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Studies on strength properties of a separable drilling milling tool

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Abstract. A drilling tool is the most important and highly loaded element of a drill rod which determines the efficiency of blast hole drilling. To improve the design of separable drilling tools (SDT), it is required to have complete information on the loads acting on bit elements. The stress-strain state of a separable cutting rotary bit (DRDF-244.5-2) was studied in ANSYS using finite-element modeling technology. Calculations were performed under maximum drilling machine and borehole bottom loads which were unevenly distributed. The article presents distribution results for fields of equivalent stresses occurring in the bit body, rotation axes and tooth-disk mills with double-row carbide cutting structures. The performance of bits under various operating conditions is analyzed.

1. Introduction

A drilling tool is the most responsible and highly loaded element of the drill rod which determines the efficiency of blast hole drilling.

In order to improve the design of separable cutting rotary drilling tools, complete information on the stress state of its basic elements is required.

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

The nature of load distribution depends on the structure of rock cutting elements of bits (tooth disc mills) which is selected depending on the type of bits and rock properties [3-5].

Despite the variety of drilling tools, the stress-strain state has been studied only for roller bits. Therefore, it is important to study strength properties of cutting rotary drilling tools with multi-row structures which can replace roller bits used for blast hole drilling and having the Protodyakonov coefficient $f = 6-8$ and layers $f = 10$ [6].

2. Materials and methods

Strength of cutting rotary drilling bits with multi-row structures was calculated in ANSYS using finite-element modeling technology under maximum forces and moments ($R_{os} = 400$ kN, $M_{bp} = 4.2$ kNm) generated by drilling machines and uneven distribution of forces and moments over bit elements interacting with the well bottom.

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



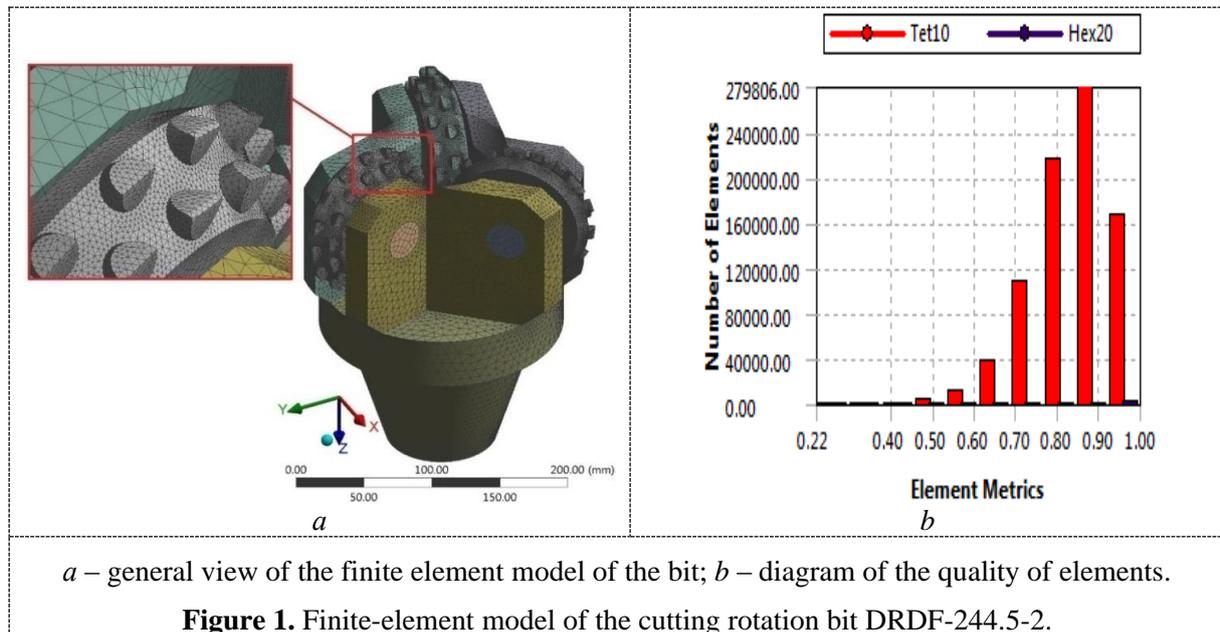
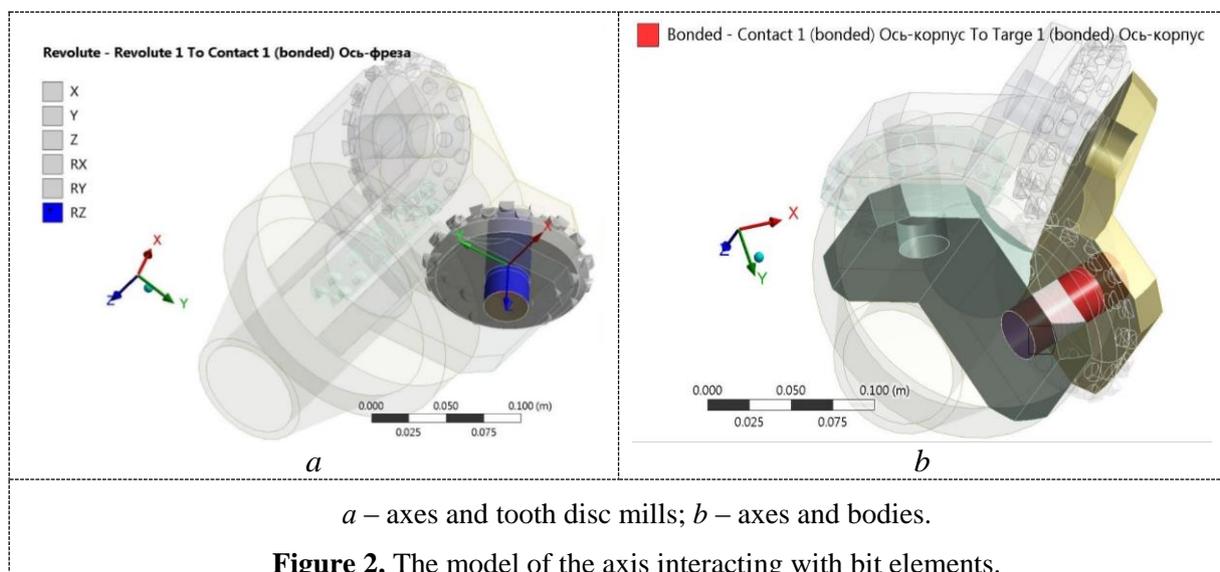


Figure 1*b* shows a diagram of the quality of elements. The diagram is used to assess the state of the model and identify the number of its elements which are not suitable for calculation [7-8]. The number of low-quality elements is 0,03% of the total number of elements (823729) which means that the model can be used for calculation.

According to the task, the tooth disk mill rotates along the axis. To simulate this condition in the software environment, a revolute joint was used [7]. Figure 2*a* shows a model of an axis interacting with one of the tooth disc mills. To prevent mill motions between surfaces of the axes and the body (Figure 2*b*), the Bonded function was used [8].



When modelling loads on tooth disc mills with multi-row structures, it is necessary to set limits on teeth movements. Taking into account the data in [9], Figure 3 shows boundary loading conditions for modeling operations of tooth disc mills.

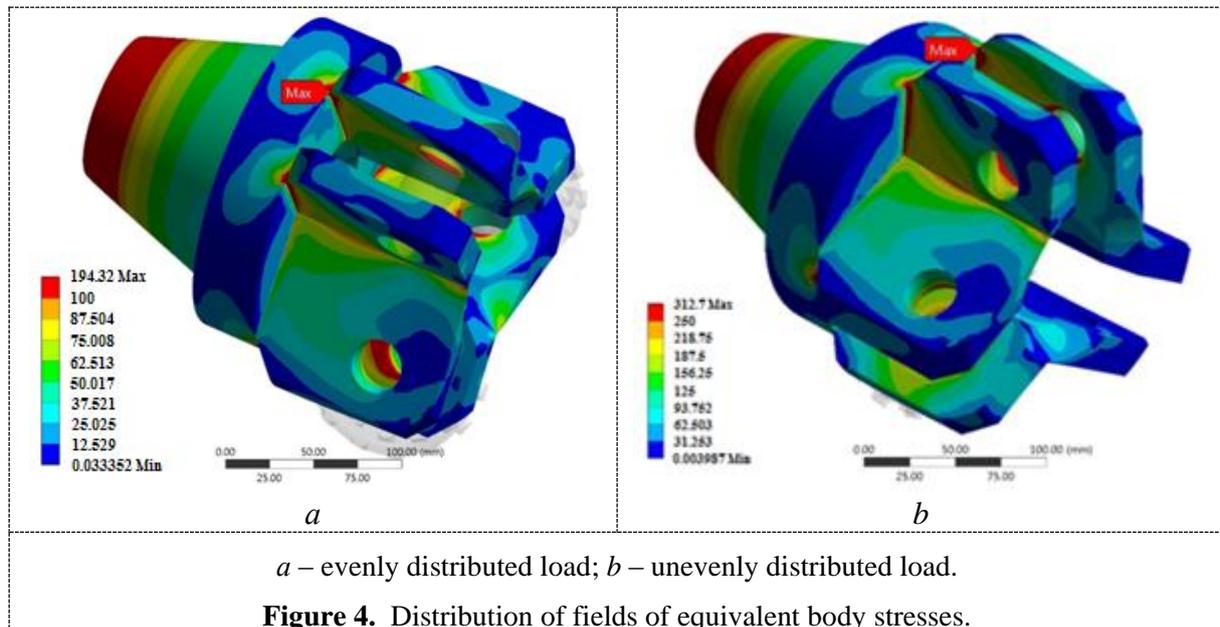


Figure 5 shows fields of von Mises equivalent stresses distributed along the rotation axes of rock-cutting elements.

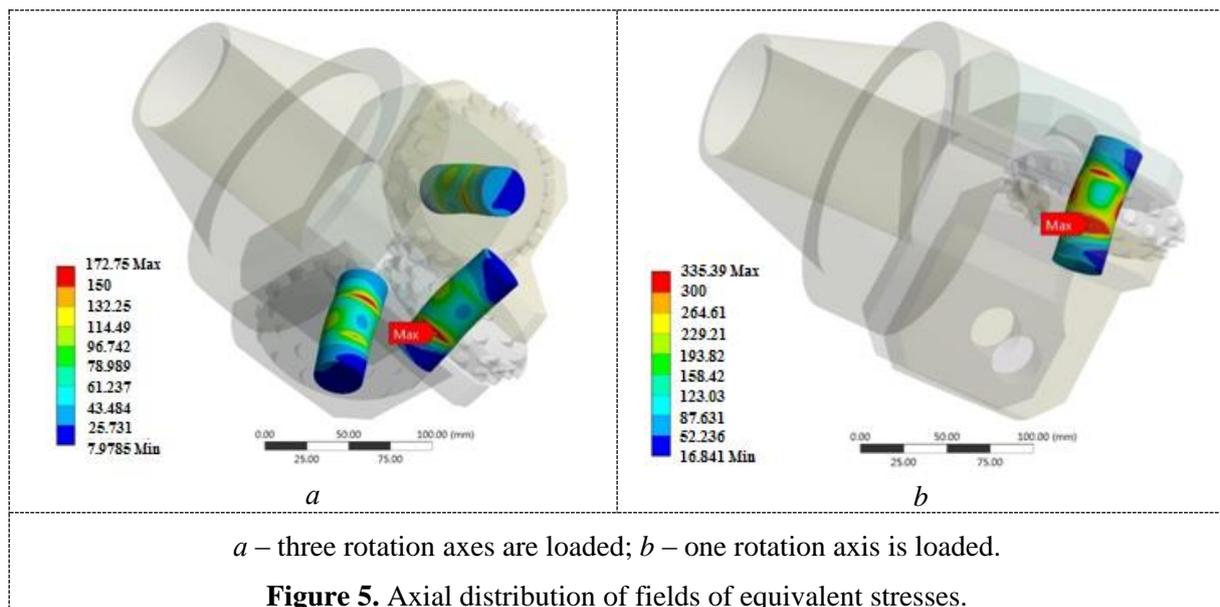
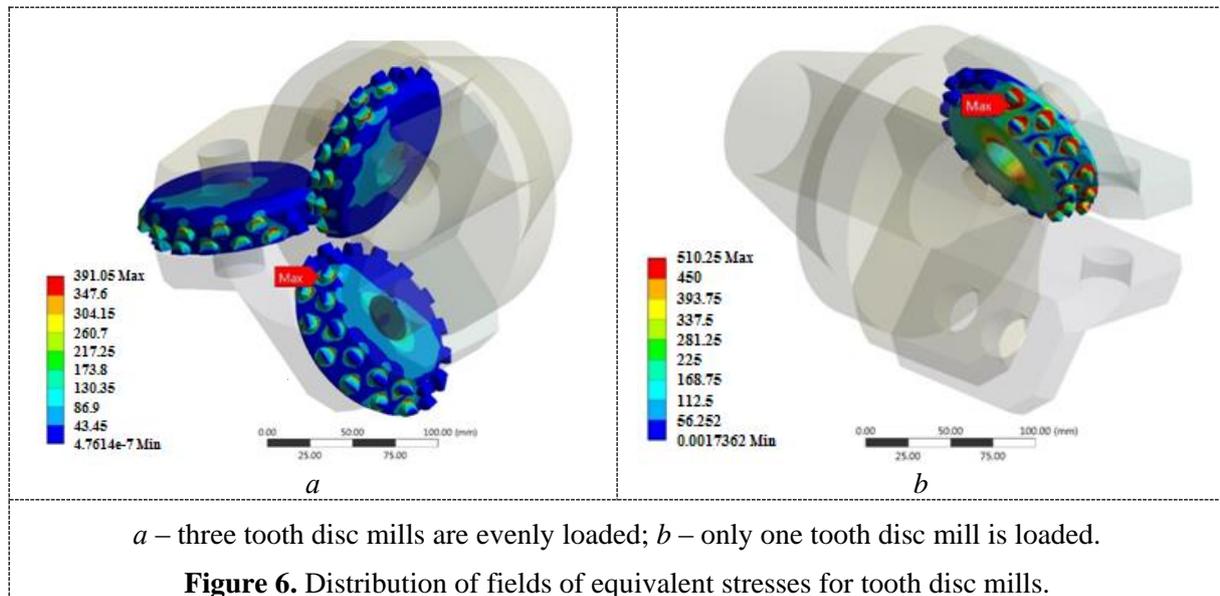


Figure 6 shows distribution fields for von Mises equivalent stresses in tooth disc mills with multi-row cutting structures.

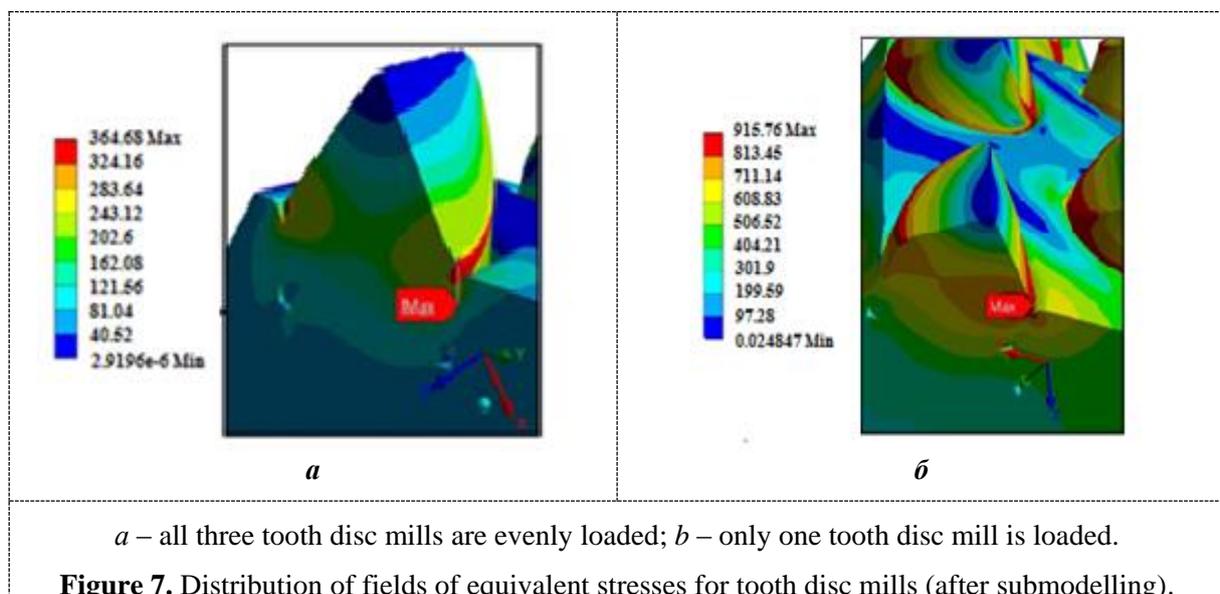


According to the data presented in Figures 5 and 6, we can draw similar conclusions. The maximum stress occurs in the body/axis junction (172.76 and 335.29 MPa for the first and second types of loading respectively). The maximum stress in the tooth disc mill occurs in the teeth/mill body junction (nominal values are 391.6 and 510.25 MPa for the first and second types of loading respectively). The maximum values of effective stresses do not exceed σ_T and σ_B σ_T of the axis and tooth disc mill material.

4. Discussion

The following simplification was made when modelling the cutting rotary bit. When modeling the bit body, roundings and chamfers were ignored (e.g., in the body/leg junction) reducing the stress concentration level by 5-15%.

When modeling the rotation axes of rock-cutting elements (tooth disc mills), chamfers in the axis/body junction were ignored. On the rotation axes, there are washers preventing tooth disc mills from twisting. They cannot change effective stresses and do not influence the bit load.



When modeling holes for soldering carbide cutting structures, roundings were ignored. It decreases effective stress values. It is necessary to take into account the fact that it is durability of carbide cutting structures determines performance of well drilling. Durability is determined by stress concentration of each tooth in the entrance zone [14]. For example, with an increase in preload during teeth soldering, stress concentration increases which affects strength properties and durability of the cutting structure.

Taking into account the data presented in Figure 6, we sub-modeled tooth disk mills, i.e. modeled mills by building their updated geometry and applying data from previous calculations as boundary conditions.

Submodeling results for tooth disc mills are presented in Figure 7.

The data presented in Figure 7 show that maximum values of effective loads occurring in the body top part when soldering the carbide cutting structure. The first type load decreased by 5%, and the second type load increased by 45-55%. Nominal values of effective stresses were 164.68 and 915.76 MPa for the first and second types of loading respectively. They do not exceed σ_T and σ_B of the tooth disc mill material (Table 1).

5. Conclusion

The following conclusions can be drawn from the study on loads and stress states of separable drilling tools with multi-row cutting structures (DRDF-244.5-2 bit):

1. The bit resist loads without critical stresses in the bit design. Therefore, the bit is strong enough and wear-resistant.
2. Multi-row cutting structures of tooth disc mills expand the area of rational exploitation of the milling bit in complex-structural rock massifs with the Protodyakonov strength coefficient varying from $f = 6-8$ to $f = 8-10$ and interlayers of $f = 12$. They do not weaken the design of tooth disc mills and do not cause material stresses exceeding allowable values.

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