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THE RESEARCH OF LOADED CONDITION OF THE DEMOUNTABLE CUTTING-ROTARY DRILLING TOOL ELEMENTS WITH A TWO-ROW CUTTING STRUCTURE

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ABSTRACT

A drilling tool is the most critical and highly loaded element of a drilling rod, on which the efficiency ofblastholedrilling largely depends. To improve the design of demountable drilling tools, complete information on the loads acting on the main bitelements is needed. This work studies the stress-strain state of a demountable cutting-rotary bit with gear-disc cutters (DRDF-244,5-2) with the use of finite-element design technologies of the ANSYS software environment. The calculations were performed under the maximum loads acting on the bit from the drilling machine and the bottom of the well and their uneven distribution over the bit elements. The results of the distribution of equivalent stress in the body of the bit, the axes of rotation, and gear-disccutters with two-row cutting structure are presented. The analysis of the bit performance under various operating conditions is also given.

Keywords: axial force, blasthole drilling, stress-strain state, drilling tool, computed model, equivalent stress

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1. INTRODUCTION

A drilling tool is the most critical and highly loaded element of a drilling rod, on which the efficiency of the blastholedrilling depends.

To improve the design of demountable cutting-rotary drilling tools, complete information about the stress state of its basic elements is required.

The stress-strain state of a drilling tool is characterized by a number of factors, the main of which are its design features and the loads acting on it [1, 2].

The nature of the load distribution largely depends on the form of bit cuttingstructure of the rock-cutting elements of bits (here, gear-disc cutters), which is selected depending on the bits' type and rock properties [3-5].

Despite the diversity of drilling tools types, a stress state has been sufficiently studied only for the construction of rolling cutter bits. Therefore, it is important to study the strength properties of cutting-rotary drilling tools with multi-row cutting structure, which can successfully replace commercially manufactured rolling bits forblastholedrilling of rocks with a coefficient of strength f=6-8 according to M.M. Protodyakonov with inter-layers up to f=10 [6].

2. MATERIALS AND METHODS

Strength calculations of a cutting-rotary type drill bit with multi-row cutting structurewere made using finite-element modeling technologies in the ANSYS software under maximum force and moments (R_{oa}=400kN, M_t=4.2kNm) generated by drilling machines, as well as their uneven distribution on the bit elements during interaction with the bottom-hole.

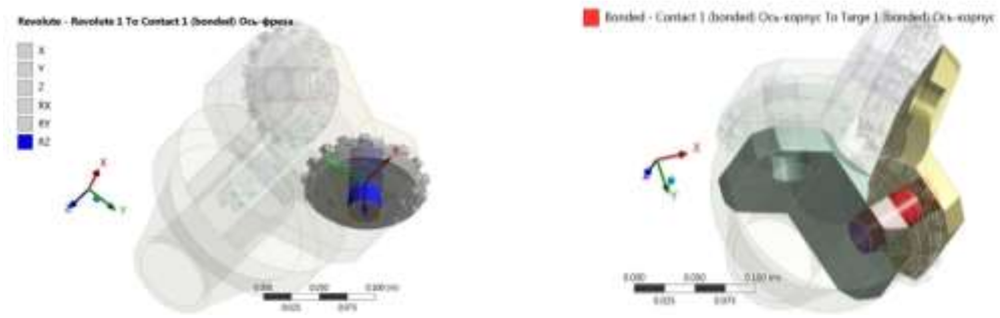
Figure 1*a* shows the finite element (FE) model of a drill bit. The main elements of this model consist of ten nodal tetrahedra, and the axes are formed by 20 nodal hexahedral elements.

a – general view of the finite element model of the bit   *b* – diagram of the quality of elements.

Figure 1 Finite element model of the drill bit of cutting-rotary actionDRDF-244,5-2.

Figure 1*b* presents a diagram of the quality of the elements. It allows assessing the state of the model and identifying the number of its elements that are not suitable for calculation [7-8]. In this case, the number of low-quality elements is 0.03% of the total number of model elements (823,729), which means that the model is allowed to be calculated.

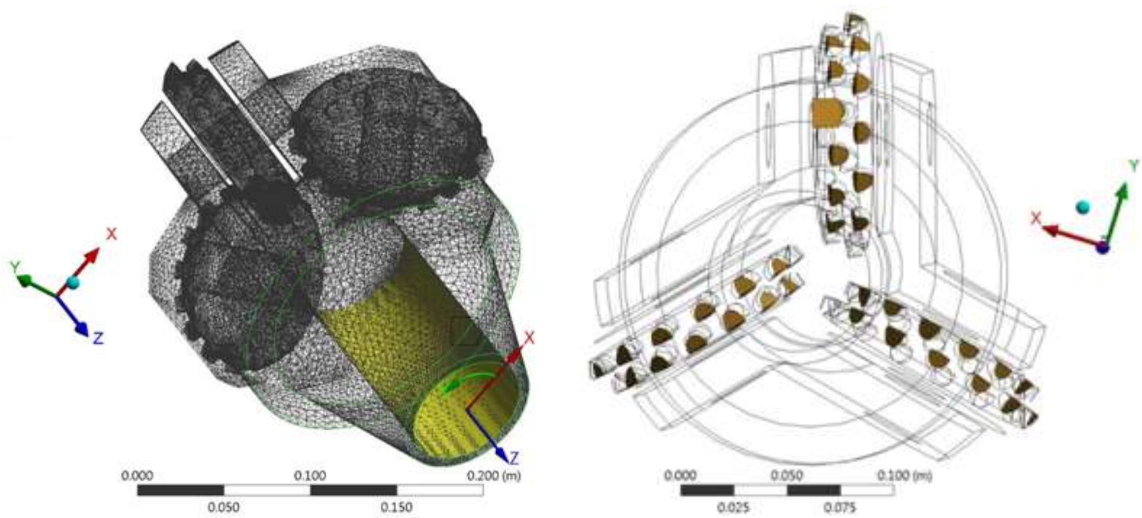
According to the statement of the problem, the gear-disccutter rotates freely on the axis. To simulate this condition in the software environment, the Joint function of Revolute type was chosen [7]. Figure 2*a* shows a model for the integration of an axis with one of the gear-disc cutters. To prevent the movement of the cutters between the surfaces of the axes and the body (Figure 2*b*), the Bonded function was used [8].



a – axes and gear-disccutters *b* – axes and bodies.

Figure 2 Model of interfacing elements of the bit

For the detailed modeling of the loading of gear-disc cutters with multi-row cutting structure, the necessary condition is to set the limits on the movement of the teeth of each cutter. Considering the data from the work [9], Figure 3 shows the boundary conditions for modeling the gear-disc cutters operation.



a – bit rotation b – the interaction of carbidecutting structure with the bottom-hole.

Figure 3 Boundary loading conditions

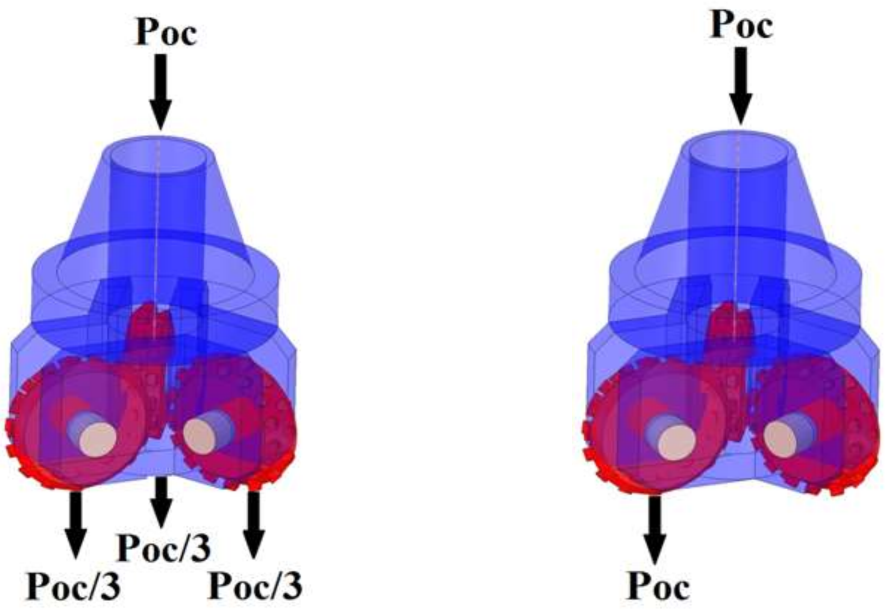
The following materials were used to produce the elements of the bit: the body is made of 35KhML steel, the axis of rotation – 40Kh steel, gear-disc cutters – 40KhN2, the bit cutting structure – metal-ceramic carbide VK8V. Properties of these materials [10] are given in Table 1.

Table 1 Properties of materials used for the production of bits

Property	**Material**		
	Body	*Axes*	*Cutter*
	Steel 35KhML	Steel 40Kh	Steel 40KhN2
Yield stress, MPa	392	780	930
Short-term stress limit, MPa	589	980	1080
Elastic modulus, MPa	2.13·10-5	2.14·10-5	2.15·10-5
Poisson's ratio	0.25	0.26	0.26

Studies of the strength properties of drilling tools [11, 12] showed that most of the load transferred from the drill rod to the bit during its operation (given the constant change in the characteristics of the bottom hole – the presence of uniformities, irregularities, cracks, etc.) can be transferred to the bottomholeafter three, two, and in some cases, one rock cutting element. As a result, there is an uneven distribution of the load among the elements of the drilling tool.

Based on this, to study the strength characteristics of a demountablecutting-rotary drilling tool with multi-row bit cutting structure, it is sufficient enough to simulate two bit loading cases (Figure 4). The first case – the entire load is evenly distributed into three gear-disc cutters, the second case –the entire load falls on one gear-disc cutter.

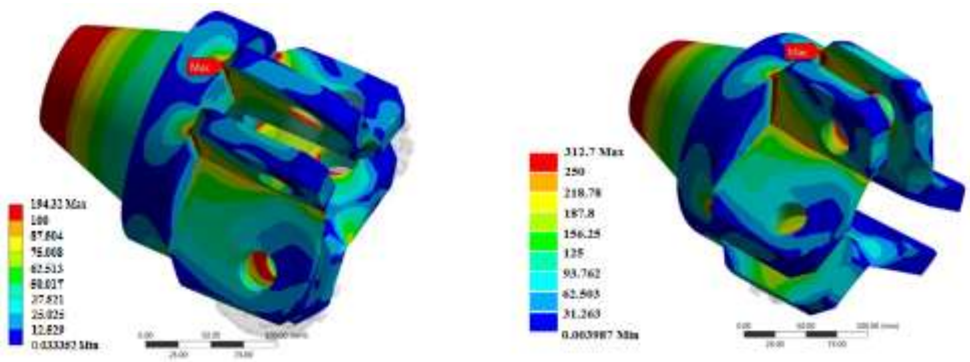


a – the load is distributed evenly onto three cutters *b* – the load falls on one cutter.

Figure 4 Bit loading conditions

3. RESULTS

Figure 5 shows the equivalent von-mises stress distribution fields in the body of the bit.

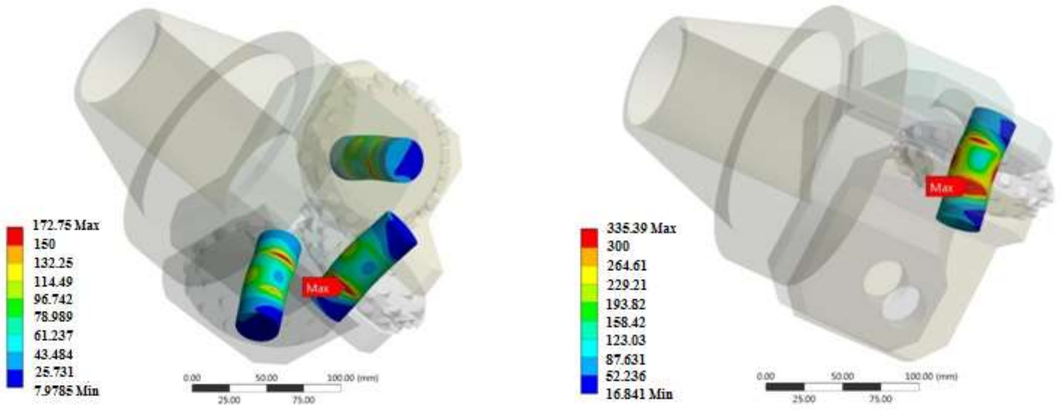


a – the load is distributed onto three gear-disc cutters *b* – the load falls on one gear-disc cutter.

Figure 5 Distribution of equivalent stress fields of the body

Analysis of the data in Figure 5 shows that the distribution of equivalent stress fields is uniform and does not exceed 5-10 MPa. The maximum values of the effective stresses occur at the junction of the case with the legs and are 194.32 and 312.7 MPa for the first and secondloading cases, respectively.It does not exceed the limit of yield (σ_y) and short-term strength of the case's material (σ_s) (Table 1).

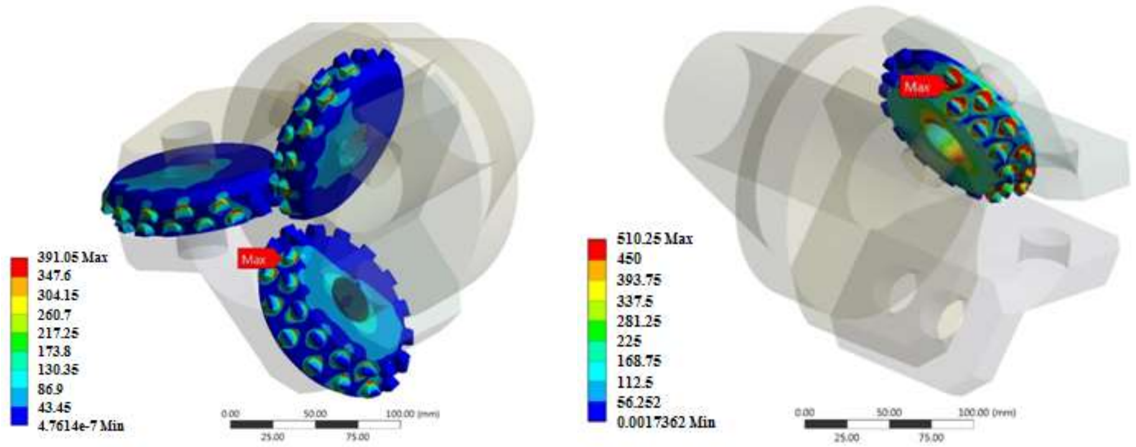
Figure 6 shows the equivalent von-mises stress distribution fields along the axes of rotation of rock-cutting elements.



a – the load is distributed onto three axes of rotation *b* – the load falls on one axis of rotation.

Figure 6 The distribution of equivalent stress fields along the axes

Figure 7 shows the equivalent von-mises stress distribution fields in gear-disc cutters with multi-row cutting structure.



a–the load is distributed evenly onto three geardisc cutters *b*–the load falls on one gear-disc cutter.

Figure 7 Distribution of equivalent stress fields alonggear-disc cutters

According to the data of Figure 6 and Figure 7, conclusions similar to Figure 5 can be made. The maximum stresses in the construction of the axes arise in the points of junction with the body, the rating values of which are 172.76 and 335.29 MPa for the first and second loading cases. The maximum stresses in the design of gear-disc cutters occur at the junction points of the teethto the cutter, the nominal values of which are 391.6 and 510.25 MPa for the first and second loading cases, respectively. In this case, the maximum values of the effective stress do not exceed σ_y and σ_s of the material of axes and gear-disccutters.

4. DISCUSSION

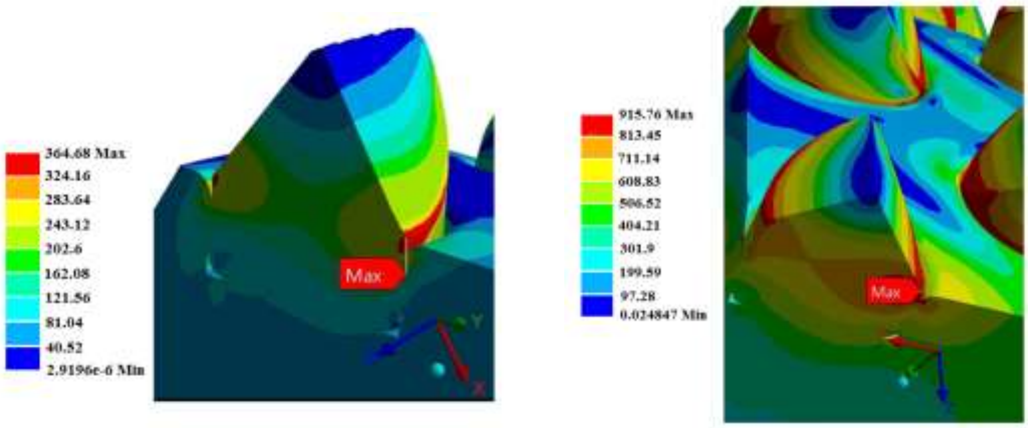
The following simplifications have been made in constructing the FE model of the cutting-rotary bit of the milling type. During the bit body design, radiussing and chamfers are not taken into account (for example, at the junction of the case and the legs). This allows reducing the level of stress concentration by 5-15%.

The design of the axes of rotation of rock-cutting elements (gear-disc cutters) does not consider the chamfers in the areas of a junction of the axis and the body. In the design of the bit on the axes of rotation, there are washers that prevent the skewed gear-disccutters on the axes. Their additional consideration also entails a change in the effective stresses, which do not affect additionally on the load of the bit.

The design of gear-disc cutters (namely, holes for soldering carbide cutting structure), does not take into account the roundings, which entails a decrease in the effective stresses. It is necessary to consider the fact that the durability of the carbide cutting structure of a drilling tool largely determines the main indicators of the effectiveness of drilling wells. In turn, it is largely determined by the stress concentration of each tooth at its junctionwith the cutter body [13]. Thus, with an increase in preload when soldering teeth, the stress concentration increases, which leads to a decrease in the strength properties and durability of the cutting structure of gear-disc cutters.

Considering the data from Figure 7, and the above-described, weperformed sub-modeling of gear-disc cutters, i.e. modeling of cutters by constructing their refined geometry and the subsequent application of data from previous calculations as boundary conditions.

The results of sub-modeling of gear-disc cutters are shown in Figure 8.



a – the load is distributed into three gear-disc cutters evenly

b – the load falls on one gear-disc cutter.

Figure 8 Distribution of equivalent stress fields ongear-disc cutters after sub-modeling

Analysis of the data presented in Figure 8 showed that the maximum values of the effective loads, as before, occur in the upper part of the cutter body holes for soldering carbidecutting structure. In the first loading case (easiest), the entire load decreased by 5%, and in the second loading case (most severe) – increased by 45-55%. The nominal values of the effective stresses after the modeling were 164.68 and 915.76 MPa for the first and second loading cases, respectively. At the same time, they do not exceed σ_y and $\sigma_s$in the material of gear-disc cutters (Table 1).

Table 2 shows the stresses that occur in the elements of the bit, as well as the allowable stress for the material, from which the elements of the bit are made.

Table 2 Stress in the elements of the bit of amilling type

Bit element	**Material**	**Working stress in the element σ_y, MPa**	**Allowable stress for the material σ_y, MPa**
Body	35KhML	194.32/312.7	392
Axis	40Kh	172.75/335.39	780
Cutter	40KhN2	364.78/915.76	930

According to Table 2, the maximum stress in the bit elements does not exceed the allowable stresses for the material, which indicates the reliability of the design, an adequate margin of safety and wear resistance.

5. CONCLUSION

The study of the loading and stress state of a demountablemilling-type drilling tool with multi-row bit structure (DRDF-244,5-2 bit) presented in this paper allowsmaking the following conclusions:

1. The cutter-type drill bit under study can withstand the loads applied to it without the occurrence of sections with critical stresses in the bit design, and, therefore, it has an adequate margin of safety and wear resistance.
2. The multi-row cutting structure of gear-disc cutters expands the area of rational operation of the bit in a complex-structural rock mass with a Protodyakonov scale of hardnesscoefficient from f=6-8 to f=8-10 with interlayers to f=12 and does not weaken the design of gear-disc cutters, and also does not cause stresses that exceed the allowable values for the material.

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