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Mechanical Friction Simulation and Optimization Design of Floating Bearing of Mechanical Tricone Bit

Ming Lei¹, Fang Peng^{1*}, Shiqiang Zhang¹, Junyuan Zheng¹, Weihua Wang¹, Wu Ying¹, Xiangrui Kong²

¹ Suzhou City University, Suzhou, Jiangsu 215104, China

² Suzhou Institute of Construction & Communications, Jiangsu 215104, China

* Corresponding author's e-mail: Fang Peng, fangpeng@szcu.edu.cn

Abstract. This paper aims to find out the most vulnerable position and the suitable clearance ratio of the floating sleeve between the inside and outside floating sleeve of the tricone bit. In this paper, the mechanical analysis model of the drill bit is established to get the simulated working condition of the tri-cone bit, and then the stress condition of the floating bearing is simulated. Finally, the multi-factor variable orthogonal test method is used to optimize the clearance ratio of the floating sleeve. The results show that the simulation results are consistent with the wear position of the floating sleeve: during the operation of the floating sleeve, the most vulnerable position is the edge position, the largest deformation is the opening position, the recommended internal clearance of the floating sleeve is 0.06–0.07 mm, the recommended external clearance is 0.02–0.04 mm, and the recommended internal clearance ratio is 2.0–2.4.

1. Introduction

Cone bit is one of the most important rock-breaking tools in oil drilling and also an important tool in open pit mining. Its service life has a direct impact on drilling costs. The floating sleeve inside the floating bearing is the most easily worn part inside the bearing. The life of the floating bearing determines the service life of the roller bit. It is of urgent problems to prolong the service life of the existing tri-cone bit bearings and improve their performance under the condition of perforation operation in the drilling field ^[1-2].

The floating bearing has two sets of new sliding bearing pairs, which can reduce the friction inside the bearing very well. It has been applied in advanced drill bits abroad and the effect is very good. The floating sleeve is the core component of the tri-cone bit ^[3-4]. It can be seen that the research on a floating bearing of a tri-cone bit is of great significance to prolong the service life and technical reserve of the bit.

The failure of roller-bit sliding bearings is mainly due to wear and bonding caused by excessive local pressure in the running process of sliding bearings ^[5-7]. The journal of the sliding bearing of the tri-cone bit mainly bears the radial load, and the internal floating sleeve is between the tooth pad and the cone. The floating sleeve in the position of the large journal is in relative motion during drilling, and the speed changes at any time and its transient force are complicated. In this paper, when the drill pipe is under maximum pressure, the wear simulation and inner and outer clearance ratio optimization design of the floating sleeve were analyzed by the static analysis method.



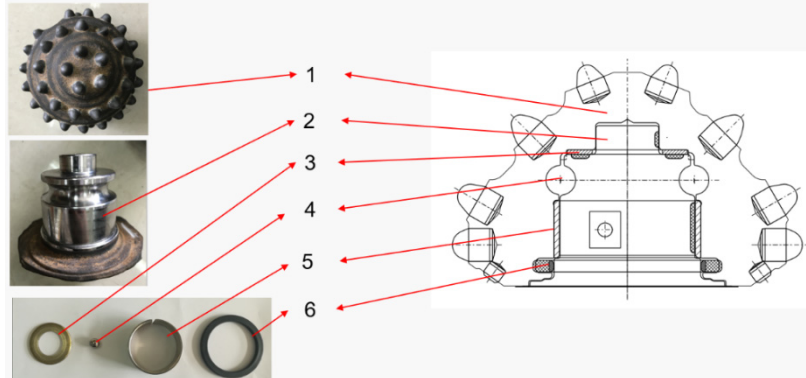
2. Floating bearing structure

In the drilling process, the surface of the tri-cone bit is in direct contact with sand and stone, and good bearing performance can greatly extend the service life of the bit. The appearance of the tri-cone bit is shown in Fig. 1.



Fig. 1 Appearance of tri-cone bit

The structure diagram of the floating bearing is shown in Fig. 2. The main components are roller bearing, tooth pad bearing, floating plate, ball, floating sleeve, and sealing gasket. The floating sleeve is located between the roller bearing and the ball bearing. The core parameters of the floating bearing are outer clearance between roller bearing and floating sleeve, inner clearance between denture bearing and floating sleeve, and inner clearance ratio between inner clearance and outer clearance.



1-Tooth palm 2-Roller cone bearing 3-metallic gasket
4-Ball Bearing 5-floating bearing ring 6-sealing gasket

Fig. 2 Structural sketch of the floating bearing

3. Theoretical mechanical analysis

Application working conditions: rotating rod speed 75 RPM, outer diameter 178 mm, inner diameter 96 mm; The Angle between the center line of the roller and the center line of the rotating rod is 54° ; The downward pressure of the pressure bar is 350–480 kN.

The pressure of the pressure rod is transferred to the bottom three rollers. The greater the pressure of the single wheel is, the greater the internal floating sleeve by the friction will be. According to the overall maximum force analysis of 480 kN, the single wheel is subjected to the downward pressure of 160 kN. The mechanical model is established. The x-y coordinate system shown in Figure 3 is established, and the force decomposition of drill pipe pressure is as follows:

$$F_x = 160 \text{ kN} \cdot \cos 54^\circ = 94.05 \text{ kN, take } 95 \text{ kN.}$$

$$F_y = 160 \text{ kN} \cdot \sin 54^\circ = 129.44 \text{ kN, take } 130 \text{ kN.}$$

F_x is the positive pressure on the tooth palm, and the greater the pressure is, the greater the friction force is. Local failure criteria of roller bit floating bearing^[5]: $fpv \leq [fpv]$. In the above formula, f means the friction factor on the surface of two touching parts; p means contact pressure; v means the relative sliding speed of two contact parts; $[fpv]$ means the allowable $[fpv]$ value of two contact surface material of floating bearing at a specific temperature.

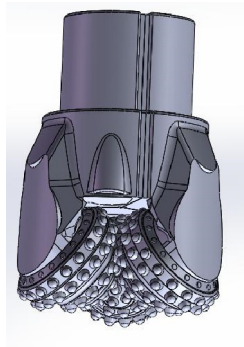
It can be concluded from the failure criterion that the local failure of the floating sleeve is related to friction factors, contact pressure, and relative velocity. We can improve the local failure of the floating sleeve by reducing the friction coefficient at the bearing. The friction coefficient can be reduced by using materials with a lower friction coefficient^[8-10]. In this paper, the floating sleeve is beryllium bronze with a lower friction coefficient.

In this paper, when the floating sleeve is in a suspension state, the friction coefficient f can be effectively reduced, and the relative sliding speed v between the tooth palm and the cone can be reduced, so the local wear fpv value of the floating bearing can be reduced.

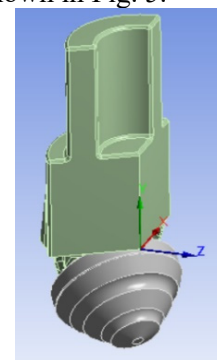
Due to the action of liquid pressure in the operation process, there is a certain outer clearance with the inner ring of the roller bearing and a certain inner clearance with the outer ring of the denture bearing. In the suspension state, friction can be effectively reduced. The inner and outer clearance ratio of the floating sleeve is an important parameter to determine the floating sleeve's suspension effect.

4. modeling and finite element analysis

To explore the optimal range of the internal and external clearance ratio of the floating sleeve, this paper uses SolidWorks to establish a three-dimensional model and uses Ansys Workbench for simulation analysis^[8-9]. The model in this paper is a 9 7/8 SF637 mining tri-cone bit. Due to the complex curved surface of the multi-tooth bit and the operational capability of the workstation computer, the overall model of the tri-cone bit and the simplified solid model of the single-cone bit are established in this paper, as shown in Fig. 3. The three-dimensional model of floating bearing is shown in Fig. 4, and the three-dimensional model of the floating sleeve is shown in Fig. 5.



(a) 3D model of the tricone bit



(b) Single cone model

Fig. 3 Mechanical mode of roller bit

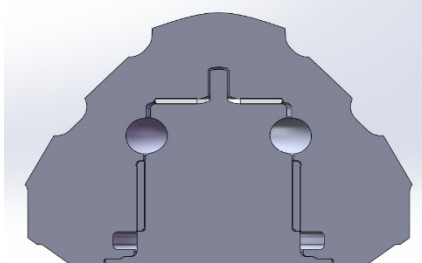


Fig. 4 3D model of the floating bearing

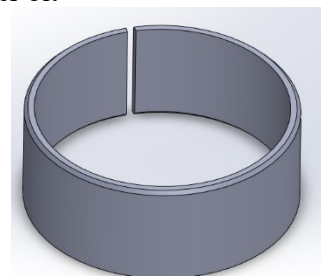


Fig. 5 3D model of the floating sleeve

The tooth palm and roller bearing are made of 15CrNiMo and the yield strength is 750 Mpa. The floating sleeve is made of CDA (UNS) ALLOY C96900 beryllium bronze with a yield strength of 1,000 MPa and tensile strength of 1,250 MPa. The roller cone bit has a large number of teeth and the

assembly bit surface is complex. Considering the computing power of the computer^[10-12], this paper simplifies the single roller cone model and establishes the coordinate system according to the working condition when the drill pipe is subjected to the maximum pressure.

The floating sleeve and the surface of the dentine bearing are defined as friction constraints. The surface of the floating sleeve and roller bearing is also defined as a friction constraint^[13-16]. The friction coefficient of the floating sleeve is 0.2. A downward vertical force of 160 KN is applied to the drill pipe, the teeth are fixed, and the rotating speed of the rod is 75 R/min, as shown in Fig. 6. As shown in Fig. 7, the overall maximum equivalent stress is 101.8 Mpa, less than the yield limit of the material, 1, 140 Mpa, which is in the static analysis of the bearing safety.

The simulation results show that the maximum stress of the floating sleeve is the position of the most vulnerable position, the maximum pressure position of the floating sleeve is shown in Fig. 8. After the floating set of samples is running for some time, the filaments damage in the edge of the surface is consistent with the simulation results, as shown in Fig. 9.

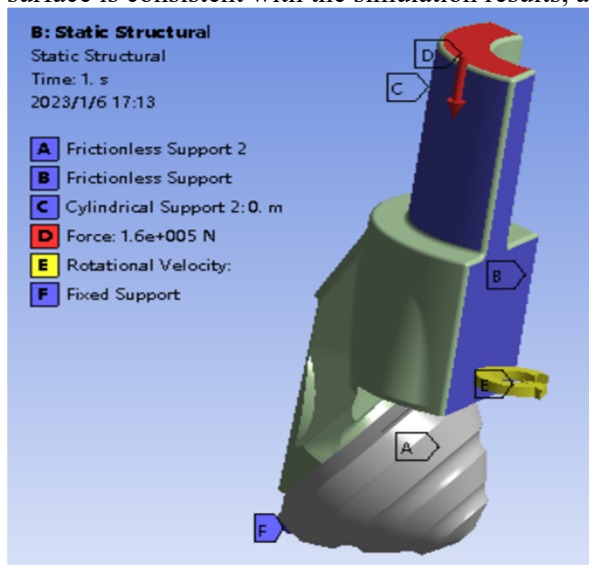


Fig. 6 constraints of the model

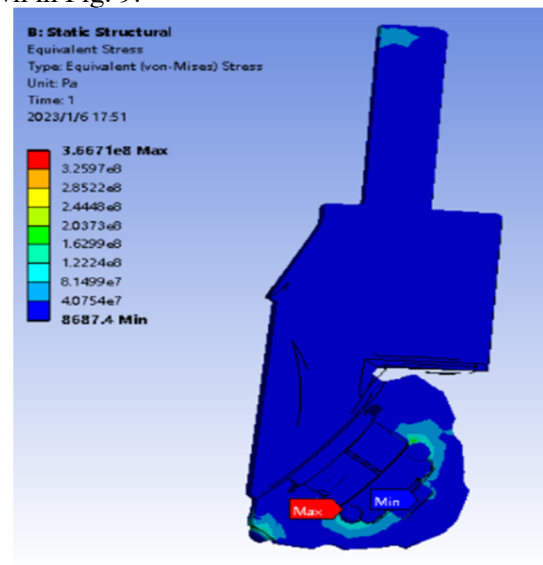


Fig. 7 Equivalent stress of floating bearing

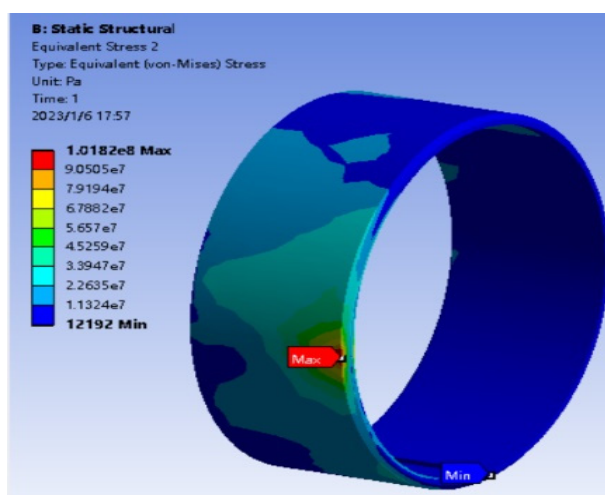


Fig. 8 Position of maximum stress



Fig. 9 Friction damage

5. Optimization design

When the floating sleeve is working, it does not rotate at a constant speed, but sometimes fast and sometimes slow. When the inner and outer clearance ratio reaches a certain value, the floating sleeve

and the cone are in a relatively static state^[17-20], and the inner and outer clearance ratio of the floating sleeve affects the friction stress of the bearing. In this paper, the optimal internal and external clearance ratio was optimized. The optimized design module built into the workbench was used to design the orthogonal test of the internal clearance and external clearance of the floating sleeve with the internal clearance and external clearance of the floating sleeve as double-factor variables, as shown in Table 1.

Table 1 Orthogonal test of internal clearance and external clearance of floating sleeve

Interring interval (mm)	Outer ring clearance (mm)	Clearance ratio between inner and outer clearance	Friction stress (MPa)	Compressive stress (MPa)
-0.05	-0.06	0.83	1.59	11.99
-0.05	-0.04	1.25	1.82	35.43
-0.03	-0.02	1.50	3.88	32.89
-0.10	-0.06	1.67	1.59	11.99
-0.04	-0.02	2.00	3.87	32.89
-0.10	-0.04	2.50	1.82	35.43
-0.03	-0.01	3.00	2.20	17.12
-0.15	-0.04	3.75	1.82	35.43
-0.04	-0.01	4.00	2.20	17.12
-0.10	-0.02	5.00	3.87	32.89
-0.15	-0.02	7.50	3.87	32.89

The variation curve of friction stress with external clearance is shown in Fig. 10. The variation curve of friction stress with internal clearance is drawn, as shown in Fig. 11. A 3D surface diagram of frictional stress changing with internal and external clearance is drawn, as shown in Fig. 12. Using 3D curved surface and clearance ratio curve, it is found that the friction stress of floating sleeve is minimum under the optimal parameter range. The results show that the optimal inner clearance of the floating sleeve is 0.06–0.07 mm, the outer clearance is 0.02–0.04 mm, and the inner clearance ratio is 2.0–2.4.

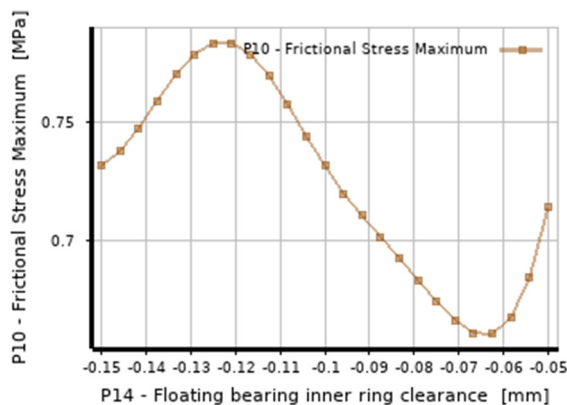


Fig. 10 Friction stress with outer clearance

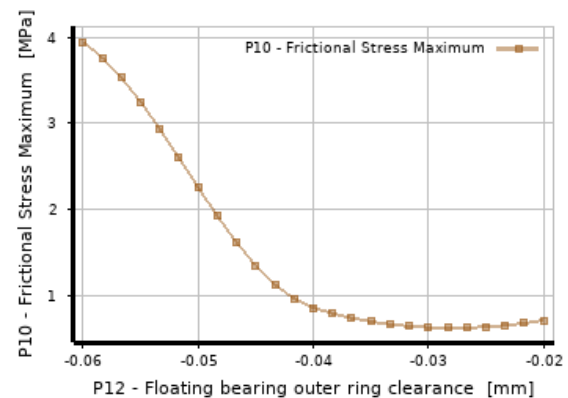


Fig. 11 Friction stress with inner clearance

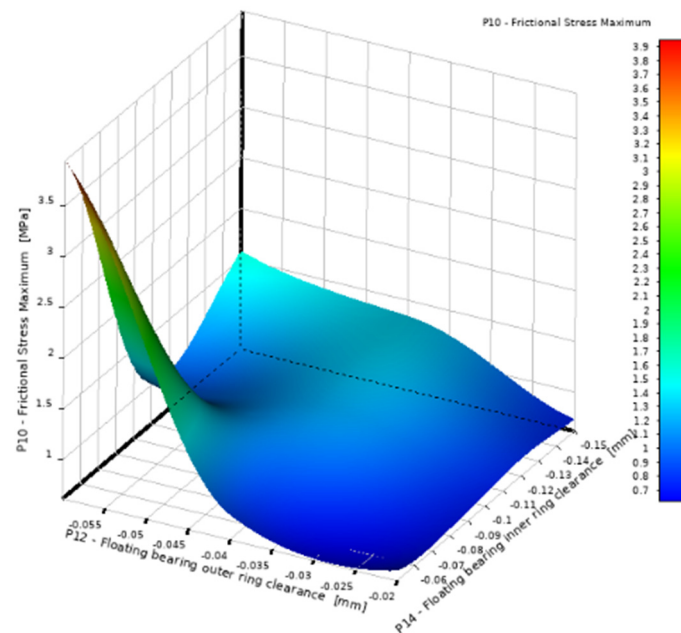


Fig. 12 Friction stress changing with internal and external clearance in the 3D diagram

6. Conclusions

(1) The simulation results show that the most vulnerable position is the edge of the floating sleeve during operation. The experimental results also show that the edge of the floating sleeve has a curling phenomenon, which is consistent with the simulation and experiment.

(2) The simulation results show that the largest deformation is the opening position. After a long period of dissection, the experimental samples showed that the opening position of the floating sleeve was deformed and closed. The simulation results agree with the experimental results.

(3) The simulation model is verified correctly with the sample results, which lays a foundation for finding the optimal inner and outer clearance ratio. This paper adopts Ansys Workbench finite element simulation software to simulate the operating condition of a floating bearing floating sleeve of a tri-cone bit. After the optimized design, the recommended internal clearance of the floating sleeve is 0.06–0.07mm, the recommended external clearance is 0.02–0.04 mm, and the recommended is 2.0–2.4.

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