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IMPROVEMENT IN THE CONSTRUCTION OF THE "TUNGSTEN CARBIDE INSERT CUTTER – CONE" JOINT FOR TRICONE DRILL BITS

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Abstract. Meet a claim is quite difficult in real production, even in specialized drilling manufacturers. Therefore, the development of reliable criteria for approaches to improving the technology of tricone drill bits is an urgent problem. This is great practical importance for domestic enterprise.

The task is set to create rock-destroying insert in the basis of the developed construction. This allows you to increase the reliability of the connection between the cutter insert and the body of the cone. Favourable conditions should be provided for the rational distribution of contact stresses in conjugate surfaces "carbide cutter insert – bush – body of cone". Crucial part here is required rigidity of the carbide cutter insert. Advanced requirements are placed on them regardless of the design and dimension-type of tricone drill bits. They must have higher requirements such as: high reliability, durability of responsible elements of support and rock-destroying equipment, productivity, ability is stand destructive forces and torque are brought through a bit for influence on a face.

This increases the reliability of its connection with the body of the drill bit. Requirements apply to the design to provide favorable conditions for the rational distribution of contact stresses in conjugate surfaces "carbide cutter – bush – body of the bit cone".

The obtained results of stress state modeling indicate that, as expected, with the same forces acting on the insert cutter from 42 kN to 57 kN, the most intense place on the cone will be the "collar" near the cutter. The intensity of stress will be up to 1050 MPa in this place for cones with serial rock-destroying equipment. At the same time, the intensity of stress will be up to 900 MPa for cones with developed destructive equipment, this is 14 % less.

Keywords: insert cutter, rock-destroying equipment, drill bit cone, accuracy, tricone drill bits, rolling-cutter row, tension, rock-destroying insert, modeling.

Introduction and Problem Statement

Important and extremely difficult problem of the drilling tool for modern production is provision for oil, gas and mining industries with high-quality tricone drill bits for drilling particularly strong rocks. Such drill bits are made with rock-destroying equipment of cones based on carbide insert cutter and fitting pieces. Specificity design of rock-destroying equipment and extremely difficult application conditions of drill bits make a set of requirements. Meet a claim is quite difficult in real production, even in specialized drilling manufacturers. Therefore, the development of reliable criteria for approaches to improving the technology of tricone drill bits is an urgent problem. This is great practical importance for domestic enterprise [1–3].

Advanced requirements are placed on them regardless of the design and dimension-type of tricone drill bits. They must have higher requirements such as: high reliability, durability of responsible elements of support and rock-destroying equipment, productivity, ability is stand destructive forces and torque are brought through a bit for influence on a face. Also, construction materials, technologies for their processing, strengthening technologies must meet a set of requirements. They are used to make drill bits. Criteria for drilling are determined by the physical and mechanical properties of rocks. Specific brands of tricone drill bits are designed for drilling rocks. It is known that the efficiency of tricone drill bits puts before modern construction of drill bit the use of advanced science-intensive technologies. Quality policy must be ensured at all stages of their production. Technical requirements for the manufacture of bits, rules for determining their quality, control methods and their testing are standardized. The highest requirements are put forward to the working surfaces of the bit such as: elements of supports, rock-destroying and protective equipment of cones, attached thread for sealed supports – sealing and lubrication systems support. The level of accuracy for the obtained dimensions, shape and geometric relationship are determined by the quality of the cone bit according to the design and technological documentation.

The quality fixation of the tungsten carbide insert cutter in the body of the cone is one of the main factors that determine the effectiveness of the formation of the face, rock destruction and well formation. The main element here is the perfection of the design for cone and especially rock-destroying tungsten carbide insert cutter. The design of tungsten carbide insert cutter determines the possibility of connection and affects the reliability and rigidity of the connection with the body of the cone. So, improving the design of tungsten carbide insert cutter is great practical importance for cone construction.

Effective design of the tungsten carbide insert cutter must be developed. This increases the reliability of its connection with the body of the drill bit. Requirements apply to the design to provide favorable conditions for the rational distribution of contact stresses in conjugate surfaces "carbide cutter – bush – body of the bit cone". Also, the required rigidity of fixing the carbide insert cutter should be provided by a reasonable choice of rational design parameters. Conditions are also imposed on ensuring and improving the manufacturability of the production of insert destructive equipment of drill bit cones.

Review of Modern Information Sources on the Subject of the Paper

Known drilling tool [4] has a body made with holes in which are placed bushes and rock-destroying inserts with a working head and a stepped shank. The degree of smaller diameter is pressed into the bush with tension. It does not exceed the tension between the bush and the body. However, this design does not provide the necessary reliability and rigidity. This can lead to the brittle destruction of the carbide insert in one case, or in the second case it falls out when drilling the bottom face.

The known construction of the rock-destroying body [5] consists of housing, bush, a wear-resistant rock-destroying insert, that including a working part and a stepped shank. Blind stepped holes must be made of high-precision and metal inserts placed in them in this design. This causes difficulties both at the stage of forming holes and during assembly operations.

The known construction of the rock-destroying insert [6] contains a carbide element as form of a cutter insert. It has a working head and a shank, which is pressed into the slot of the tool body through the intermediate bush. It has a bottom with a hole and a notch on the side of the bottom. The connection is made by clearance fit and length is less than the thickness of the bottom. The hardness of the bush is less than the hardness of the shank, and its dimensions correspond to such ratios $0.69 \pi \frac{d_1}{d_2} \pi 1$; $0.4 \le \frac{d_1 N_1}{d_2 N_2} \le 0.5$, were d_1 – diameter of the inner surface of the bush, d_2 – diameter of the outer surface of the bush, N_1 – tension providing the inner surface of the bush with a diameter d_1, N_2 – tension providing the outer surface of the bush with a diameter d_2. However, this construction does not provide the necessary rigidity and reliability of the carbide element. Factor of elasticity is absent in the lower part of the shaft joint. The bush is exposed plastic deformation because tungsten carbide insert falls out.

The closest to the developed structure is a rock-destroying insert [7]. It includes a carbide element, which is made with a two-stage shank with equal steps in height. Diameters satisfy the ratio: $\frac{d_3}{d_4} = \frac{1.8}{1.5}$, where d_3 – the diameter of the greater degree of the shank, d_4 – the diameter of the smaller degree of the shank, pressed into the socket of the bush, the bottom which is made with a central aperture, and the dimensions of the bush satisfy the ratio: $0.69\,\pi\,\frac{d_1}{d_2}\,\pi\,1$; $0.4 \le \frac{d_1 N_1}{d_2 N_2} \le 0.5$, where d_1 – diameter of the inner surface of the bush, d_2 – diameter of the outer surface of the bush, N_1 – tension provided by the inner surface of the bush with a diameter d_1, N_2 – tension provided by the outer surface of the bush with a diameter d_2. The shank is made of two-stage with equal in height steps, the diameters of which satisfy the ratio: $\frac{d_3}{d_4} = \frac{1.8}{1.5}$, where d_3 – the diameter of the greater degree of the shank, d_4 – the diameter of the smaller degree of the shank (Fig. 1). However, this construction does not provide the necessary rigidity of the connection between destructive insert and body of the destructive tool, and it does not ensure the reliability of the carbide element. The stress distribution is unfavorable in the area of contact of the joint surfaces of the tungsten carbide insert cutter with the intermediate bush. Similarly, the stress distribution is unfavorable in the area of contact between the destructive insert and the bottom of the aperture under it in the body of the tool. Also this construction does not provide an increase in manufacturability, because you need to use a special cutting tool. It is necessary to make for selection of a bottom of an aperture in a body of the rock-destroying tool for qualitative and reliable pressing of a rock-destroying insert.

Main Material Presentation

The task is set to create rock-destroying insert in the basis of the developed construction. This allows you to increase the reliability of the connection between the cutter insert and the body of the cone. Favourable conditions should be provided for the rational distribution of contact stresses in conjugate surfaces “carbide cutter insert – bush – body of cone”. Crucial part here is required rigidity of the carbide cutter insert. This is done due to the reasonable choice of rational construction parameters of the rock-destroying insert’s shank. The rock-destroying insert must provide increased manufacturability in both manufactured and join operation. Such conditions are used in the manufacture of cone bits for efficient development of production.

The task was solved by improving the well-chosen prototype. It is the construction of the rock-destroying bush for the drill bit. It includes a carbide cutter insert, which is made with a two-stage shank with equal degrees of height [8]. Reasonable changes have been made to the construction of the shank. Therefore, the developed construction of the rock-inserting bush differs in that the bush is made in the form of a cone with an angle at the apex of 120°. The conjugate generatrix surfaces of the small shank’s degree and the corresponding surface of the generators for inner aperture of the bush is made with a taper. Their values has range 1:30 to 1:50. They are mutually oriented in different directions. Conjugations are made in the form of hollow chamfer between large and small diameters of the shank's carbide element. The radius is within 2–3 mm and the angle β = 160–165° is at the base’s top of the large diameter shank. Inner surface of the bush is coupled with the small diameter of the shank for carbide element.

The developed construction of the rock-leveling insert [7] provides rational parameters for the distribution of contact stresses in the areas of conjugation “carbide cutter insert – bush – body of the cone bit”. The necessary rigidity of the system “cone bit – rock-destroying cutter insert – bottom rock” creates opportunities to increase the strength of the connection “rock-destroying cutter insert – body of cone bit”. The secure fit of the conjugate contact surfaces prevents the carbide cutter insert from falling out of the bush. The resistance of the carbide cutter inserts increase in a dangerous section when we have a brittle fracture. The tightness of the conjugate surfaces “cutter insert shank–bush” is improved during technological operations of assembling the rock-destroying bush.

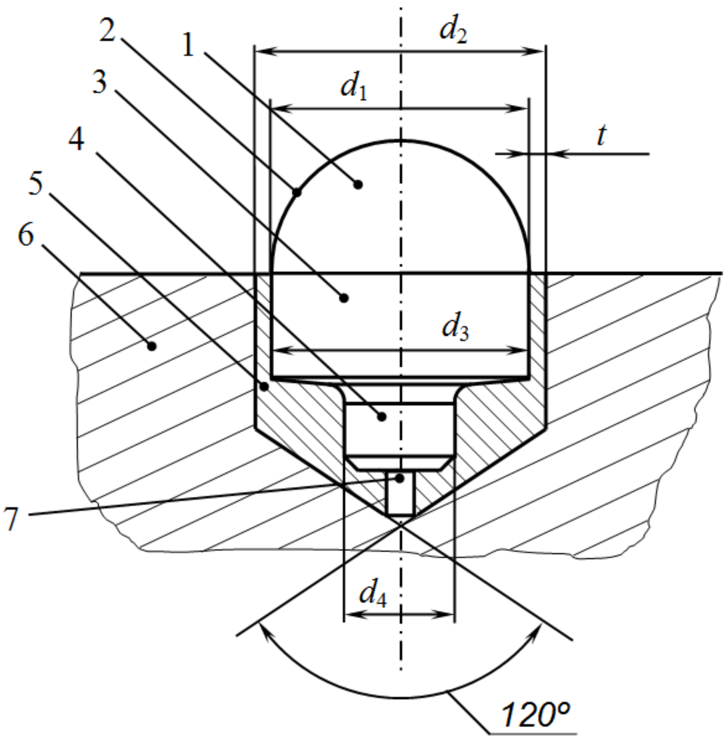


Fig. 1. Rock-destroying insert that consist: bush with carbide cutter insert, they are pressed into the body of the cone drill bit

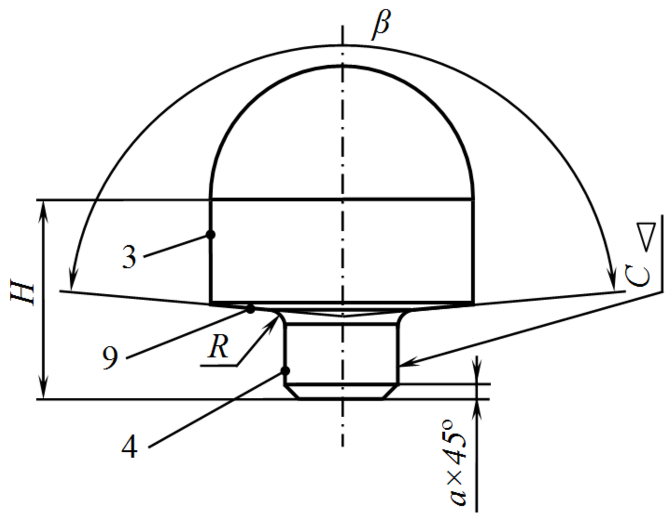


Fig. 2. Rock-destroying tungsten carbide cutters insert

The rock-destroying insert consists of a tungsten carbide cutters insert 1, having a working head 2 and a cylindrical two-stage shank including a stage with a larger diameter d_3 3 and degree with a smaller diameter d_4 4, in the folded state, the drill bit insert is pressed into the socket of the roller body 6. The bush 5 has an outer surface with a diameter d_3 (Fig. 1) and internal d_5 (Fig. 3). The outer fitting surface of the bush's base 5 is made as a cone with an angle at the apex of 120°. It provides rational contact when fitting a destructive cutters insert in the slot of the cone's body 6. The central hole 7 is made in the conical part of the bush 5 (Fig. 1).

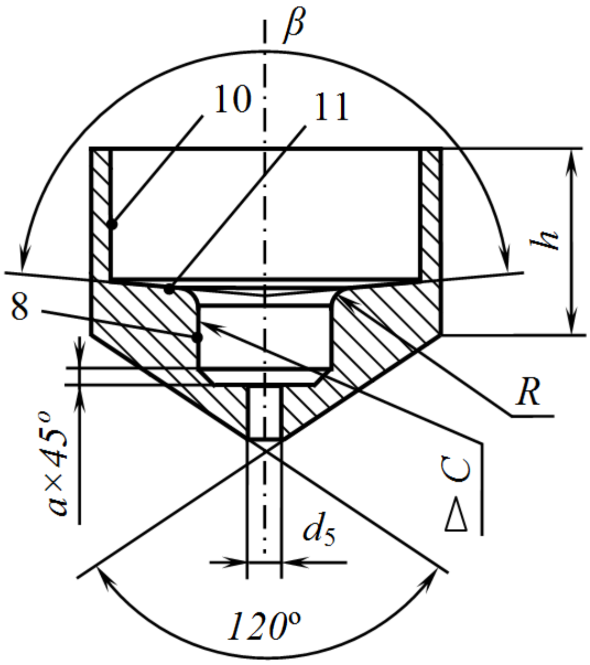


Fig. 3. Bush for fit of the tungsten carbide cutters insert's shank

Rock-destroying insert is shown. It includes a tungsten carbide cutters insert with a bush, which is pressed into the body of the cone drill bit in cross section in Fig. 1, where:

1 – tungsten carbide cutters insert;

2 – working head of the tungsten carbide cutters insert;

3 – cylindrical shank of a tungsten carbide cutters insert with a larger diameter d_3;

4 – cylindrical shank of a tungsten carbide cutters insert with a smaller diameter d_4;

5 – bush;

6 – body of roller cone bit;

7 – the central hole in the conical part of the bushing;

8 – inner hole of the bush with diameter d_4;

9 – base of the shank of the tungsten carbide cutters insert with a diameter d_3;

10 – inner hole of the bush with a diameter d_3;

11 – base of bush:

R – hollow chamfer in limits 2–3 mm;

β – angle at the top of the base of the shank diameter d_3 tungsten carbide cutters insert. Selected in limits 160–165°.

H – height of the combined flank of the cutters insert;

t – wall thickness of the bush at the height of the diameter d_3;

a – chamfer on the leg of the tungsten carbide cutters insert;

h – the height of the cylindrical outer surface of the bush.

The size of the smaller stage d_4 is chosen in accordance with the diameter of the larger stage of the shank d_3 to provide the required structural strength (Fig. 1). For example, for cutters insert with a shank of larger diameter d_3 = 14 mm possible ratio diameters of the steps of the shank $\frac{d_3}{d_4} = \frac{1.8}{1.5}$. The conjugate surfaces of the low-grade shank generators 4 of the tungsten carbide cutters insert 1 and the corresponding generating surface of the inner hole 8 of the bush 5 is made with a taper, the value of which is in the range from 1:30 to 1:50, mutually oriented in different directions, and the conjugation between the large diameters 3 and small diameters of the shank 4 of the tungsten carbide cutters insert 1 (Fig. 1), and made in the form of a filler, including the radius within, R = 2–3 mm and the angle β at the top of the base 9 of the shank of large diameter 3 (Fig. 2) tungsten carbide cutters insert 1 is selected in the range of 160–165°. The conjugation 11 between the large 10 and small 8 holes of the bush 5 has the same geometric parameters: the conjugation radius is selected within R = 2–3 mm, and the angle β at the top of the base 11 of the large diameter hole 10 of the bush 5 is selected in the range of 160–165° (Fig. 3). The dimensions of the bush 5 correspond to the following relations: $0.69 \pi \frac{d_1}{d_2} \pi 1$; $0.4 \le \frac{d_1 N_1}{d_2 N_2} \le 0.5$, where d_1 – the diameter of the inner surface of the bush, d_2 – the diameter of the outer surface of the bush, N_1 – tension provided by the inner surface of the bush with a diameter d_1, N_2 – tension provided by the outer surface of the bush with a diameter d_2.

The hardness of the bush material 5 must be less than the hardness of the stepped shank 3, 4 of the tungsten carbide cutters insert.

The wall thickness of the bush 5 – t and its outer diameter are values of different order, which defines the bush thin-walled.

The technology of rock-destroying equipment of drill bits includes the following stages: forming holes, assigning rational tensions by selecting selective groups of bush, assembly of the connection “destructive cutters insert – bush”, pressing of the collected destructive inserts into certain (selective) holes in the body of the roller. So, the connection of the tungsten carbide cutters insert 1 with the bush 5 is carried out by fitting with tension on the inner surface of the bush 5. For this, the inner surface of the bush 5 in diameter d_1, which is made on the fit, which provides the maximum tension allowed without the risk of crumpling the inner surface of the bush 5 carbide shank 3 and 4. When assembling the insert, the central hole 7 serves to release air expelled by the tungsten carbide cutters insert 1 from the inner cavity of the bush 5. Pressing should ensure no gap between the larger shank 3 and the hole 10 of the bush 5, and is made by a press in order to ensure the efficiency of the connection, thermal pressing is used, which is based on heating the bush 5 and cooling the tungsten carbide cutters insert 1. This avoids plastic deformation of the conjugate conical surfaces 8 of the bush 5 and damage to the conical surface 9 of the tungsten carbide cutters insert 1. Under such conditions a reliable lock in the conjugate elements of a smaller degree of the shank 4 of the tungsten carbide cutters insert 1 and the small diameter of the hole 8 of the bush 5, which provides the best performance of the destructive insert.

Outer surface of the bush 5 can be fall under processing to create a tension fit. This tension is usually greater than the inner surface after assembly.

Pressing the rock-destroying insert into the socket of the body of tool 6 can be carried out both when the heated body of the cone of the drill bit, and when it cold. The effort of the press is carried out by pressing the rock-destroying insert. The force is applied to the working head 2 of the cutters insert 1, which is transmitted to the shank 3, 4 and the sleeve 5. In this case, the outer layer of the surface of the bushing 5 in diameter d_2 comes into contact with the surface of the socket of the body roller 6 and it is fall under elastic deformation. This promotes a fuller contact of the surfaces, increases the contact area and reduces the possibility of crumpling of the conjugate surfaces. There is a force which additionally compresses a shaft 4 when pressing.

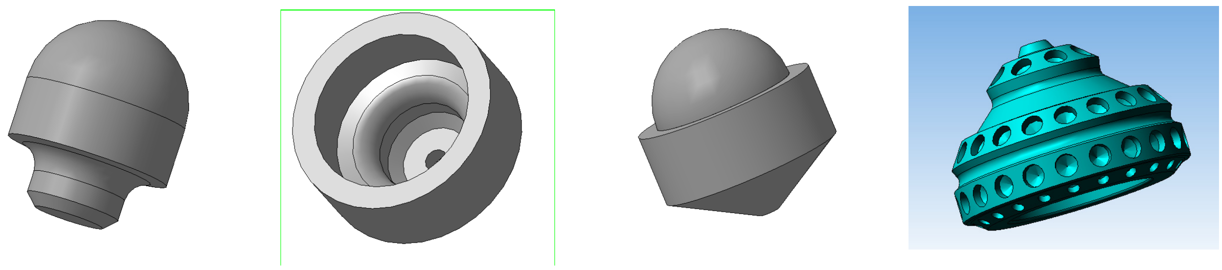
Rational correspondence of the bush’s and the tensions in the inner and outer surface makes it possible to transfer to the shank 3 of the carbide cutters insert 1 the rational value of the compression force.

The destructive insert with the bush is pressed against the bottom of the socket, while the conical surface and the hole at the top of the base of the bush prevent the occurrence of unfavorable stress distribution in the bottom of the hole in the body of the roller 6. The cavity of the central hole 7 also provides sufficient volume for compressed air during the pressing process, which helps to press the insert all the way into the bottom of the socket of the tool 6.

Hole 7 is also useful for dismantling the tungsten carbide cutters insert 1 from the cone of the spent drill bit for processing a valuable hard alloy. To do this, part of the tool body can be cut along the cross section passing in the area of the hole 7 of the bushing 5, after which, through the hole 7, the tungsten carbide cutters insert 1 can be extruded.

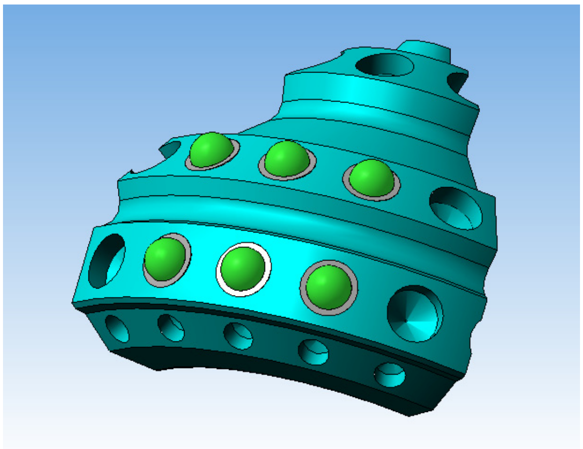
The developed new design of the rock-destroying insert is based on the results of research and development of experimental studies, including the following results of modeling in the software product environment COMPAS-3D APM FEM. First, we created 3D models of the developed design of the rock-destroying insert (rock-destroying cutters insert, bush) for fitting in the holes of the tricone drill bit (Fig. 4).

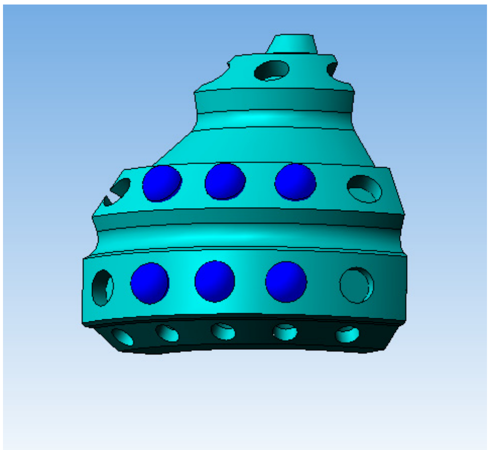
To compare the nature of stress distributions in the cross sections of roller with developed rock-destroying equipment and basic (serial technology) 3D models were created for a similar design of roller equipped with standard rock-destroying equipment – rock-destroying cutters insert with cylindrical shanks installed in the rolling-cutter row of the cone.



a *b* *c* *d*

Fig. 4. 3D model of the elements for the developed structure and insert cutters are built to study the stress state of rock-destroying equipment of cones for simulation of operating conditions; *a* – tungsten carbide insert cutter; *b* – bush of the tungsten carbide insert cutter; *c* – rock-destroying bush ∅18 mm; *d* – model of the cones for tricone drill bit





a *b*

Fig. 5. 3D model of fragments for tricone roller bits. The diameter is 302 mm; *a* – fragment of cone with rock-destroying equipment of the developed design; *b* – fragment of a cone with serial rock-destroying equipment

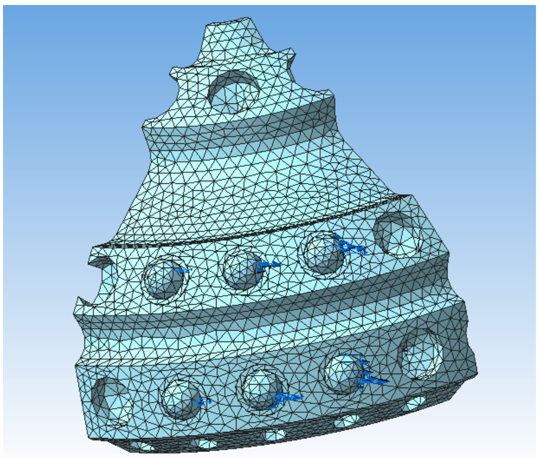
The analysis was performed for a tricone drill bit with a diameter of 302 mm. Strength analysis for cones was performed on a dangerous section, which are equipped with comparable versions of rock-destroying equipment. The combined force is applied to the main carbide insert cutter of the model for the case when it reaches 70 kN [9].

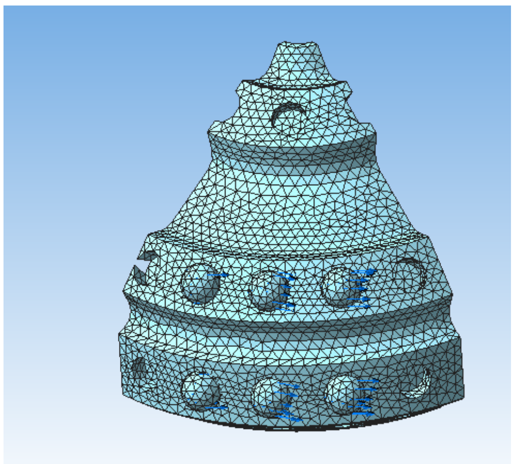
The fragment was modeled with 3 working insert cutters (Fig. 5), which they work in the following conditions:

- on the main insert cutter, which is located inside – the force is applied at 57.5 kN.
- on adjacent insert cutters – amount of force applied is 42.5 kN.
- pressure affects all the shanks of the insert cutters and the holes of the cone and it is equal to 1000MPa [6], it occurs when pressing the carbide insert cutter.

Thus, each cone will be subjected to up to 130 kN in the contact zone. This affects the stress state for the rolling-cutter row of the cone [9]. The generated grid of finite elements (Fig. 6) received the nature of the stress state in the rolling-cutter row of the cone (Fig. 7).

Therefore, there are two main crowns in the studied design of the cone. After analyzing the nature of the damage to the rolling-cutter row, it was found that they are subject to the greatest loads. This is consistent with the data in the study [10].





a *b*

Fig. 6. Generated finite element grid on fragments of cone. The diameter is 302 mm; *a* – developed rock-destroying equipment; *b* – serial rock-destroying equipment

Static analysis of the stress state for rock-destroying element will be performed for the obtained designs of insert cutters (Fig. 6–10)

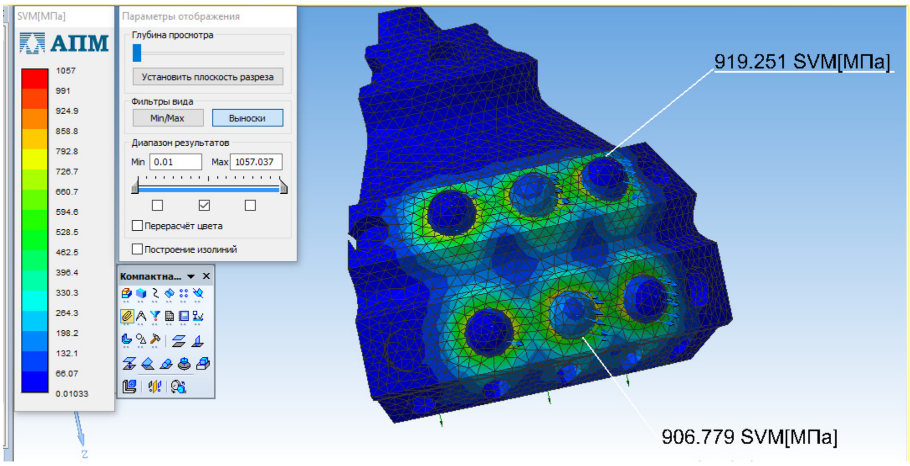


Fig. 7. Modeling of the stress state on the main rolling-cutter row of the cone with rock-destroying equipment of serial construction in the areas of conjugation "shank of insert cutter – cone hole"

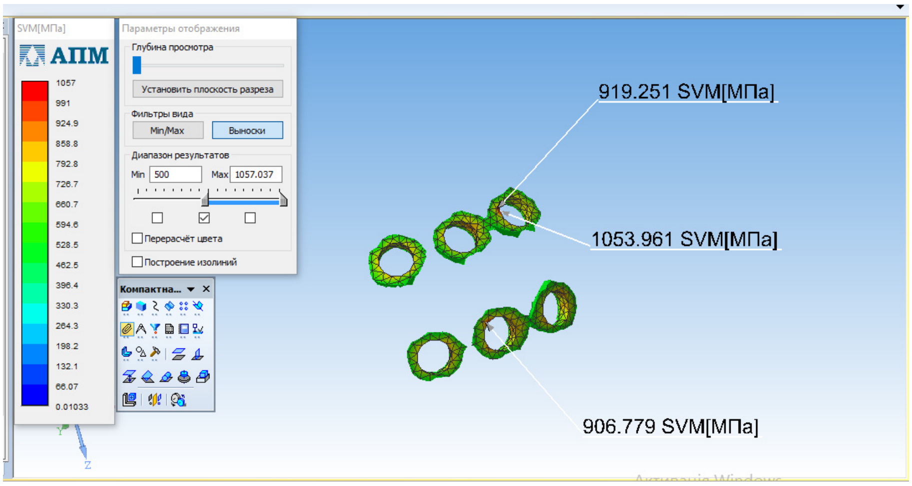


Fig. 8. Representation of the stress state in the fragment of a cone with rock-destroying equipment of serial construction where the stress is range of 500MPa to 1060MPa

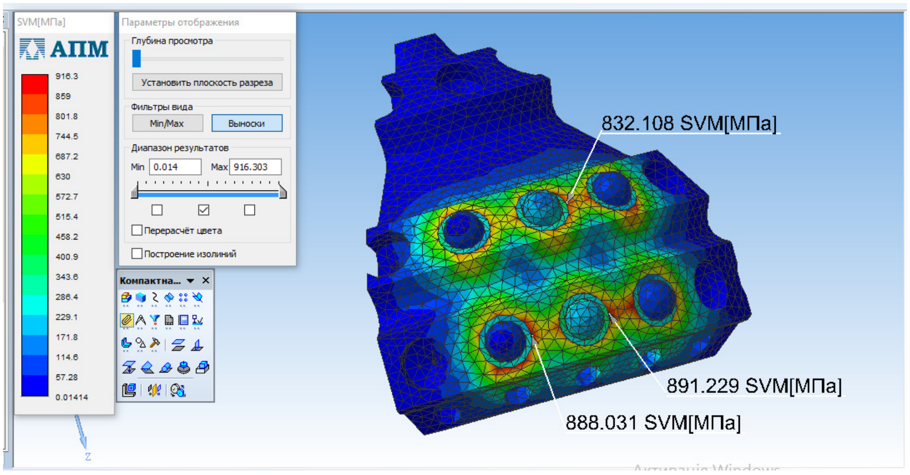


Fig. 9. Modeling of the stress state on the main rolling-cutter row of the cone with rock-destroying equipment of the developed structure, in the areas of conjugation "shank of insert cutter – cone hole"

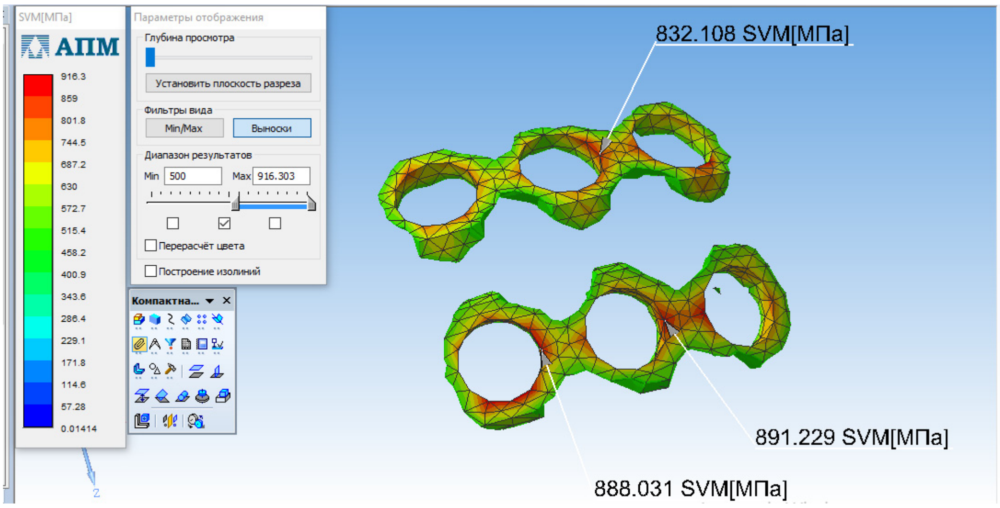


Fig. 10. The image of the stress state in the fragment of the cone with rock-destroying equipment of the developed structure, where the stress is range of 635MPa to 920MPa

The obtained results of stress state modeling (Figs. 6–10) indicate that, as expected, with the same forces acting on the insert cutter from 42 kN to 57 kN, the most intense place on the cone will be the "collar" near the cutter. The intensity of stress will be up to 1050 MPa in this place for cones with serial rock-destroying equipment. At the same time, the intensity of stress will be up to 900 MPa for cones with developed destructive equipment, this is 14 % less.

Thus, the developed design of the rock-destroying insert cutter opens new opportunities not only to increase the strength of the connection with the cone body, but also this provide conditions to resist cracking of carbide insert cutter with a sharp increase in stresses in the press joint during overload during destruction of high-strength rocks.

Conclusions

Parameters of the effective design for tungsten carbide insert cutters are substantiated theoretically and experimentally. It allows to increase possible the reliability of its connection with the body of the cone. The qualitative and quantitative support of favorable conditions for the rational distribution of contact stresses in conjugate surfaces "carbide insert cutter – bush – body of the cone" is established by analyzing the stress state modeling of the developed new design. It is determined that the design parameters of the insert cutter, because there is a balance in the conjugations. The intermediate bush is used and this allows to qualitatively changing the rigidity of the carbide insert cutter. This prevents the destruction of the carbide insert cutter during overload during the destruction of rocks of high strength. There are also opportunities for the use of hard alloys with higher strength. This prevents the formation of cracks in the body of the cone during the pressing of the inserts in the process of destruction of the rock. The newly developed design of the insert cutter allows not only organizing selective assembly, but the allowed reject is eliminated successfully at formation of holes. It is necessary to find the required diameter for the holes that fall sharply out of the row for fit, provided the use of solid carbide insert cutter.

The developed design allows creating the required number of insert bush not only in selective groups, but also in some "emergency" cases due to the intermediate bush mobile with the same design parameters of the tungsten carbide insert cutter.

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