The Contact Analysis for Deep Groove Ball Bearing Based on ANSYS

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Abstract

A 3-D model of deep groove ball bearing was built by using APDL language embedded in the finite element software ANSYS. Through contact analysis, the changes could be showed in stress, strain, penetration, sliding distance, friction stress among the inner ring, outer ring, rolling elements and cage. Furthermore, the simulation results revealed that the computational values were consistent with theoretical values. The all showed that the model and boundary conditions were correct and rational, and it would provide a scientific basis for optimum design of rolling bearings under complicated loads.

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Keywords: Deep groove ball bearing; Parameterize; Finite element analysis; Contact analysis

1. Introduction

Deep groove ball bearing’s structure is simple and is widely applied. Its main failure mode is contact fatigue spalling of rolling elements. The contact finite element analysis can show bearings’ information under contact, such as contact stress, strain, penetration and sliding distance, and so on, which play a significant role in optimum design of complicated rolling bearings.

Contact is a complex nonlinear phenomenon, which involves not only change in state, but also accompanies with heat or electricity. Contact problem mainly includes two considerable difficulties at present. Firstly, before solving problems, the specific contact area isn’t usually been known. With the change of load, material, boundary condition or the other factors, touch or separation will take place

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between surfaces. That is hard to predict, even is a abrupt change. Secondly, most frictional effects on contact problems are needed to be considered. They may be disordered as well as nonlinear. How to simulate the similar contact problems quickly and exactly is one of the heat problems that scholars care [1].

ANSYS gives a good blue print for contact analysis which can take friction heat and electrical contact into account. It also has a special contact guide which is conveniently for creating contact pairs. The internal expert system of contact analysis does not require any settings of related contact parameter in a general contact analysis. So it can easily establish contact analysis. The paper took deep groove ball bearing 6200 for an example, discussed bearing contact, and built its finite element 3-D parameterized model by using the APDL (ANSYS Parametric Design Language) of ANSYS. Based on that, the nonlinear contact state was researched and analyzed.

2. The contact state analysis and theoretic calculation for deep groove ball bearing

When ball bearing works, it is usually that more than one rolling ball bears the load. The condition is complex between rollers and rings. When the load is 0, the contact area is a point, i.e., point-contact. When the load increases in running, the bearing inner ring, outer ring and rolling elements bring forth plastic deformation in the contact area, so the point-contact becomes face-contact [2]. Furthermore, contact area gradually becomes ellipse, and generates residual stress [3]. The contact parameters, such as the place, size, shape of contact area, as well as the contact pressure and friction force distribution, will be variable with loads change. These are typical boundary nonlinear problems. On the base of Hertzian theory, deep groove ball bearing’s contact stress is:

\[ P_m = \frac{1}{\pi e_a e_b} \times \sqrt{\left(\sum \rho\right)^2 \frac{5F_r}{Z \cos \alpha}} \]  

In the formula, \( e_a, e_b \) is respectively Hertzian contact coefficient; \( \sum \rho \) is the sum of main curvature; \( F_r \) is the radial load; and \( Z \) is the number of rolling elements; \( \alpha \) is contact angle under loads.

3. The basic steps in the bearing’s contact Analysis

In contact problem involved two boundaries, it is natural that take one boundary as target surface and take the other one as contact surface. Surface-surface contact is very suitable for those problems just as: interference fitting installation, or embedded contact, forging and deep-drawing.

Typical surface-surface contact’s analysis steps mainly include: (1) Build 3D geometry model and mesh; (2) Identify contact pairs; (3) Name target surface and contact surface; (4) Define target surface; (5) Define contact surface; (6) Set up element key options and real constants; (7) Define and control rigid goal’s movement (only applicable in rigid-flexible contact); (8) Apply the necessary boundary condition; (9) Define solution options and load steps; (10) Solve contact problems; (11) look over and analyze results.

ANSYS supports surface contact elements of rigid-flexible or flexible-flexible. The elements form contact pairs by using target and contact surface. For the rigid-flexible contact, it can be chosen as contact surface such as convex surface, dense meshing or little size surface, otherwise chosen as target surface.

4. Build bearing’s Finite element model

By use of APDL of ANSYS, in theory, it is feasible that model can be changed with model’s parameters change such as material property, restrained displacement and applied load, and so on. The
parametric modelling mode can realize design automation, enhance design efficiency, furthermore provide base for reliability and optimum design.

Deep groove ball bearing is mainly composed of inner ring, outer ring, rolling elements and cage. Due to the different conditions, some bearings have snap ring groove, shield, seal, bearing peak thread, and so on. Because bearing’s some structures have a little influence on stress distribution, such as chamfer, edges, snap ring groove, shield, seal and bearing peak thread, which can be ignored in modelling. Taking the deep groove ball bearing’s simple structure into consideration and radial loads converge on the lower part of bore surface of inner ring, this paper used the whole modelling mode.

Table 1 and table 2 are the interrelated materials and size parameters about bearing 6200.

### Table 1. Material’s properties

| Bearing part name | Material       | Modulus of elasticity(N/mm²) | Density(kg/m³) | Poisson’s ratio |
|-------------------|----------------|------------------------------|----------------|-----------------|
| Inner ring        | GCr15SiMn      | $2.16 \times 10^{11}$        | 7820           | 0.29            |
| Outer ring        | GCr15SiMn      | $2.16 \times 10^{11}$        | 7820           | 0.29            |
| Rolling element   | GCr15SiMn      | $2.16 \times 10^{11}$        | 7820           | 0.29            |
| Cage              | Yellow brass   | $1.0 \times 10^{11}$         | 8500           | 0.324           |

### Table 2. Bearing’s parameters

| Parameter name          | Value (mm) | Parameter name          | Value (mm) | Parameter name          | Value (mm) | Parameter name          | Value (mm) | Parameter name          | Value (mm) | Parameter name          | Value (mm) |
|-------------------------|------------|-------------------------|------------|-------------------------|------------|-------------------------|------------|-------------------------|------------|-------------------------|------------|
| Bearing outside diameter| 30         | Bearing bore diameter   | 10         | Bearing width           | 9          | Ball diameter           | 4.762      | Number of balls         | 8          | (piece)                 |
| Rib diameter of outer ring | 23.8      | Rib diameter of inner ring | 17.4      | Raceway diameter of outer ring | 25.27 | Raceway diameter of inner ring | 15.738 | Radial load          | 5000       | (N)                     |
| Raceway groove curvature radius of outer ring | 2.49 | Raceway groove curvature radius of inner ring | 2.44 | Pitch diameter of ball set | 20.5 | Velocity          | 209.44     | (rad/s)                |

Figure 1 is the Finite element model of deep groove ball bearing. Bearing’s inner ring, outer ring, rolling element and cage all use SOLID45 element with 8 nodes and 6 faces. Using free meshing of size as 1.5mm, the whole model has 54224 nodes and 258666 elements.

Fig. 1. (a) the Finite element model of deep groove ball bearing; (b) partial enlarged view

Because each rolling ball contacts with inner ring’s raceway only by a half of the spherical surface and contacts with outer ring’s raceway by the other half of the spherical surface at any moment, so it must be
paid attention to the direction of the ball in the process of modeling, in order that the two halves of spherical surface can separately correspond to raceway groove surfaces of inner ring and outer ring.

5. Define contact and check contact element

Taking separately the raceway’s groove surface of inner and outer ring as target surface, and taking correspondingly half sphere surfaces of balls as target surface, two contact pairs can be built. It is necessary that to make sure the contact is rigid-flexible contact between rolling element and inner or outer ring, to choose CONTA174 as contact element type which has 8 nodes and quadrilateral include middle-node, and to choose TARGE170 as target element type which has 3 nodes without middle-node, to set 0.1 as normal penalty stiffness (FKN) value of each contact pair (if the value is excessive, it will cause some problems which contact analysis doesn’t convergent ), to set 0.01 as initial contact closure(ICONT) value and 0.003 as friction factor value.

After meshing contact element, it is important to check the outer normal direction. To 3D element, the outer normal direction is decided by nodes’ number and the right rule. The outer normal direction of contact surface must face to target surface. Otherwise, at the beginning of analysis and calculation, program maybe believes that the contact surface has exceeded penetration, and it will be difficult to find initial solution, so as to program stop executing. If the direction is wrong, it must be changed by reversing the wrong nodes number (Command: ESURF,.REVE or GUI: Main Menu>Preprocessor>Create> Elements>Surf to Surf),or to redefine element normal direction (Command: ENORM or GUI: Main Menu>Preprocessor>Create> Move/Modify> Surf Normals).

In figure 2, the outer normal direction of outer ring groove surface is consistent with the rolling ball’s, while the inner ring groove surface’s doesn’t be, and it is needed to be reversed.

![Fig. 2. (a)Raceway groove elements’ outer normal direction; (b) partial enlarged view](image)

![Fig. 3. setting boundary conditions and applying load](image)
6. Set boundary conditions and apply loads

Figure 3 shows setting boundary conditions and loads, which restrained the all degrees of freedom (DOF) of bearing outer ring’s cylinder surface, fixed the displacement of the axial direction (UZ in Cartesian coordinate system) and circle direction (UY in cylindrical coordinate system) of groove surface and bore surface of outer ring, groove surface and cylinder surface of inner ring, ball and cage’s nodes in pitch diameter of ball set, added constraint of the axial direction and radial direction (UX in cylindrical coordinate system), and applied radial loads to the lower part’s nodes of bore surface in inner ring.

7. Define options of solution and load steps

This analysis is belong to low-strain, little-displacement, little-sliding, by setting up NLGEOM,OFF, it will quicken the search and shorten the search time. Time step must be set enough small so as to capture appropriate contact area, because if it is too big, the contact force’s smooth transmission will be destroyed. Based on reasonable time step, number of equilibrium iterations should be set. If contact status is changed during iterations, it will maybe occur to discontinuity. In order to avoid converging too slowly, modified stiffness matrix can be used and Newton-Raphson option can be set as FULL. For surface-surface problems, automatic time stepping is usually helpless, it is recommended to switch it off.

8. Analyze contact stress results

By means of simulation, the contact change status can be got, such as contact stress, strain, penetration and sliding distance, contact friction stress, contact pressure, among the inner and outer ring, balls and cage, as well as bearing’s displacement at the same time.

Figure 4 shows von Mises total strain. The bigger contact displacement mainly concentrated on the lower part of inner ring, and the lowest ball had the largest strain. The biggest total displacement and strain of bearing respectively is DMX=0.09335, SMX=0.056806; Specifically, the inner ring had the largest total displacement, and the ball had the biggest total strain, which were consistent with the fact.

From Figure 4, we can also know that the contact area had an approximate ellipse shape in contact area of inner ring and rolling element, which was consistent with the Hertzian contact theory.

![Fig. 4. (a)Nodes’ von Mises total strain of bearing; (b) inner ring and rolling elements; (c) rolling element](image)

From Figure 5, we can know that the contact stress change. The biggest stress was at the contact point to correspond the line which radial force loads. The lowest ball had the biggest stress SMX which equalled to 8599 and the inner ring raceway’s equalled to 2005 where the point contacted rolling element, which was consistent with the fact.
Through simulation, the calculation result of the maximal contact stress was 8599 MPa, while the Hertzian theory value was 8572 MPa. The comparison revealed that there was good consistency between the Hertzian theory solution and finite element solution.

Also, ANSYS analysis can acquire bearing parts’ other information under contact, such as contact penetration and contact sliding distance, contact friction stress, contact pressure, and so on, as Figure 6.

Figure 6 (a) contact penetration; (b) contact sliding distance

9. Conclusions

(1) By using ANSYS to numerically simulate and analyze on stress and strain during deep groove ball bearing contacts, the finite element solutions were got, which had good consistency with the Hertzian theory solutions;

(2) The contact analysis of finite element method can easily and intuitively get the stress and strain values as well as their cloud imagery, which can efficiently understand the parts’ running information, such as contact penetration, contact sliding distance, and so on. Those will provide reference and evidence for strength Analysis, life-design and structural optimum about complex bearing.

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