Integral finite element analysis of turntable bearing with flexible rings

Biao Deng[1], Yunfei Liu[1,*], Yuan Guo[1], Shengjin Tang[1], Wenbin Su[2], Zhufeng Lei[2], Pengcheng Wang[1]

[1]Xi'an Research Institute of High Technology, Xi'an 710025, China

[2] Xi'an Jiaotong University, Xi'an 710025, China

*Corresponding author e-mail: 18706843801@163.com

Abstract. This paper suggests a method to calculate the internal load distribution and contact stress of the thrust angular contact ball turntable bearing by FEA. The influence of the stiffness of the bearing structure and the plastic deformation of contact area on the internal load distribution and contact stress of the bearing is considered. In this method, the load-deformation relationship of the rolling elements is determined by the finite element contact analysis of a single rolling element and the raceway. Based on this, the nonlinear contact between the rolling elements and the inner and outer ring raceways is same as a nonlinear compression spring and bearing integral finite element analysis model including support structure was established. The effects of structural deformation and plastic deformation on the built-in stress distribution of slewing bearing are investigated on basis of comparing the consequences of load distribution, inner and outer ring stress, contact stress and other finite element analysis results with the traditional bearing theory, which has guiding function for improving the design of slewing bearing.

1. Introduction

Turntable bearings are pervasive application in large turning gear such as mining machines, construction machinery, armarium, and launchers, and it can withstand big comprehensive load, which has the characteristics of high stress, slow speed and negligible dynamic load. In the last few years, researchers have begun to pay attention to the mechanics of turntable bearings. The literature [1] built the model of slewing bearing in the condition in which the slewing bearing has different angle. The literature also works out the relationship between contact angle and bearing capacity. The literature [2] established the FE model including the slewing bearing with supporting structure. And the literature think that the contact between bearing enclose raceway and rolling body is equivalent to unidirectional compression spring. The literature [3] established a finite element model of roller bearing based on dynamic to study stress in different load condition. The literature [4] [5] [6] built FE model of angular-contact ball bearing which have high velocity. This literature considers friction and carry out the simulation of bearing in the condition of axial load. In the past research work, the linear elastic analysis model was mostly used, and the plastic deformation was not considered completely. In

addition, in order to save computational resources, the entire bearing model including the bracing structure is not established.

This paper built bearing finite element analysis model. The plastic deformation between rolling body and raceway is taken into account by choosing the BKIN model. Compared with the previous work, the bearing can be accurately simulated loaded internal load distribution and contact stress conditions Compared with the previous works, you can more accurately simulate the turntable bearing internal load distribution and contact stress conditions.

2. Finite element contact analysis

2.1. turntable bearing size
Structure diagram of the bearing a rocket launcher used shown in Figure 1, the bearing structure parameters shown in Table 1.
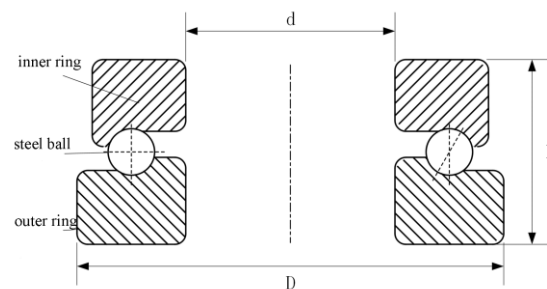
Figure 1. structure drawing of slewing bearings

Table 1. bearing structure parameters.

| Structural parameters	Numerica
Outer radius R/mm	1087.5
inner radius r/mm	1037.5
pitch radius dm/mm	1062.5
Steel ball radius Rw/mm	19.75
Bearing height h/mm	170
Bearing width b/mm	100
curvature radius of Inner ring groove /fi	0.542
curvature radius of outer ring groove /fo	0.542
Number of balls/Z	298
Contact angle $\alpha/^0$	60

2.2. solid modelling
Due to the contact analysis of only one rolling element- raceway model, only a raceway part of a steel ball was selected to establish the finite element contact analysis model to study the plastic deformation. So as to simplified calculation, improve the computational efficiency and make full use of the structural symmetry, only the 1/2 model of   rolling element-raceway was built, as shown in Fig.3. In the section through the center of the steel ball, the corresponding key points of the contour lines of the bearing enclose are firstly established and the adjacent key points defined in turn are connected to form the cross-sectional contour line；Then, the cross section of the bearing enclose is generated on the basis of the contour line, and the bearing enclose raceway models were obtained through the stretching operation；Finally, a steel ball model is generated at the center of the section.In order to facilitate the

establishment of contact pairs and lessen the scale of the calculation, the area the rolling bodies and the ball track may be contact required to be separated to form independent contact surfaces.

2.3. Cell type, material selection and mesh generation

The steel ball and inner and outer ring raceways use a three-dimensional, 8-node solid structural unit, SOLID185, that utilizes mixed formulation to simulate the elastoplastic behavior of an almost incompressible material and the superelastic behavior of a completely incompressible material. The material properties can not be defined as linear elastomers on account of the plastic deformation of the steel ball in contact with the internal and external roll paths of bearings. Plastic deformation of the steel ball and the internal and external roll paths of bearings are cold plastic deformation, so it can be considered that its present rate is independent of behavior and low strain rate. As shown in Figure 2, point A is the yield point of a material σ_s, and yield strength is 1280MPa; Line 1 slope represents the elastic modulus E, and this article takes 210GPa ; Line 2 slope represents the shear modulus E_T, and the elastic modulus this article takes is 1/200, which is 2Gpa.
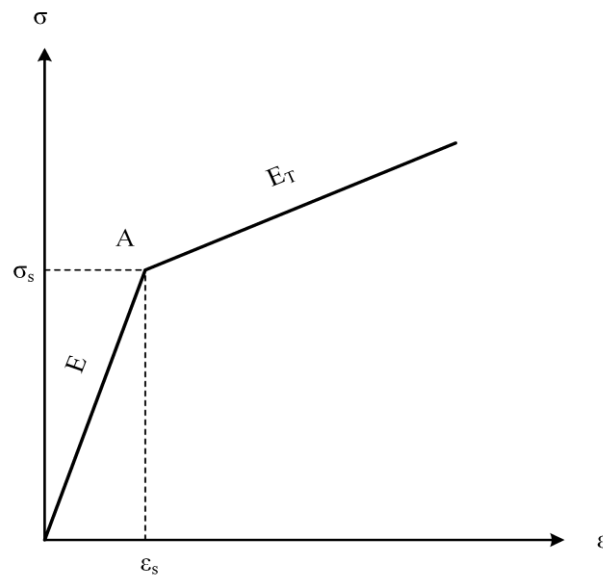
Fig 2.model of bilinear kinematic hardening

To reduce the amount of model computation, different assemblyunits are setted to different materials as shown in Table 2.Steel ball contacts with the inner ring inner layer and outer ring inner layer respectively, undergoing elastic deformation, plastic deformation or even failure process, so the inner assembly units of inner and outer ring and the ball are setted to elastoplastic material, the mesh generation is thinner to improve the calculation accuracy; The remaining assembly units are setted to rigid materials, densities appropriate to take large when dividing the grid to save calculation time, the various components of the material as shown in Table 2.

Table 2.material detail of model parts

Parts	Outer of inner ring	Lining of inner ring	Steel ball	lining of outer ring	Out of outer ring
material	Rigidity	elastoplasticity	elastoplasticity	elastoplasticity	Rigidity

2.4. boundary condition

Figure 3 shows the boundary conditions for the contact analysis model. The slewing ring bearing outer ring was fastened to the permanent seat of the underframe with the action of bolt pre-tightening force, so a total freedom constraint is imposed on all nodes on the outer ring end face of the turntable bearing; Due to the symmetrical model, a symmetric constraint needs to be applied on the symmetry section to make the node on the cross section cannot be moved outside the flat and no rotation can occur in the flat; Coupling Internal ring circumferential surface node degree of freedom to ensure the overall axial

translation of the inner ring; So as to lessen the difficulty of the application of load, an auxiliary node is established at the geometric center of the top surface of the inner ring and meshed with the MASS21 mass element. Then, the upper node and the auxiliary node are rigidly coupled to form a rigid region, and then apply load to the auxiliary node; Steel ball and the bearing enclose are used to establish face - face flexible contact element, The surface of the inside and outside circle raceway is set as the destination face, and using Targe170 element. The steel ball surface was selected as the contact area, which use Contal 169 element.
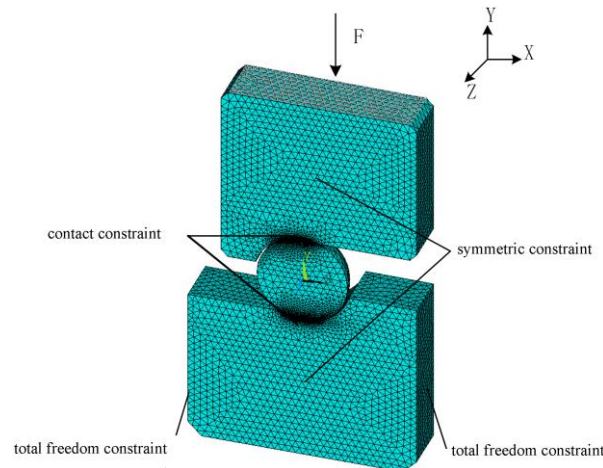

Fig 3. contact analysis model

3. analysis and calculation

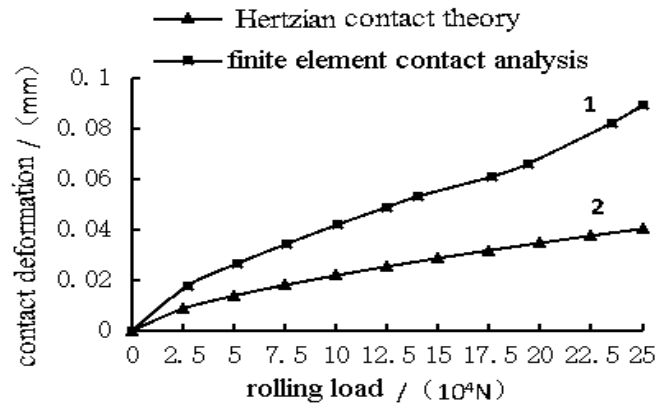### 3.1. relation curve between rolling body load and contact deformation

According to the above method, a single rolling element-raceway model is analyzed and calculated. The model divides 178, 999 nodes, 906, 940 8-node entities and 81, 612 three dimention surface contact elements. A node on the surface of the ball is extracted. As shown in Fig. 4, the node is situated at the center of the rolling element width which contacts with the inner ring raceway. The node number is 84, 693, and the contact load and deformation displacement of the node are obtained and discussed.
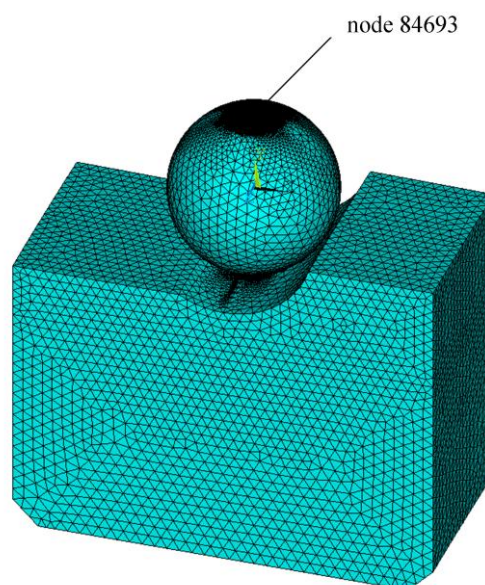
Fig 4. node selection

Curve 1 in Fig. 5 is the deformation curve of contact load between steel ball and raceway obtained though the finite element contact analysis. From the curve, it can be seen that when the load is small, the slope of the curve is stable and shows a linear change, and only the elastic deformation occurs. When the load increases to a certain degree, the slope of curve begins to change, showing non-linearity, and the steel ball and the raceway have plastic deformation.

Curve 2 is the connection between the load and contact deformation on the grounds of Hertzian contact theory. The slope is always stable. It can only describe the elastic deformation stage when the steel ball contacts the raceway, and can not reflect the plastic deformation stage under heavy load condition.

**Fig 5.** relation curve between rolling load and contact deformation

3.2. overall finite element analysis

3.2.1. load distribution of bearing rolling body. By extracting the force of each spring element, the load distribution of the slewing bearing rolling element was obtained. The fig.6 shows that the steel ball with the specified azimuth of 0^0 is located above the first quadrant supporting jack. The load on the maximum loaded rolling body is 25296N. The traditional Hertzian contact theory calculates the rolling body load distribution as shown in Fig. 8, and the load on the maximum loaded rolling body is 27890N. The comparison shows that the maximum load on the rolling element calculated on the basis of the finite element method is lower than that of the Hertzian contact theory. On the one hand, this is on account of the plastic deformation on the rolling element during the contact with the bearing enclose. The calculated stress of the plastic material model is less than the linear elasticity. On the other hand, under the combined load, some structural deformations occur on the mounting support of the turntable bearing, which causes the structural deformation of the flexible ferrule, which increases the number of rolling bodies involved in carrying and enlarges the area of carrying.
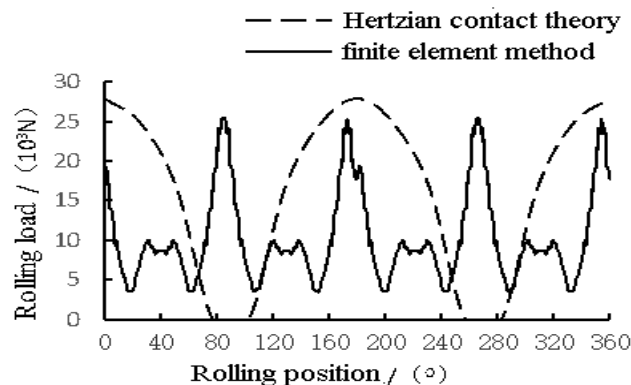

Fig 6.rolling load distribution

3.2.2. inner and outer ring stress. Fig. 7 shows the vons equivalent stress nephogram of inner and outer bearing rings. We can know that that the largest equivalent stress inside the ferrule is 734.8MPa. Although this stress does not cause strength damage to the bearing, it has deformed the ferrule. Further analysis shows that the inner and outer rings are fixedly connected with the upper and lower frames respectively. Under the combined load, the inner and outer rings undergo bending and torsion deformation along with the upper and lower connecting frames. Therefore, the rigid ring hypothesis is no longer suitable for large thin-walled turntable bearings.
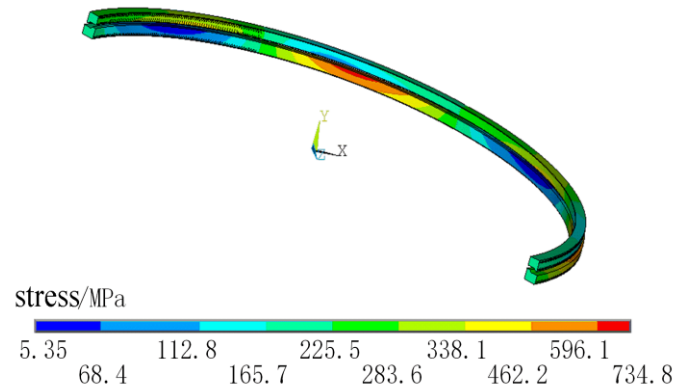
Fig 7. vons equivalent stress nephogram of inner and outer ring of bearing

3.2.3. raceway and steel ball contact stress Based on the finite element model of a single rolling body-raceway contact analysis, the contact with the most loaded rolling element is calculated. Figure 8 shows the rolling element-raceway contact stress nephogram. The figure shows that the maximum contact pressure between the rolling body and the raceway is 1455 MPa, and the rolling body and the raceway have been plastically deformed.
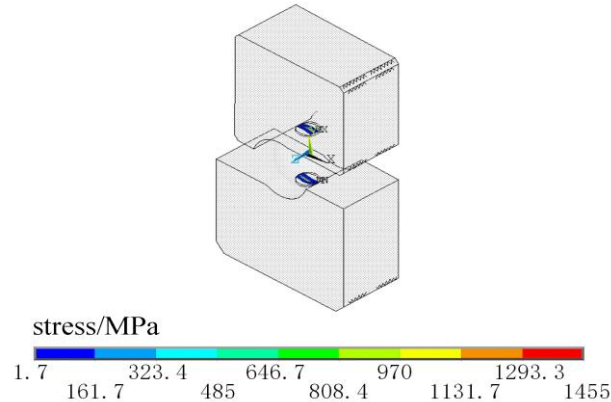
Fig 8. contact stress nephogram

Table 3 shows the comparison of the contact stress calculation results of the two methods. From Table 3，we can see that the contact stress obtained by the finite element contact analysis is obviously lower than the Hertzian contact theory because plastic deformation occurs during the contact of the rolling bodies with the raceway and the contact area becomes larger so that the contact stress is reduced, which is in accordance with the actual engineering conditions.

Table 3. calculation results of contact stress

	Contact stress of rolling body and inner ring/MPa	Contact stress of rolling body and outer ring /MPa
Hertz contact theory	3383.3	3263.7
Finite elementcontact analysis	1455	1316.3

4. conclusion

(1) Because the bearing enclose are connected with the foundation, there is large bending and torsional stress in the bearing ring under the joint load, which is inconsistent with the assumption of no stress in the rigid ring. Therefore, the rigid ring hypothesis no longer applies to the large thin-wall turntable bearing .

(2) Under the heavy load, the rolling contact with the inner and outer ring raceway have plastic deformation, and plastic material model in finite element analysis can simulate the actual conditions better.

(3) in the slewing bearing with flexible ring, the deformation of the bearing enclose makes the number of rolling bodies involved in bearing increase, while the loads distribution of the rolling bodies is relatively more uniform, reducing the load of the largest loaded rolling body, and improving the bearing capacity.

(4) Taking into account the load distribution of the rolling elements getted from the integral finite element analysis of the support stiffness, the load distribution of the rolling elements is quite different rigid ring hypothesis. The stiffness of the foundation have a significant impact to the rolling body load distribution. Therefore, when analyzing the load distribution of the rolling bearing of a large-scale thin-walled slewing bearing, the rigidity influence of the supporting structure must be considered.

The proposed integral finite element method of the slewing bearing considers the plastic deformation of the rolling body in contact with the raceway and the influence of the rigidity of the structure support on the heavy load condition. The method is more accord with reality of the engineering; The large-scale calculation and convergence difficulties brought by the finite element contact analysis are solved and provide the basis for the improved design of the turntable bearing.

References

[1]   Wang Shaojun, Hou Li, Wang Hong . FEM Analysis and Optimization on Slewing Bearing in Large Cable Tower Bridge Inspection Vehicle, J. Bearing, 2017,(06):19-20.

[2]   Shang Zhenguo, Dong Huimin, Mao Fanhai. Finite element analysis method of slewing bearing with plastic deformation, J. Transactions of the Chinese Society of agricultural Engineering, 2011,27(12):52-55.

[3]   Xu Hongyi, Zhang Chenhui. Finite element analysis of roller bearing based on the plastic material model, J. Journal of Mechanical Engineer, 2010, 46(11):30-34.

[4]   Yu Xiaokai, Zhao Chunjiang, Ge Shidong. Analysis of high speed ball bearing under axial load based on abaqus,J. Mechanical Engineering&Automation, 2011, (5):51-55.

[5]   Jiang Wei, Yang Xianqi, Chang Zongyu. Analysis on Dynamic Characteristics of High speed Angular Contact Ball Bearing, J. Bearing, 2008, (6):2-4,39.

[6]   Chen Zhenyu. Analysis on the Dynamic Characteristics of the High Speed Angular-contact Ball Bearing, J. Manufacture Information Engineering of China, 2006, 35(13):65-68.