristic of real drilling conditions.

Most studies that take into consideration the peculiarities of the processes characteristic of actual working conditions are carried out by mathematical modeling, simulation, as well as laboratory modeling because of the high cost of conducting full-fledged industrial tests [16]. The authors of [17, 18] studied oscillatory processes both experimentally and using the method of finite elements. The application of industrial drilling bits and rock samples for the research made it possible to obtain an equivalent friction model. That took into consideration the friction and cutting components of the interaction of the chisel and the rock. The extinction of torsional vibrations of the drilling column at drilling was experimentally and numerically investigated. Despite the practical significance of the reported results, the authors did not consider the effect of the degree of wear of the equipment of the rock-destroying tool.

Given the above unresolved issues, it is necessary to assess and predict the wear of the equipment of the rock-destroying tool in the process of its work. One of the ways of such an assessment is implemented on the basis of the analysis of industrial data. To this end, it is necessary to carry out continuous monitoring of the drilling parameters to be adjusted in order to achieve optimal conditions for the operation of the tool. The implementation of this approach is possible in the presence of modern interactive technologies that make it possible to record on-line the values of the regime parameters of drilling. The use of such technologies is not always possible and expedient, especially when conducting drilling operations on small geological structures with a long payback period. Under such conditions, modern rock-crushing tools can be used in certain intervals of several wells until they are fully exhausted. Because of this, in each of the wells, the process of destruction of rocks of the face will be determined by the current state of the equipment of the rock-destroying tool.

According to another approach, a drilling model of the geological structure is constructed on the basis of primary information obtained from the results of preliminary drilling. The theoretical basis of information processing methods is analytical dependences describing the work of the chisel on the face. The description of such interaction should take into consideration the main characteristics of rock-crushing tools and rock, as well as include the parameters of drilling modes [19].

It should also be noted that by the time of full wear, modern rock-destroying tools can be used in certain intervals of several wells. Because of this, the nature of the process of destruction of rocks of the face in each of them will differ and will be determined by the current state of the equipment of the rock-destroying tool. At the same time, the relationship of the state of the equipment of the rock-destroying tool with the vibration processes characteristic of its operation is not fully investigated. All of them are due to the interaction of rock-destroying tools with rock.

Given the current state of the drilling bit service market, it is impossible to carry out such an analysis for all sizes based on the results of industrial implementation. Therefore, one should pay attention to the possibilities of such an assessment based on the results of laboratory experiments. In this case, it is necessary to use the methods of not only physical modeling but also analytical and numerical, to be implemented using modern software.

The criteria for assessing the effectiveness of rock destruction, in addition to the mechanical drilling speed and the amount of penetration, should also consider such energy indicators as work done, power spent, energy intensity of destruction, etc.

3. The aim and objectives of the study

The aim of this study is to improve a technique for assessing the condition and predicting the wear of the equipment of the rock-destroying tool, taking into consideration the peculiarities of its interaction with the rock. This will make it possible to improve the efficiency of rock destruction and enable optimal performance of rock-crushing tools.

To accomplish the aim, the following tasks have been set:

– to conduct experimental studies into the process of destruction of rocks under different force and kinematic parameters to derive the function of changing the generalized coordinate of an arbitrary cross-section of the drilling tool;

– to determine and evaluate the energy indicators of the process of destruction of rocks of the face using the derived functions of changing the generalized coordinate of an arbitrary cross-section of the drilling tool.

4. The study materials and methods

For our research, we used a bench based on the drilling rig SBA-500 (Ukraine). The study was conducted on blocks of sandstone. As a rock-destroying tool, a cutter of the RS-140 type (Ukraine) was used. To measure the vibrations of the drilling tool, a vibrodiagnostic set-up was designed. We registered the axial vibration displacement of the drilling tool during experimental studies using an inductive sensor of vibration displacement. In this case, the distance from the photodiode of the inductive sensor to the surface of the measuring platform was measured (Fig. 1).

Taking into consideration the parameters of the technical characteristics of the drilling rig, the studies were carried out at rotational speeds n=82 rpm, n=131 rpm, and n=181 rpm, with a change in the axial load on the chisel in the range from 4 kN to 8 kN. The course of experimental research involved the following steps:

– start-up of the drilling rig and establishment of design values of the regime parameters;

– the registration of axial vibration displacement in analog form;

– primary processing of registered parameters and saving them in digital form;

– secondary processing of oscillation parameters.

Fig. 1. General view of the vibrodiagnostic set-up: 1 – vibration shift sensor; 2 – primary processing unit; 3 – stopwatch; 4 – secondary processing unit; 5 – connecting cables

The speed of rotation of the drilling tool was set by turning on the corresponding gear in the gearbox. The magnitude of the axial load on the chisel was adjusted by the distributor of the hydraulic system of the machine. We registered axial vibration displacements of the tool at the appropriate mode parameters by measuring equipment online for no more than 120 seconds.

The authors of [20] proposed a mathematical model for the study of the parameters of longitudinal and torsional oscillations of the drilling tool on a bench. In that case, the drilling tool was represented as a dual-mass mechanical system loaded with axial force and reactive torque from the face. Both force factors are characterized by cutting and friction components. Bodies in the system are connected by elastic-dissipative elements. With the help of four generalized coordinates and their derivatives, expressions for the potential and kinetic energy of the mechanical system and generalized force factors were written. Based on the Lagrange equations of the II kind, taking into consideration the obtained expressions, a system of differential equations of system motion was compiled.

Taking the model [20] as a basis and conducting a series of analytical transformations, dependences were derived to determine the length of the wear part of the cutter l (1) of the rock-destroying tool and the intensity of its performance ξ (2):

$$l=\frac{2\left[\frac{J_2}{d^2}\ddot{x}_2-\left(m_1+\frac{J_2}{d^2}\right)\ddot{x}_1+\frac{J_1}{d}\ddot{\varphi}_1+\alpha_1\left(\dot{x}_2-\dot{x}_1\right)\right]}{zr\sigma\left[1+\operatorname{sign}\left(\dot{x}_1\right)\right]}+\frac{2\left[k_1\left(x_2-x_1\right)+\frac{c_1}{d^2}\left(x_2-x_1\right)+\frac{c_1}{d}\left(\varphi_1-\varphi_3\right)+zr\varsigma\varepsilon h\right]}{zr\sigma\left[1+\operatorname{sign}\left(\dot{x}_1\right)\right]}; \quad (1)$$

$$\xi=\frac{\frac{2}{r\mu}\left[\frac{J_2}{d}\left(\ddot{x}_1-\ddot{x}_2\right)-\left(J_1+J_2\right)\ddot{\varphi}_1+\frac{c_1}{d}\left(\varphi_3-\varphi_2\right)-\frac{1}{2}zr^2\varepsilon h\right]}{\frac{J_2}{d^2}\ddot{x}_2-\left(m_1+\frac{J_2}{d^2}\right)\ddot{x}_1+\frac{J_1}{d}\ddot{\varphi}_1+\alpha_1\left(\dot{x}_2-\dot{x}_1\right)+\left(k_1+\frac{c_1}{d^2}\right)\left(x_2-x_1\right)+\frac{c_1}{d}\left(\varphi_1-\varphi_3\right)+zr\varsigma\varepsilon h}, \quad (2)$$

where m_1 is the mass of the rock-destroying tool; J_1 and J_2 – the moment of inertia of the rock-crushing tool and pipe, respectively; x_1, x_2 – axial coordinates of the rock-destroying tool, pipe; φ_1, φ_2, φ_3 – angular coordinates of the rock-destroying tool, pipe, and transferor; k_1 – rigidity of the threaded connection; α_1 – coefficients of damping of the threaded connection; c_1, d – rigidity and kinematic parameter of the connection of the pipe and the rock-destroying tool with the help of a Morse cone; z – the number of cutters on the rock-destroying tool; r – radius of the rock-destroying tool; ε – internal specific cutting energy; ζ – a parameter that determines the position of the rock-crushing tool; h – the value of the deepening of the face by the rock-destroying tool, μ – the coefficient of friction, σ – the stress of destruction.

In general, the operation of PDC bits is based on constant accounting of performance and the degree of wear of their equipment during operation. One of the problems is the different time of failure of the cutting elements, which causes the occurrence of excessive vibration loads and, as a result, their breakdowns. Given this, it is necessary to control the drilling modes in order to enable trouble-free operation of the rock-destroying tool until complete wear-out. An important aspect, in this case, is the study of the interaction of the equipment of the rock-destroying tool with the rock at different stages of wear-out. This requires a number of diverse studies using modern mathematical, hardware, and technical means. It is this integrated approach that was used in improving the technique for assessing the condition and predicting the wear of the equipment of the rock-destroying tool. It involves conducting experimental studies with the subsequent processing of their results to establish the main characteristics of the process of destruction of rocks of the face. The implementation of the proposed approach was carried out with the help of a laboratory drilling bench equipped with a measuring complex and tools for mathematical modeling and statistics. The assessment of the parameters characterizing the process of interaction of the equipment of the rock-destroying tool with the rock is proposed to be carried out experimentally-theoretically according to the scheme shown in Fig. 2.

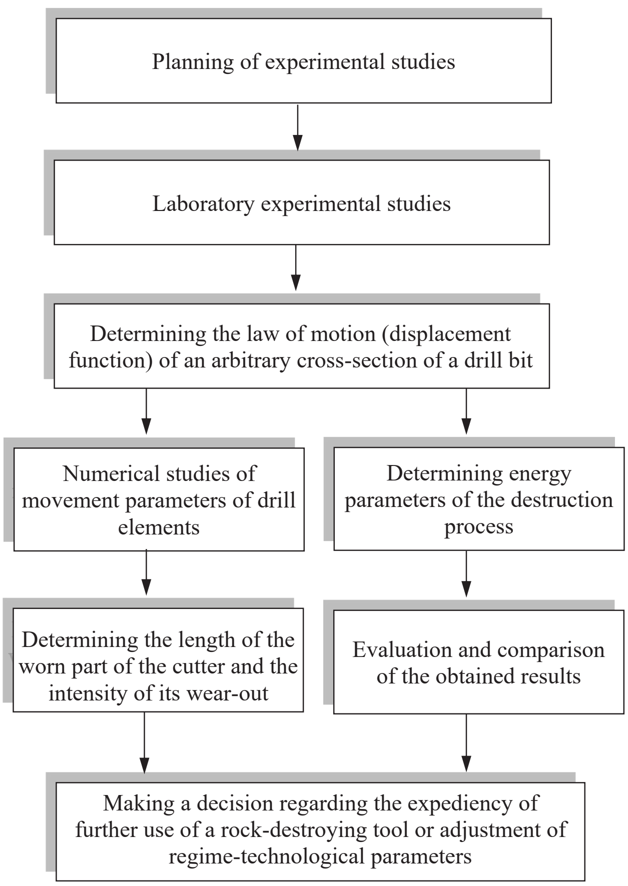

Fig. 2. Conceptual scheme of the study of the interaction of rock-destroying tools and rock

For studying the wear-out of the equipment of the rock-destroying tool relative to the generalized coordinates x_1, x_2, φ_1, φ_2, it is sufficient to have a law of change of at least one of them. One of the ways to obtain it is to conduct experimental studies with the measurement of the axial vibration displacement of the drilling tool at the appropriate regime parameters.

Next, using the differential equations of the longitudinal and rotational motion of the rock-destroying tool and the drill pipe, simulation models are built, with the help of which other parameters are evaluated, which are employed in dependences (1), (2). The set of necessary data obtained in this way is the basis for assessing the length of the wear part of the cutter l of the rock-destroying tool and the intensity of its wear-out ξ.

Along with this, the presence of registered experimental data makes it possible to establish the function of moving the rock-destroying tool under different force and kinematic parameters of the process. Based on them, taking into account the axial load created in the course of research, it is possible to determine its performance and power with a further assessment of the feasibility of using a rock-destructive tool or adjusting the regime and technological parameters.

5. Results of studying the wear-out of the equipment of the rock-destroying tool

5. 1. Results of experimental studies of the process of rock destruction under various force and kinematic parameters

In order to obtain the laws of change of one of the generalized coordinates, namely the axial coordinate of the cross-section of the drill pipe of the rock-destroying tool x_2, which corresponds to the deepening H, a number of experimental studies were carried out at different force and kinematic parameters of the process.

All laws of change in the axial generalized coordinate have a distinct oscillatory character. Approximation (regression analysis) of such experimental oscillograms made it possible to obtain analytical expressions describing the movement $S(t)$ of the center of an arbitrary cross-section of the drilling tool. Polynomial approximation was used to analyze experimental data (Fig. 3–5). To ensure greater reliability of the approximation, polynomials of different powers are considered. The best level of reliability was achieved by using third-degree polynomials (Table 1). At the same time, the level of reliability of approximation ranged from 0.49 to 0.82. Based on the results obtained, the amplitudes of oscillation amplitudes of the drilling tool were also established (Table 2).

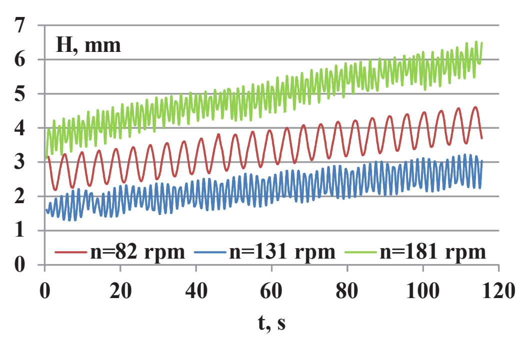

Fig. 3. Visualization of research results at axial load P=6 kN and different rotational speeds n for a new rock-destroying tool

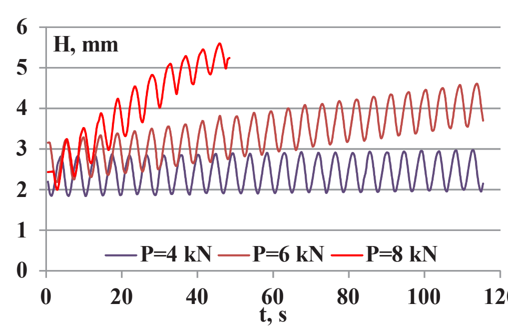

Fig. 4. Visualization of research results at rotational speed n=82 rpm and various axial loads P for a new rock-crushing tool

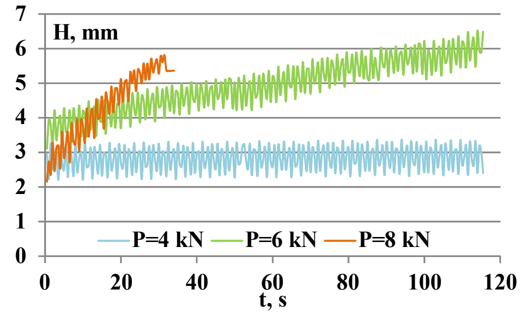

Fig. 5. Visualization of research results at rotational speed n=181 rpm and various axial loads P for a new rock-crushing tool

Table 1

Results of approximation of experimental data for a new rock-crushing tool

Rotation frequency n, rpm	Axial load, P, kN	The law of motion (displacement function) of an arbitrary cross-section of a drilling tool
82	4	$S(t)=10^{-7}t^3-2\cdot10^{-5}t^2+0.0026t+2.3177$
	6	$S(t)=10^{-8}t^3+10^{-5}t^2+0.0129t+2.6484$
	8	$S(t)=10^{-6}t^3+0.0003t^2+0.0859t+2.2178$
131	6	$S(t)=10^{-7}t^3-2\cdot10^{-5}t^2+0.0109t+1.6262$
181	4	$S(t)=-10^{-7}t^3+2\cdot10^{-5}t^2+0.001t+2.7463$
	6	$S(t)=7\cdot10^{-7}t^3-0.0002t^2+0.0293t+3.6439$
	8	$S(t)=3\cdot10^{-5}t^3-0.0016t^2+0.1331t+2.4838$

Table 2

The amplitude of vibration displacements; the work and power to destroy rocks of the face

Axial load P, kN	Amplitude, mm		Work A_P, J		Power N_P, W	
	new	worn-out	during 30 s	during 120 s	second 30	second 120
n=82 rpm						
4	0.557	0.371	0.251	0.787	0.007	0.008
6	0.568	0.379	2.329	9.478	0.077	0.081
8	0.432	0.324	18.672	–	0.565	–
n=131 rpm						
6	0.412	0.303	1.870	7.157	0.060	0.063
n=181 rpm						
4	0.525	0.468	0.181	0.941	0.008	0.006
6	0.461	0.346	4.307	11.074	0.115	0.069
8	0.407	0.312	26.904	–	0.945	–

Similarly, a study was conducted using a rock-destroying tool with signs of wear on its equipment. For comparison, Table 2 gives the derived values of the amplitudes of oscillations of the drilling tool.

5. 2. Determining energy indicators using the function of change in the generalized coordinate

The main force factors in the destruction of the face are the axial load on the chisel, and torque. The result of their actions directly depends on the state of the equipment of the rock-destroying tool. It largely forms the energy costs of rock destruction, characterized by mechanical work and force.

The mechanical work of the axial load reflects the intensity of its action at a given recess of the face. The magnitude of the deepening of the face in the axial direction is equal to the difference between the final and initial coordinates of the lower end of the chisel, that is, its movement S. Therefore, the work of the axial load on the finite movement can be determined as follows:

$$A_P = \int_{S_0}^{S_i} P_i(S)\,\mathrm{d}S, \tag{3}$$

where $P_i(S)$ is the axial load on the drilling tool as a function of moving its cross-section.

With a constant axial load on the chisel P, its mechanical work when deepened by the value of S can be defined as the product of these quantities:

$$A_P = P\cdot S. \tag{4}$$

However, in the process of drilling, the deepening of the face, due to technical, technological, mining, and geological conditions is not constant in time and is characterized by a certain law of change $S=S(t)$. Therefore, the work performed by the constant axial load will obey an appropriate time dependence $A_p=A_p(t)$. Differentiation of the function of the work makes it possible to estimate the force of the axial load:

$$N_P = \frac{dA_P}{dt} = P\frac{dS}{dt}. \tag{5}$$

To determine the work and power of the axial load according to the above dependences (4) and (5), the approximation functions obtained at the previous stage (Table 1) were used as functions $S(t)$. At the same time, in order to reduce the results obtained to a common origin, the approximation curves were adjusted by extracting the free term of the polynomial. The results are given in Table 2 and shown in Fig. 6.

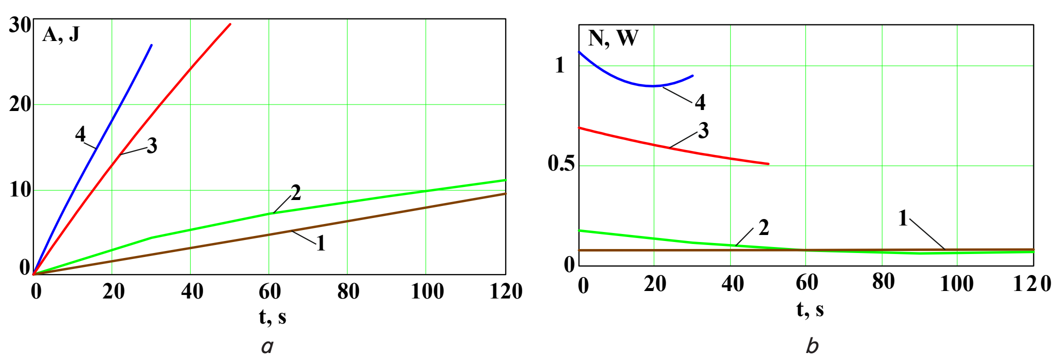

Fig. 6. Graphic dependences: a – the work of the axial load on the time of implementation; b – the axial load force on the implementation time; 1 – P=6 kN, n=82 rpm; 2 – P=6 kN, n=181 rpm; 3 – P=8 kN, n=82 rpm; 4 – P=8 kN, n=181 rpm

It should be noted that the obtained dependences reflect a short-term technological process with a slight deepening of the face. Given the limited range of registration of vibration displacements (oscillograms) of available tools, the duration of the received records is different (Fig. 4, 5). In view of this, Table 2 gives the intermediate (t=30 s) and final (t=120 s) values for the studied interval of the work and power.

6. Discussion of results of studying the interaction of rock-crushing tools and rock

As a result of our series of experiments, it was established that sandstone drilling is accompanied by a monotonous close to the linear deepening of the face. Dominant in the vibration signal is the cutting harmonic. At the same time, the nature of the obtained dependences is determined by the kinematic and force parameters of the process (Fig. 3–5), as well as the state of equipment of the rock-destroying tool (Table 2). Changing the rotational speed of the rock-destroying tool does not significantly affect the deepening speed of the face (Fig. 3). More significant is the creation of an axial load to enable contact force sufficient for the effective destruction of the rocks of the face. Thus, at rotational speeds of 82 rpm and 181 rpm, effective destruction is observed at an axial load of 8 kN (Fig. 4, 5).

It should be noted that the amplitude of longitudinal oscillations with increasing load partially decreases. In addition, as evidenced by the results of research (Table 2), the amplitudes of the longitudinal oscillations of the rock-destroying tool, which does not contain signs of wear, are larger. This is due to the amount of deepening of the cutting elements into the rock and the horizontal components of the cutting forces. The amplitude of oscillations at a time limit of 120 s, under all considered loading conditions, does not exceed 0.6 mm. Wear of the cutter by 1 mm causes a decrease in the amplitude of longitudinal oscillations by an average of 1.4 times.

In general, the nature of the change in the work of the axial load (Fig. 6, *a*) at a certain interval of implementation corresponds to the nature of the change in the deepening of the face. Directly, its values are determined by the level of the applied load. Thus, at a rotational speed of 82 rpm, the work of an axial load of 4 kN, 6 kN, and 8 kN during the implementation of the process (t=30 s) is 0.251 J, 2.329 J, and 18.672 J. At a frequency of 181 rpm, respectively – 0.181 J, 4.307 J, and 26.904 J. Defined in this way, the values of the work of the new rock-destroying tool can serve to assess the condition of the equipment and the effectiveness of its operation during the voyage.

Taking into consideration (5), the magnitude of the axial load force at different mode parameters (Table 2) was also established, which is reflected by graphic dependences (Fig. 6, *b*). At an axial load of 6 kN, there are slight deviations in power functions relative to their average values. At an axial load of 8 kN, a significant change in power within the considered range is characteristic. This is due to the relatively short time of data registration and, accordingly, the lower level of reliability of their approximation.

It is also worth noting the fact that the rotation of the drilling tool with an angular velocity of 82 rpm is accompanied by low-frequency monoharmonic, and with an angular velocity of 181 rpm – by high-frequency polyharmonic axial oscillations. Visually, it is clearly seen that low-frequency (monoharmonic) oscillations occur at the same frequency, which corresponds to the frequency of penetration of cutters into the rock and, accordingly, is the cutting frequency. The high-frequency ones are a combination of several oscillations: with a cutting frequency, friction frequency, as well as subharmonics with frequencies multiples of the cutting frequency and friction, which are formed as a result of frequency modulation.

High-frequency oscillations (n=181 rpm) in contrast to low-frequency ones (n=82 rpm) are more energy-intensive, with the same axial load P=8 kN, 1.44 times more work is performed to destroy the face and, at the same time, the power is 1.67 times more.

In general, our research and reported results are an attempt to establish the relationship of the state of equipment of the rock-destroying tool with the parameters of oscillatory processes under different force and kinematic loading conditions. It should be noted that the presence and possibility of its use for assessing the state and predicting the wear of rock-crushing instruments were not considered in [14, 16, 18].

The use of the proposed technique can be widely used only in the presence of appropriate measuring instruments. They should be interactive and contain means of registration and prompt transmission of information both from the mouth and from the face of the well in the online mode with sufficient accuracy. At the same time, they should provide the possibility of accumulating information and its operational analysis. The presence of such characteristics significantly increases their cost and hinders their widespread introduction into the industry. For a complete assessment and prediction of the wear of the rock-destroying tool in accordance with the proposed method, it is necessary to build numerical models. They should reflect the mechanical system and provide the possibility of obtaining the values of parameters not established by the results of a laboratory experiment, using the sizes of rock-destroying tools common in deep drilling.

7. Conclusions

1. Based on our bench experimental studies, the functions of changing the generalized coordinate of an arbitrary cross-section of the drilling tool were obtained. The nature of oscillatory processes, the nature of their distribution, as well as quantitative indicators have been established. Changing the rotational speed of the rock-destroying tool does not significantly affect the deepening speed of the face. Essential to enable the effective destruction of the rocks of the face is the creation of the necessary axial load, which, for the conditions of our experiment, was about 8 kN at rotational speeds of 82 rpm and 181 rpm.

According to the results of approximation of experimental oscillograms, analytical expressions were built describing the movement of the center of an arbitrary cross-section of the drilling tool with a reliability of 0.49 to 0.82. In addition, we established the amplitudes of oscillations of the drilling tool, which, under the considered load conditions, do not exceed 0.6 mm. Wear of the cutter by 1 mm causes a decrease in the amplitude of longitudinal oscillations by an average of 1.4 times.

2. Based on the obtained functions of moving cross-sections of the column, the energy indicators of the process of destruction of rock by the face have been established. Already at the time of implementation of the process of 30 s, a significant difference has been established between the work performed by the axial load of 6 kN and 8 kN at different rotational speeds. At a rotation frequency of 82 rpm, the work is 2.329 J and 18.672 J, and at a frequency of 181 rpm –

4.307 J and 26.904 J, respectively. The high-frequency oscillations, unlike low-frequency ones, are more energy-intensive, with the same axial load P=8 kN, 1.44 times more work is performed on the destruction of the rocks of the face. The values determined in this way to make a new rock-destroying tool can serve to assess the condition of the equipment and the effectiveness of its operation during the voyage.

Minor deviations in power functions relative to their average values are observed at an axial load of 6 kN. A significant change in power within the considered range is characteristic of an axial load of 8 kN, which is due to the short data registration time.

The values of the energy parameters of the new tool determined in this way can serve to assess the condition of the equipment and the effectiveness of its operation within the framework of the proposed method implementation.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

References

1. Organization of the Petroleum Exporting Countries. OPEC Annual Statistical Bulletin. Available at: https://asb.opec.org/ASB_PDFDownload.php
2. Yurych, L. R., Ivasiv, V. M., Rachkevych, R. V., Yurych, A. R., Kozlov, A. A. (2016). The use of elastic elements for wellbore trajectory management. OIJ, 2, 36–37. Available at: https://onepetro.org/OIJ/article/2016/02/36/15528/The-use-of-elastic-elements-for-wellbore
3. Sun, T., Zhang, H., Gao, D., Liu, S., Cao, Y. (2019). Application of the Artificial Fish Swarm Algorithm to Well Trajectory Optimization. Chemistry and Technology of Fuels and Oils, 55 (2), 213–218. doi: https://doi.org/10.1007/s10553-019-01023-7
4. Lyu, Z., Lei, Q., Yang, L., Heaney, C., Song, X., Salinas, P. et. al. (2021). A novel approach to optimising well trajectory in heterogeneous reservoirs based on the fast-marching method. Journal of Natural Gas Science and Engineering, 88, 103853. doi: https://doi.org/10.1016/j.jngse.2021.103853
5. Chudyk, I. I., Femiak, Y., Orynchak, M. Ya., Sudakov, A. I., Riznychuk, A. I. (2021). New methods for preventing crumbling and collapse of the borehole walls. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 4, 17–22. doi: https://doi.org/10.33271/nvngu/2021-4/017
6. Biletsky, V., Vitryk, V., Mishchuk, Y., Fyk, M., Dzhus, A., Kovalchuk, J. et. al. (2018). Examining the current of drilling mud in a power section of the screw downhole motor. Eastern-European Journal of Enterprise Technologies, 2 (5 (92)), 41–47. doi: https://doi.org/10.15587/1729-4061.2018.126230
7. Built for hard and abrasive formations. Varel International. Available at: https://cdn.thomasnet.com/ccp/00080007/143518.pdf
8. Capability. Drilling. NOV. Available at: https://www.nov.com/products-and-services/capabilities/drilling#capabilities=&brands
9. Schlumberger. Available at: https://www.slb.com/drilling/bottomhole-assemblies/drill-bits
10. Che, D., Han, P., Guo, P., Ehmann, K. (2012). Issues in Polycrystalline Diamond Compact Cutter–Rock Interaction From a Metal Machining Point of View – Part I: Temperature, Stresses, and Forces. Journal of Manufacturing Science and Engineering, 134 (6). doi: https://doi.org/10.1115/1.4007468
11. Che, D., Han, P., Guo, P., Ehmann, K. (2012). Issues in Polycrystalline Diamond Compact Cutter–Rock Interaction From a Metal Machining Point of View – Part II: Bit Performance and Rock Cutting Mechanics. Journal of Manufacturing Science and Engineering, 134 (6). doi: https://doi.org/10.1115/1.4007623
12. Che, D., Ehmann, K. (2014). Experimental study of force responses in polycrystalline diamond face turning of rock. International Journal of Rock Mechanics and Mining Sciences, 72, 80–91. doi: https://doi.org/10.1016/j.ijrmms.2014.08.014
13. Akbari, B., Miska, S. Z., Yu, M., Rahmani, R. (2014). The Effects of Size, Chamfer Geometry, and Back Rake Angle on Frictional Response of PDC Cutters. Paper presented at the 48th U.S. Rock Mechanics/Geomechanics Symposium. Minneapolis. Available at: https://onepetro.org/ARMAUSRMS/proceedings/ARMA14/All-ARMA14/ARMA-2014-7458/123878
14. Akbari, B., Miska, S. (2016). The effects of chamfer and back rake angle on PDC cutters friction. Journal of Natural Gas Science and Engineering, 35, 347–353. doi: https://doi.org/10.1016/j.jngse.2016.08.043
15. Ivasiv, V., Yurych, A., Zabolotnyi, S., Yurych, L., Bui, V., Ivasiv, O. (2020). Determining the influence of the condition of rock-destroying tools on the rock cutting force. Eastern-European Journal of Enterprise Technologies, 1 (1 (103)), 15–20. doi: https://doi.org/10.15587/1729-4061.2020.195355
16. Wiercigroch, M. (2010). Modelling and Analysis of BHA and Drill-string Vibrations. R&D project sponsored by the BG Group.
17. Kapitaniak, M., Hamaneh, V. V., Wiercigroch, M. (2016). Torsional vibrations of helically buckled drill-strings: experiments and FE modelling. Journal of Physics: Conference Series, 721, 012012. doi: https://doi.org/10.1088/1742-6596/721/1/012012
18. Vaziri, V., Kapitaniak, M., Wiercigroch, M. (2018). Suppression of drill-string stick–slip vibration by sliding mode control: Numerical and experimental studies. European Journal of Applied Mathematics, 29 (5), 805–825. doi: https://doi.org/10.1017/s0956792518000232
19. Fedorov, B., Ratov, B., Sharauova, A. (2017). Development of the model of petroleum well boreability with PDC bore bits for Uzen oilfield (the Republic of Kazakhstan). Eastern-European Journal of Enterprise Technologies, 3 (1 (87)), 16–22. doi: https://doi.org/10.15587/1729-4061.2017.99032
20. Chudyk, I., Raiter, P., Grydzhuk, Y., Yurych, L. (2020). Mathematical model of oscillations of a drill tool with a drill bit of cutting-scraping type. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 1, 52–57. doi: https://doi.org/10.33271/nvngu/2020-1/052