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To cite this article: Ming Lei *et al* 2023 *J. Phys.: Conf. Ser.* **2483** 012035

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Mechanical optimization design and experimental analysis of mine tricone bit nozzle

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Abstract. This paper explores the optimal design of cone bit nozzle diameter and a comparative analysis of cone tooth stress. When drilling the tricone bit, direct contact between the roller casing and the wellbore is prone to wear. The fluid emitted from the cone bit nozzle helps reduce friction and reduce temperature. In this paper, a three-dimensional model is established using the software, and then the surface shear stress of the cone bit under the action of the flow field is simulated. The larger the shear stress is, the more serious the wear is. The simulation results show that when the nozzle diameter is $\phi 17\text{mm}$, the maximum shear stress on the surface of the roller is 6640Pa. When the nozzle diameter is $\phi 22\text{mm}$, the maximum shear stress on the surface of the roller is 3040Pa, which is 50% lower than that of the nozzle diameter $\phi 17\text{mm}$. Through the analysis, improving the wear of the cone housing of the drill bit, the diameter of the nozzle of the 9SRA545R tricone bit is changed from $\phi 17\text{mm}$ to $\phi 22\text{mm}$, which can effectively reduce the erosion degree of the rock debris on the surface of the cone, to improve the wear degree of the cone housing.

1. Introduction

The drilling industry was born with the exploration and exploitation of oil deep in the earth. A tricone bit is an important tool in oil drilling and a rock-breaking tool in constructing the main road of trans-regional large-capacity transmission of the high-voltage power grid, which is widely used. The service life and performance of the bit directly affect the cost and efficiency of the overall drilling project. With the upgrading of petroleum exploration technology and the increasing difficulty of drilling, it is urgent to improve the performance of cone bit [1-4].

In the process of drilling, the cone housing of the tricone bit is directly in contact with the crust, which can easily cause the cutting structure's failure. In the highly abrasive strata, it is easy to lead to serious wear of the cone housing, such as bearing wear, alloy tooth wear, broken tooth, tooth loss, etc. Taking Christmas Creek Mine in Western Australia as an example, the average drill length in conventional formation is about 4000 meters, and bearing failure is the main problem, with few broken teeth. In the face of soft abrasive formation, the average length is about 2000-2500 meters, a large



number of cone shell serious wear, one or two rows of teeth, and back cone teeth broken phenomenon. The three-cone bit is welded with three single-cone components. During drilling, the casing of the cone is prone to wear in direct contact with the good path. The fluid from the cone bit nozzle helps to reduce friction and temperature. The overall drilling rig is shown in Figure 1, and the actual cone bit is shown in Figure 2; the nozzle position of the single cone is shown in Figure 3.



Fig.1 Drilling machine

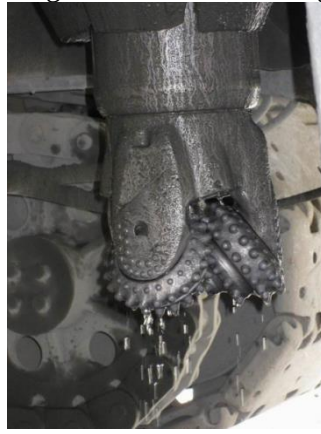


Fig.2 Tricone bit

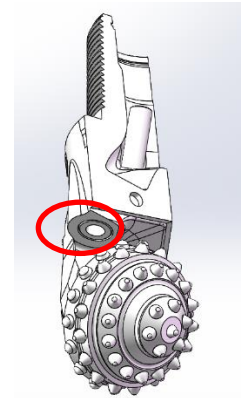


Fig.3 The location of the circular nozzle

Therefore, in this paper, a 9SRA545R tricone bit model was first established by using 3D modeling software. Secondly, the finite element method was used to simulate the flow field and the shear stress on the tooth surface of the tricone bit in the nozzle diameter of $\Phi 17\text{mm}$ and $\Phi 22\text{mm}$. The greater the shear stress, the greater the wear. Finally, the use effect of the new 9SRA545R tricone bit is analyzed through the calculation results. The research results can provide technical guidance for the optimization and research of drilling tools in the later period.

2. Model Building

This paper uses SolidWorks to build a 3D model. The nozzle diameter of the original bit was 17mm. Still, the nozzle diameter was optimized to 22mm according to customer requirements in this paper, and the stress of the two groups of diameter bits was compared. The drill bit diameter is $\phi 232\text{mm}$, and the inner diameter of the wellbore model is designed to be $\Phi 235\text{mm}$. The drill pipe diameter was 177.8mm, and the drill bit penetration depth was set at 3mm.

Rock debris is suspended in the shaft wall near the cone, rapidly wearing the shell near the tooth, resulting in excessive exposure of the tooth column, broken teeth, and tooth loss, failing the bit [5-7]. Given this phenomenon, this paper starts by improving the slag discharge system, enlarging the nozzle diameter, and increasing the air volume to ensure the rock debris flow speed so that the rock debris can be carried out from the bottom of the hole faster. The optimized design of the original nozzle, the diameter of the original nozzle is $\phi 17\text{mm}$. The optimized design is $\phi 22\text{mm}$. The effect before and after optimization is compared, the central vent hole is increased, the rock debris near the cone is taken away faster, the shear stress on the cone surface is reduced, and the rock debris wear on the shell is reduced.

This paper established a three-dimensional model of the drill bit and wellbore. The finite element calculation [8-13] was used to compare the influence of two nozzle diameters on the flow field of cuttings at the bottom of the hole and the wear of the cone shell. In this way, the proper nozzle diameter can be selected to improve the wear phenomenon of the cone housing to improve the service life of the bit[14-17].

3. FEA simulation

3.1 Material Properties

The injection medium of the mining drill is air, and the material properties are shown in Table 1 below:

Table 1 Material properties

Material	density /kg·M-3	viscosity (kg/(m·s))
air	1.225	1.789e-5

3.2 Grid Model

Establish a 3D model, as shown in Figure 4. and import the finite element analysis software, as shown in Figure 5. The bit model is divided into grids, and the grid model is established. The number of drill nodes is 81,436, and the number of elements is 350,644. The overall number of nodes in the good passage and bit is 231,743, and the number of units is 1,096138:

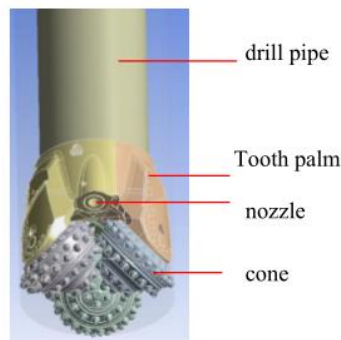


Fig.4 Structure of tricone bit

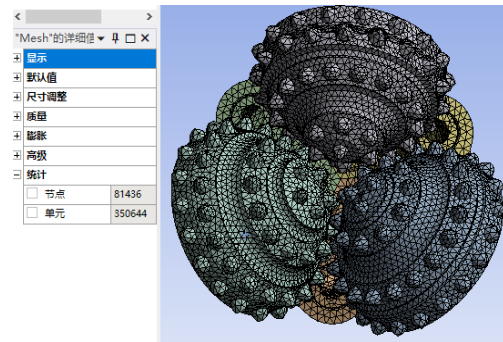


Fig.5 Model of mesh

3.3 Load and boundary conditions

According to the working condition, set the rated air volume of the air compressor of the drilling rig to 53.8m³/min. Therefore, the inlet flow rate is set at 53.8m³/min. Gas compression is temporarily ignored. The boundary conditions are set as shown in Figure 6:

4. Simulation and comparative analysis

4.1 Shear stress on the surface of the roller

The purpose of analyzing the shear stress on the cone's surface is to analyze the fluid's cleaning effect on the cone's surface. In this paper, when the nozzle diameters are $\phi 17\text{mm}$ and $\Phi 22\text{mm}$, respectively, the nozzle flow field is shown in Figure 7. The distribution of shear stress on the surface of the roller is shown in Figure 8.

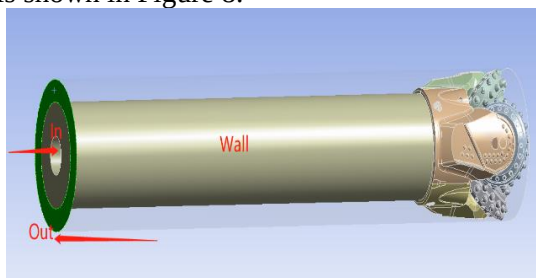


Fig.6 Terminal condition

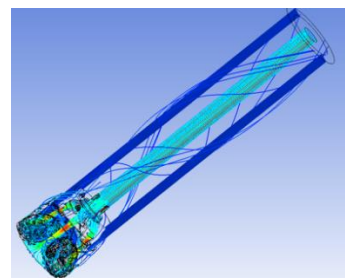


Fig.7 Nozzle flow field model

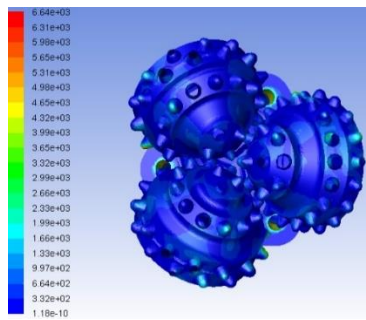
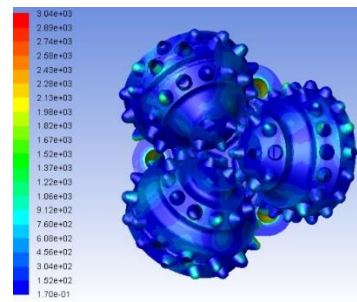
(a) Surface shear stress (Pa) of $\Phi 17\text{mm}$ (b) Surface shear stress (Pa) of $\Phi 22\text{mm}$

Fig.8 Surface Shear stress of roller (Pa)

As can be seen from the figure, the maximum wall shear stress of the nozzle diameter $\Phi 17\text{mm}$ model is 6640Pa, and the maximum wall shear stress of the nozzle diameter $\Phi 22\text{mm}$ model is 3040Pa. The shear stress of $\Phi 22\text{mm}$ is 50% lower than that of the nozzle diameter of $\Phi 17\text{mm}$. That is, the wall wear is smaller. The maximum stress position appears on the tooth, which is the first to be broken in the drilling process. The broken tooth diagram in the drilling process is shown in Figure 9, and the simulation is consistent with the actual working condition.



Fig.9 Photos of a broken tooth in actual working condition

4.2 Bottom hole turbulence strength -- analysis of cuttings' ability to escape the bottom hole under fluid action

When the nozzle diameter is $\phi 17\text{mm}$ and $\Phi 22\text{mm}$, respectively, the cuttings' ability to leave the bottom hole under fluid action is analyzed, namely, the bottom hole turbulence intensity calculation.

The maximum bottom hole turbulence intensity of the model with a nozzle diameter of 17mm is 60%, and that of the model with a nozzle diameter of 22mm is 42%. The distribution of bottom-hole turbulence intensity is shown in Figure 10 below. As can be seen from the diagram, the ability of cuttings to escape from the bottom hole is relatively weak at the junction between the center of the hole (the center of the bit) and the cone.

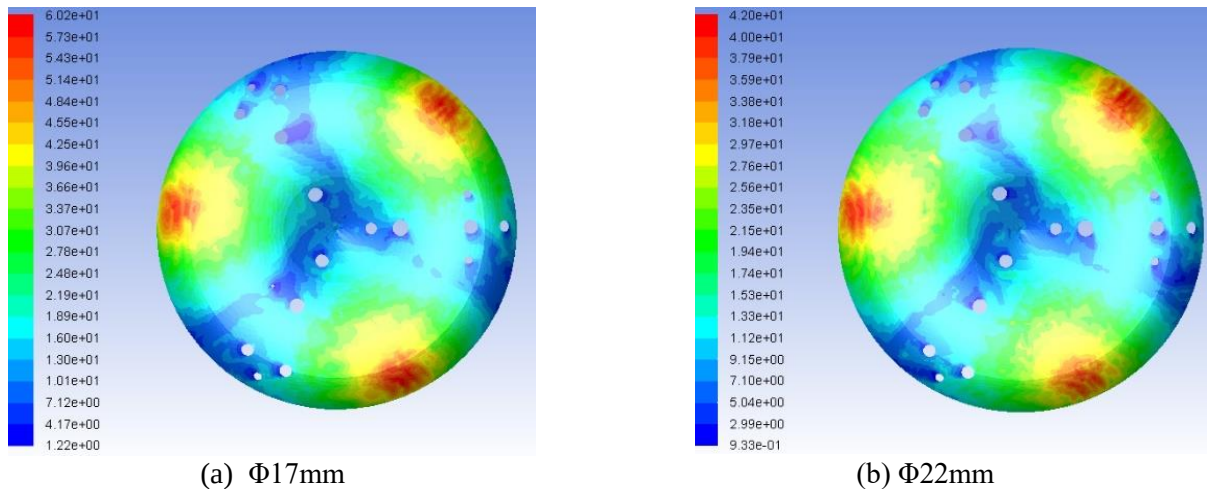


Fig.10 Turbulence intensity at the bottom hole

4.3 Bottom hole flow velocity -- Analyze the migration capacity of fluid to bottom hole cuttings

When the nozzle diameter is $\phi 17\text{mm}$ and $\Phi 22\text{mm}$, respectively, the migration ability of fluid to the bottom hole debris is analyzed, that is, the calculation of the bottom hole flow velocity.

A model with a nozzle diameter of $\Phi 17\text{mm}$ has a maximum flow velocity of 84m/s , while a model with a nozzle diameter of $\Phi 22\text{mm}$ has a maximum flow velocity of 57m/s . The distribution of bottom-hole flood velocity is shown in Figure 11.

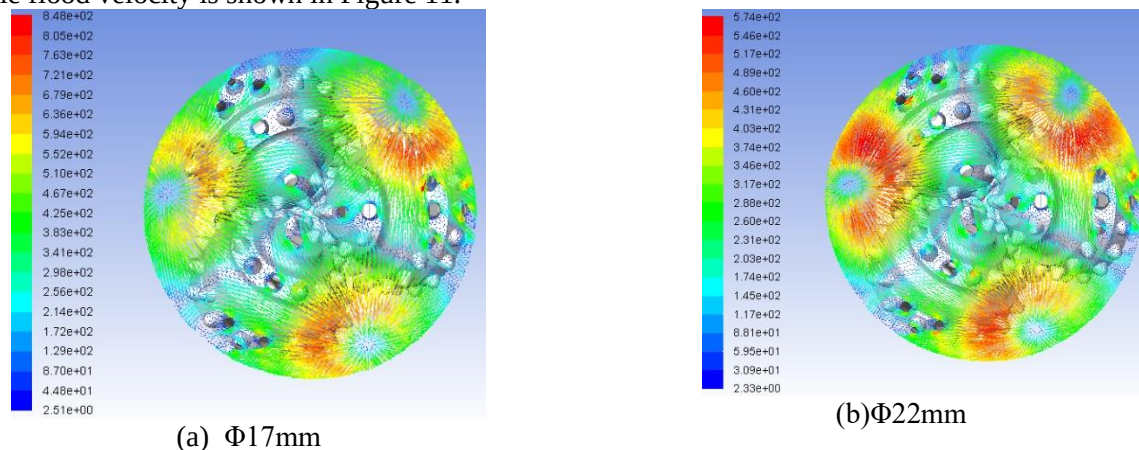


Fig.11 Diffuse velocity

V_1 is the initial up-flow velocity of the cuttings, V_2 is the velocity of the cuttings when they reach the orifice, and h is the height of the up-flow velocity. The relation is as follows:

$$V_1^2 - V_2^2 = 2gh.$$

If the good depth is $h=20\text{m}$, when $V_2=0$, that is, when the debris reaches the orifice, the velocity is 0 , $g=9.8\text{m/s}^2$, and the minimum initial top-up velocity $a=19.8\text{m/s}$. The minimum up-flow velocity required is about 20m/s , and the maximum overflow velocity can meet the up-flow requirement when the nozzle diameter is $\phi 17\text{mm}$ and $\Phi 22\text{mm}$.

4.4 Up flow diagram of fluid -- analysis of fluid lifting ability to cuttings in annulus

When the nozzle diameter is $\phi 17\text{mm}$ and $\Phi 22\text{mm}$, respectively, the lifting ability of the fluid to the cuttings in the annulus is analyzed, that is, the fluid up-flow velocity calculation. Under the two nozzle diameters, the bottom hole flow lines are well distributed, and the flow lines flow smoothly up and back after passing through the chip discharge slots. However, there is an obvious vortex between the drill bit and the drill pipe. The bottom hole flow diagram is shown in Figure 12.

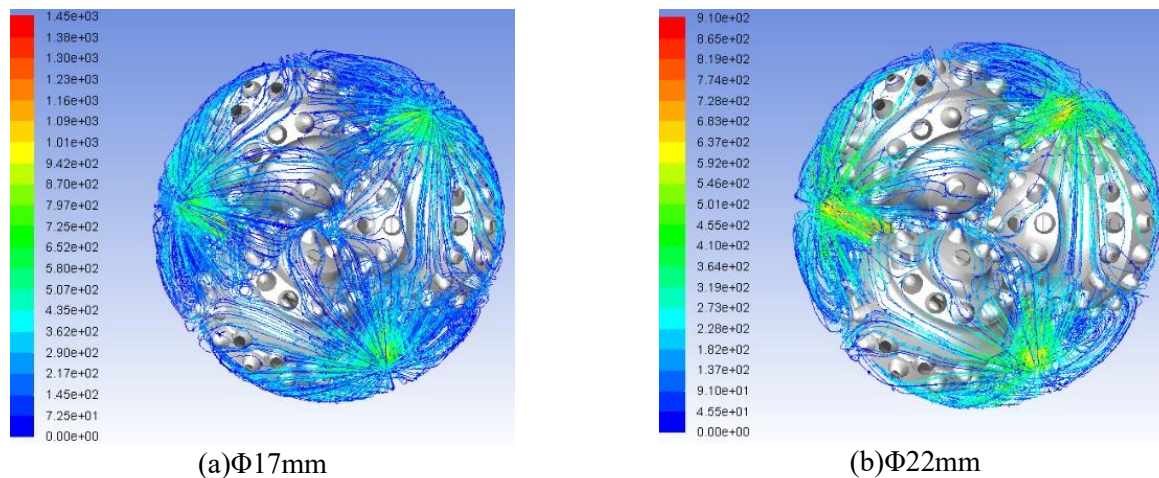


Fig.12 Bottomhole flow line

5. Analysis and conclusion

(1) In the drilling process of the tricone bit, the maximum stress position is on the teeth. That is, the most easily worn and broken parts are the teeth of the cone.

(2). When the nozzle diameter is $\Phi 17\text{mm}$, the maximum surface shear stress of the cone is 6640Pa; When the nozzle diameter is optimized to be $\Phi 22\text{mm}$, the maximum shear stress on the surface of the cone is 3040Pa. The pressure of the teeth after optimization is reduced by 50% compared with that before optimization, and the erosion degree of the cone surface can be reduced to improve the cone shell's wear degree.

(3) According to the distribution diagram of bottom hole turbulence intensity, the cuttings' ability to leave the bottom hole is relatively weak in the center area of the drill bit and the junction of the cone. When the nozzle diameter is $\Phi 22\text{mm}$, the bottom hole turbulence intensity and flow velocity are lower than $\Phi 17\text{mm}$. However, with $\Phi 22\text{mm}$, the flow line at the bottom of the hole is well distributed, and the flow line flows smoothly up and back through the chip discharge chutes. And with $\Phi 22\text{mm}$, the maximum flow rate at the bottom of the hole is 57m/s, which is enough to ensure that the cuttings are taken out of the hole. Through the above analysis, the diameter of the nozzle is changed from $\phi 17\text{mm}$ to $\phi 22\text{mm}$, the protection of the pair teeth of the cone is increased, and the wear-resistant layer is sprayed on the surface of the cone.

(4) The simulation model and the sample results are verified correctly. After the three-dimensional modeling is adopted in this paper, finite element simulation is carried out before the formal production of the product, which can greatly reduce the product development cycle. This paper provides technical support for the next step of product development. It can be used as a reference for the structure optimization design and application of similar products.

Acknowledgments

The authors thank the financial support from Suzhou City University to M. Lei via the 2022 Jiangsu Province University Laboratory Research Association Sponsored Research Project (GS220222BZZ36), 2021 Jiangsu Province University Basic Science (Natural Science) Research Project(21KJD460006); Industry-university Cooperative Education Project of Higher Education Department of Ministry of Education(202101321014); 2021 Jiangsu Province University Basic Science (Natural Science) Research Project (21KJD140007); Jiangsu Province University "College Student Labor Education" Project (106); 2022 Jiangsu Province University Basic Science (Natural Science) Research Project(22KJB460033).

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