IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Studies on strength properties of a separable drilling milling tool

To cite this article: K A Bovin *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **229** 012010

IOP Conf. Series: Earth and Environmental Science 229 (2019) 012010 doi:10.1088/1755-1315/229/1/012010

Studies on strength properties of a separable drilling milling tool

К A Bovin, A V Gilev, A O Shigin

Siberian Federal University, Russia

E-mail koct.91@mail.ru

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].

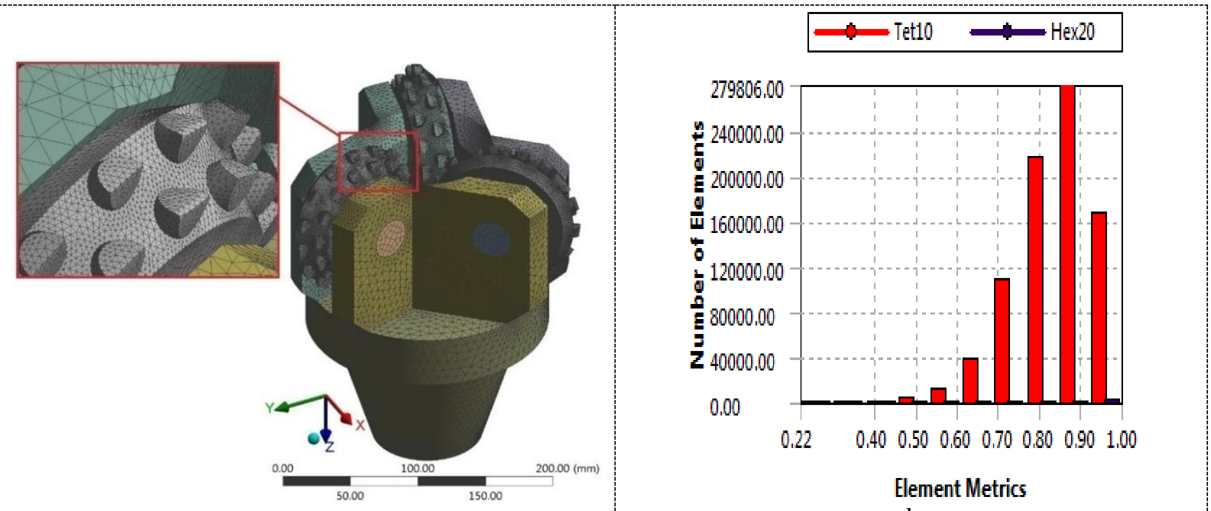
The nature of load distribution depends on the structure of rock cutting elements of bits (tooth disc mills) which is selected depending on the type of bits and rock properties [3-5].

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, $M_{вр}$ = 4.2 kNm) generated by drilling machines and uneven distribution of forces and moments over bit elements interacting with the well bottom.

Figure 1*a* 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.



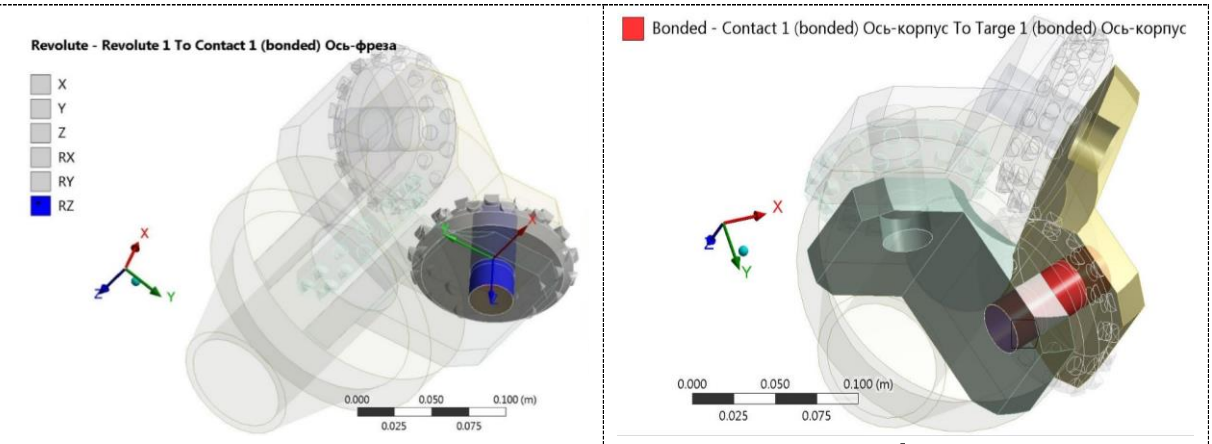
a *b*

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 cutting rotation bit DRDF-244.5-2.

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].

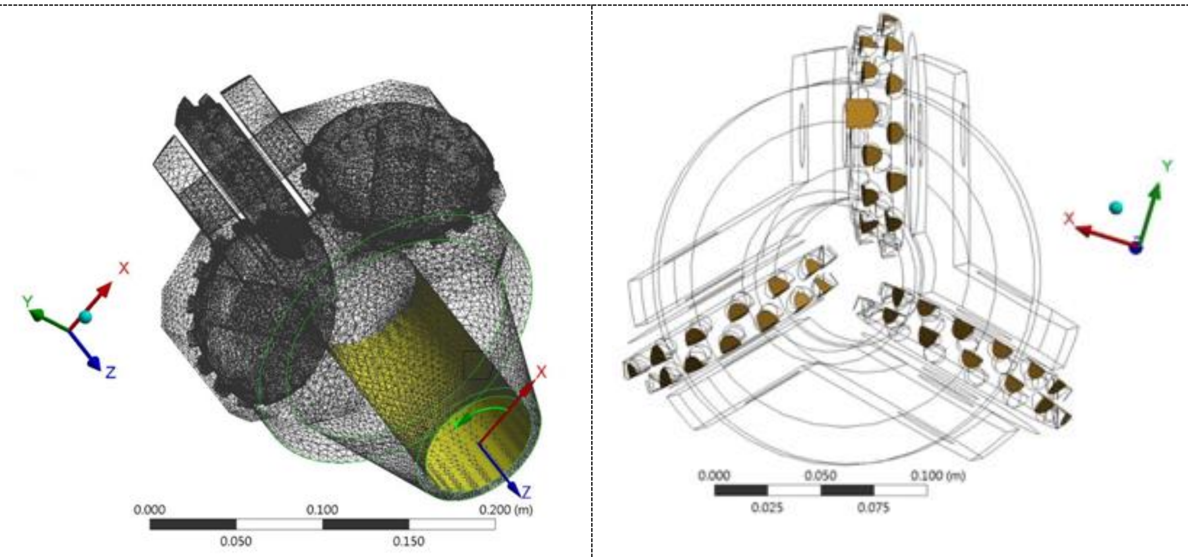


a *b*

a – axes and tooth disc mills; *b* – axes and bodies.

Figure 2. The model of the axis interacting with bit elements.

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.



a *b*

a – bit rotation; *b* – carbide cutting structure-bottom hole interaction.

Figure 3. Boundary loading conditions.

The following materials were used to produce bit elements: the body was made of 35KhML steel, the rotation axes were made of 40H steel, tooth disc mills were made of 40KhN2 steel, the cutting structure was made of VK8V metal ceramic hard alloy. Properties of these materials [10] are presented in Table 1.

Table 1. Properties of materials used in bit production.

Properties	Material		
	Body	Axes	Mill
	35KHML	40KH	40KHN2
Yield strength, MPa	392	780	930
Short term strength, MPa	589	980	1080
Modulus of elasticity, MPa	$2.13{\cdot}10^{-5}$	$2.14{\cdot}10^{-5}$	$2.15{\cdot}10^{-5}$
Poisson ratio	0.25	0.26	0.26

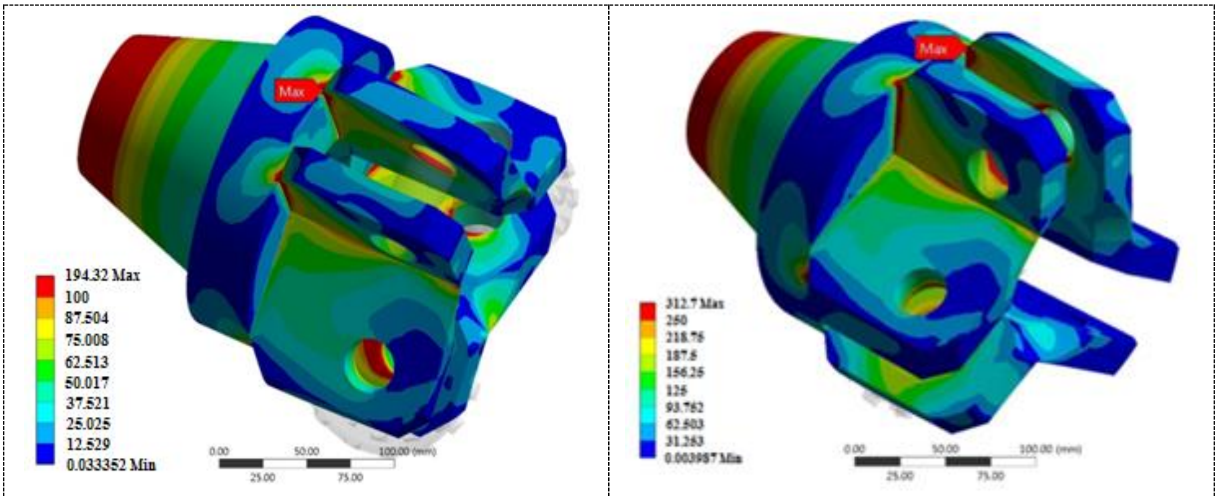
Studies of strength properties of drilling tools [11-13] showed that loads from the drill rod (given the constant change in the characteristics of the bottom hole - continuities, irregularities, cracks, etc.) can be transferred to the bottom through three, two, or even one rock cutting element. As a result, loads are distributed unevenly.

To study strength properties of separable cutting rotary drilling tools with multi-row structures, it is sufficient to simulate evenly load and unevenly distributed loads.

3. Results and analysis

Figure 4 shows the fields of distribution of the von Mises equivalent stresses in the bit body.

Analysis of the data presented in Figure 4 shows that distribution of equivalent stress fields is even and does not exceed 5-10 MPa. The maximum stress occurs in the body/legs junction (194.32 and 312.7 MPa for the first and second types of loading respectively). They do not exceed the yield strength ($\sigma_т$) and short-term strength of the body material ($\sigma_в$) (Table 1).

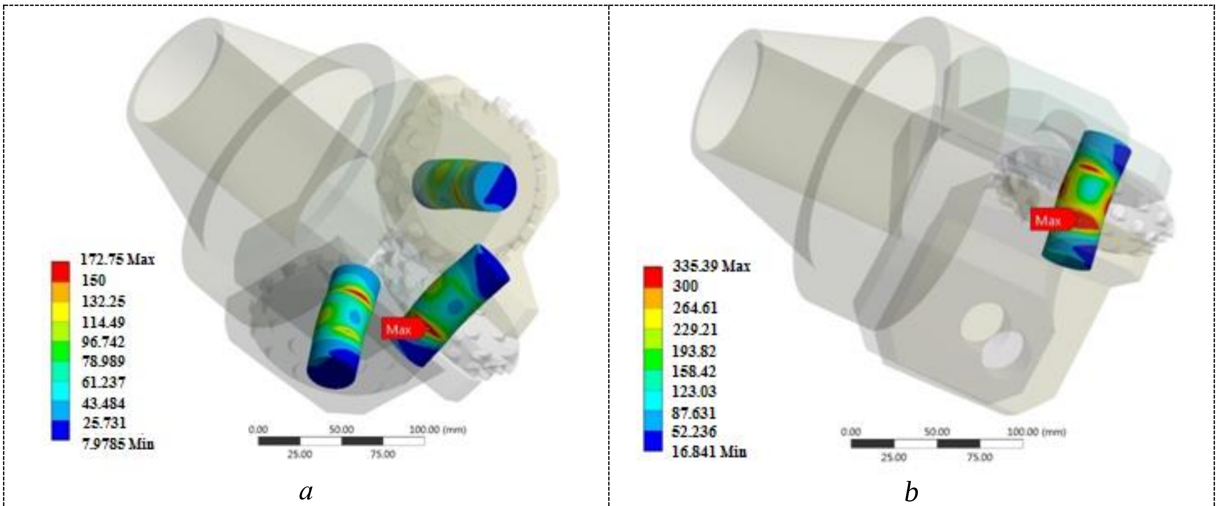


a *b*

a – evenly distributed load; *b* – unevenly distributed load.

Figure 4. Distribution of fields of equivalent body stresses.

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

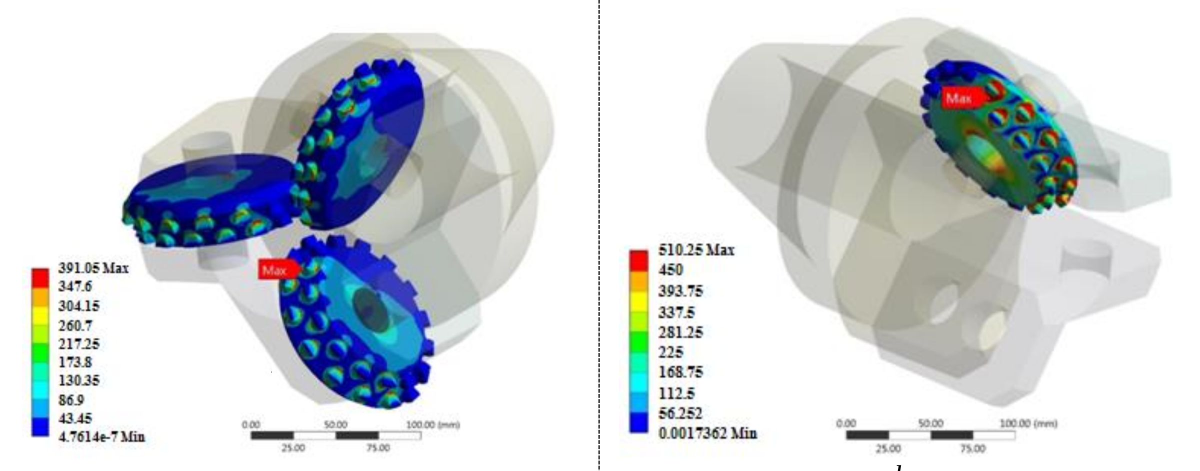


a *b*

a – three rotation axes are loaded; *b* – one rotation axis is loaded.

Figure 5. Axial distribution of fields of equivalent stresses.

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



a *b*

a – three tooth disc mills are evenly loaded; *b* – only one tooth disc mill is loaded.

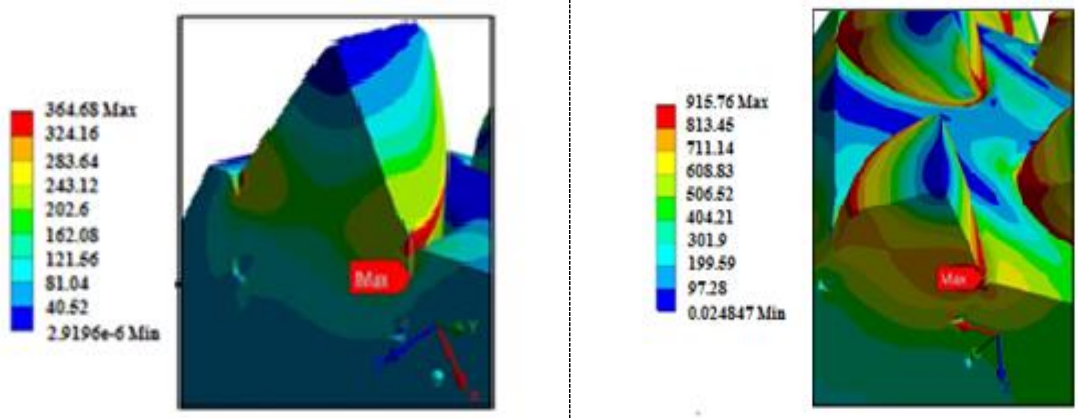
Figure 6. Distribution of fields of equivalent stresses for tooth disc mills.

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 $\sigma_{т}$ and $\sigma_{в}$ σT 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.



a ***б***

a – all three tooth disc mills are evenly loaded; *b* – only one tooth disc mill is loaded.

Figure 7. Distribution of fields of equivalent stresses for tooth disc mills (after submodelling).

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 not cause material stresses exceeding allowable values.

Acknowledgments

The research is a part of the study funded by the Grant of the President of the Russian Federation for government support of young Russian scientists – MD-2211.2018.8.

References

[1] Zubov V V and Khazin M L 2015 Increased wear resistance of carbide drilling tools. *Mining Information-analytical bulletin* **6** pp 168–170.

[2] Dhanraj Patel, Rajesh Verma 2015 Analysis of drilling tool life – a review. *International journal of Mechanical Engineering and Robotics Research* **4** pp 329–359.

[3] Petrovsky E A, Danilov A K, Soloviev E A, Bukhtoyarov V V and Privalikhin R S 2015 Design of highly efficient drilling tools. *Actual problems in machine building* **2** pp 304–308.

[4] Pawar P, Ballav R and Kumar A 2016 Finite element method broach tool drilling analysis using explicit dynamics ansys. *International journal of Modern Manufacturing Technologies* **8(2)** pp 54–60.

[5] Gilev A V, Shigin A O, Doronin S V and Chesnokov V T 2010 Influence of the form of equipment on the stress state of a drilling tool. *Fundamental researches (Electronic resource)* **12** pp 80–87.

[6] Gilev A V, Bovin K A, Shigin A O and Belozerov I R 2017 Justification of kinematic and mode parameters of cutting-rotary bits with multi-row cutting structure. *Fundamental researches (Electronic resource)* **1(2)** pp 278–283.

[7] Thompson M K and Thompson J M 2017 *ANSYS Mechanical APDL for Finite Element Analysis*. USA: Butterworth-Heinemann p 466.

[8] Basov K A 2016 *ANSYS for designers*. Moscow: DMK-Press p 241.

[9] Bovin K A and Gilev A V 2017 Justification of rational rock drilling parameters for cutting rotary bits. *Izvestiya of higher educational institutions. Mining Journal* **6** pp 101–108.

[10] Dragunov Yu G, Zubchenko A S, Kashirsky Yu V, Degtyarev A F, Zharov V V, Koloskov M M, Orlov A S and Skorobogatykh V N 2015 *Marker of steels and alloys*. Moscow: Mashinostroenie. p 1216.
[11] Shigin A O and Gilev A V 2012 On the loads on rock-cutting tools when drilling complex structural rocks. *Mining equipment and electrical mechanical engineering* **6** pp 16–-20.
[12] Butkin V D 2005 *Designing of drilling bits for open pit mining, excavation and construction operations*. Moscow: MaxPress p 304.
[13] Belyaev A E, Krasnoshtanov S Yu, Shevchenko AN and Uvarov IA 2016 Engineering procedure of blasthole drilling in permafrost. *Mining Journal* vol. **3** pp 42–46. DOI 10.17580/gzh.2016.03.09
[14] Serikov D Yu 2017 Ways to improve the reliability of mounting carbide teeth in the roller cutter body. Sphere. *Oil and gas* **2** pp 10–18.