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Original article

# Mechanical performance analysis of hollow cylindrical roller bearing of cone bit by FEM

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ABSTRACT

Bearings are key components of cone bit, thus its rapid failure is a major cause of leading to lower life of the bit. To improve the bearing performance and prolong working life, contact mechanics of hollow cylindrical roller bearing of cone bit was simulated. Effects of hollow size, drilling pressure, friction coefficient and fitting clearance on mechanics performance of the bearing were studied. The results show that the maximum equivalent stress of the hollow cylindrical roller bearing appears on the claw journal, and the maximum contact stress appears on the contact pair of the hollow roller. Besides, hollow sizes have a greater impact on the equivalent stress and contact stress of the cylindrical roller, while the influence on the stress of the cone and claw journal is relatively small. With the increasing of the drilling pressure and fitting clearance, equivalent stress and contact stress of bearing parts increase. The friction coefficient has little impact on mechanical performance of the bearing. As the 121/4SWPI517 type hollow cylindrical roller bearing of cone bit an example, the optimal hollow size is 55%, the drilling pressure is 140 kN and the fitting clearance is 0–0.02 mm.



## 1. Introduction

The bearing of cone bit is a complicated system which is mainly consisting of a big radial bearing and a small one, a plane thrust bearing and an axial support ball bearing for preventing cone pushed inward from falling off. In the process of high speed drilling, the contact fatigue caused by complex working conditions is the main factor of failure of rolling bearing of cone bit [1]. Compared with the solid cylindrical roller bearing, the hollow cylindrical roller bearing can better adapt to the working condition of vibration impact, reduce centrifugal force of the high-speed bearing, improve the condition of the bearing lubrication, cooling and chip removal, and improve the ability of resisting contact fatigue of the bearing, thus enhance the working performance and life of the bit. Therefore, it is great significance for the study of the mechanical properties of hollow cylindrical roller bearing to prolong the working life of the bit [2].

Many scholars have done a lot of research about the hollow cylindrical roller bearing of cone bit. For example, in the early 1970s, Bowen discovered preload, cageless and full complement hollow cylindrical roller bearings that have characteristics of high rotation accuracy and high speed [3]. Luo studied the contact status of the hollow cylindrical roller by numerical simulation [4]. Chen analyzed the contact condition and load distribution of the hollow cylindrical roller bearing of cone bit in theory [5]. Based on the sliding bearing, roller bearing and floating sleeve bearing, Han designed the hollow skid composite bearing of cone bit [6]. Li put forward a method calculating contact deformation of the hollow roller through the analysis of the contact characteristics of the hollow cylindrical roller [7]. Liu studied that temperature has influence on the load-carrying ability and stiffness of the pre-loaded hollow cylindrical roller bearing [8]. Han studied that under three kinds of load conditions (the even load, the “trapezoid” partial load and “triangle”

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partial load), different hollow sizes have influence on contact status of the hollow cylindrical roller bearing [2]. Zhang studied the deep hole hollow roller bearing of cone bit through numerical analysis methods [9]. However, most of the literature only analyzed the cylindrical roller bearing that bears the largest load, which can't fully response the mechanical properties of hollow cylindrical roller bearing of cone bit. Based on this, the whole model of hollow cylindrical roller bearing of cone bit was established by the finite element software, and contact conditions under the effect of drilling pressure were simulated, and at the same time, the paper studied that the hollow size, drilling pressure, friction coefficient and fitting clearance have influence on mechanical performance of the bearing.

## 2. Load distribution of the hollow cylindrical roller bearing

It is the assumption that under the effect of the radial force $F$, the bearing inner ring moves along the action line direction of the force $\delta_r$, and the load of rollers increases, at the moment, from the roller born the largest load beginning, the total contact deformation of the $i$ roller is regarded as $\delta_i$.

$$\delta_i = \delta_r \cos\theta - \frac{u_r}{2} \tag{1}$$

where, $\theta$ is angle between the action line of the radial load and the center line of the $i$ roller. $u_i$ is radial clearance of the bearing.

At the same time, $\delta_i$ can also be expressed as:

$$\delta_i = \delta_{i0} + \delta_{ii} + \delta_{ir} \tag{2}$$

where, $\delta_{ir}$ is contact deformation of the $i$ roller. $\delta_{i0}$ is contact deformation of the contact point that the $i$ roller contacts with the bearing inner ring. $\delta_{ii}$ is contact deformation of the contact point that the $i$ roller contacts with the bearing outer ring.

$$\delta_{i0} + \delta_{ii} = \frac{2(1-v^2)F}{\pi LE} \cdot \ln\left(\frac{2\sqrt{e}L}{b}\right) \tag{3}$$

where, $F$ is the load in the bearing. $E$ is elasticity modulus of the cylindrical roller. $L$ is the effective length of the hollow cylindrical roller. $b$ is Contact half width. $e$ is the conversion coefficient of the solid cylindrical roller with corresponding size. v is Poisson's ratio.

When the bearing is in the balance, the relationship between the load on the roller and external load $F$ is follow:

$$F = F_0 + 2\sum_{i=1}^{n} F_i \cos\theta \tag{4}$$

where, $F_0$ is the load of the rolling element born the biggest load in the bearing. $F_i$ is from the roller born the biggest load, the load of the $i$ roller.

Based on the Eqs. (1)–(4), by the iterative method can solve the load distribution of the hollow cylindrical roller bearing [5].

## 3. Calculation model

### 3.1. Finite element model

There are many kinds of rolling bearing of cone bit, and the 121/4SWPI517 type was selected to study its mechanical properties. Due to the complexity of model structure and analysis structure parameters easily, the paper used APDL (ANSYS Parametric Design Language) program Language to parameterize modeling. In addition, because of the symmetry of the bearing structure, 1/2 of the model was constructed and analyzed, and the model which is consisting of the three teeth respectively taking from the three gear rings of cone bit was created at the same time. Those teeth can meet demands of the force analysis. Model was meshed with the SOLID187 element, and the element size was 3 mm. The finite element model of hollow cylindrical roller bearing of cone bit after meshing is shown as Fig. 1. Besides, the hollow size of the roller is 40%, and there are three contact pairs in the hollow cylindrical roller bearing, thrust bearing and the path to the sliding bearing respectively. The friction coefficient is 0.05 on the contact pairs, and the initial contact interference is 0.001 mm. The material of cone is 20Ni4Mo, and the material of claw journal is 20CrNiMo, and the material of cylindrical roller is 55SiMoV. Elastic modulus is 218 GPa, 219 GPa and 210 GPa respectively, and Poisson's ratio is 0.3. The density is 7830 kg/m$^3$, 7850 kg/m$^3$ and 7800 kg/m$^3$ [10].

### 3.2. Load and boundary conditions

Through the manual of tri-cone bit (User Manual of Tri-one Bit, 1978) [11], we can know that the actual working condition of the 121/4SWPI517 cone bit is low speed and overloading,

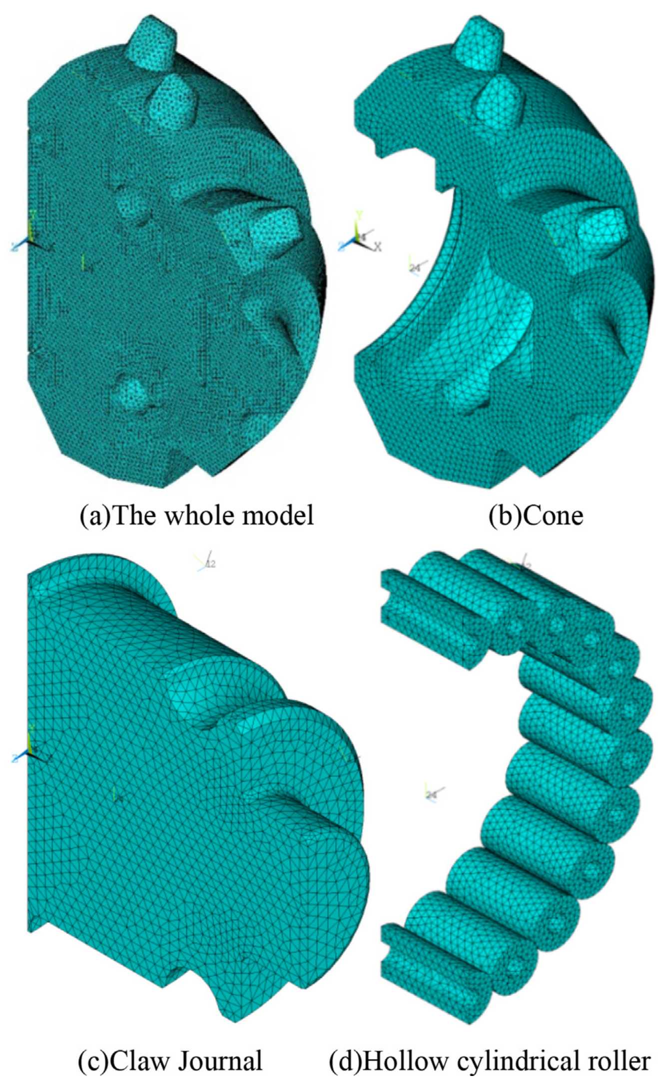


**Fig. 1.** Finite element model.