Bending stress of rolling element in elastic composite cylindrical roller bearing

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Abstract: A new structure design method of elastic composite cylindrical roller bearing is proposed, in which PTFE is embedded into a hollow cylindrical rolling element, according to the principle of creative combinations and through innovation research on cylindrical roller bearing structure. In order to systematically investigate the inner wall bending stress of the rolling element in elastic composite cylindrical roller bearing, finite element analysis on different elastic composite cylindrical rolling elements was conducted. The results show that, the bending stress of the elastic composite cylindrical rolling increases along with the increase of hollowness with the same filling material. The bending stress of the elastic composite cylindrical rolling element decreases along with the increase of the elasticity modulus of the material under the same physical dimension. Under the same load, on hollow cylindrical rolling element, the maximum bending–tensile stress values of the elastic composite cylindrical rolling element after material filling at 0° and 180° are 8.2% and 9.5%, respectively, lower than those of the deep cavity hollow cylindrical rolling element. In addition, the maximum bending-compressive stress value at 90° is decreased by 6.1%.

Key words: elastic composite cylindrical roller bearing; hollowness (degree of filling); finite element analysis; bending stress; rolling element

1 Introduction

As a kind of important mechanical element, the cylindrical roller bearing directly affects the working performance of the whole machine. It is found that the solid cylindrical roller bearing has defects including low load bearing precision, high vibration noise, and being easily damaged under high speed or heavy load conditions. In order to overcome these disadvantages, hollow cylindrical roller bearings [1−3] have been designed and thoroughly investigated. The structural characteristic of the hollow cylindrical roller bearing is that the rolling element is hollow, which is classified into two types: with preload and without preload [4]. Because the hollow cylindrical rolling element possesses higher elasticity compared to the solid one, contact area between the hollow cylindrical roller bearing and ring increases in the case of load, therefore, service life is prolonged due to reduction of contact stress [5−7]. Because the hollow cylindrical roller bearing has lighter weight, smaller centrifugal inertial force and higher adaptive rotation speed [8], it has been paid wide attention in high-speed bearing. Various kinds of new types of hollow cylindrical roller bearings are continuously designed, in addition, large quantity of work has been done regarding structural design, and theoretical analysis as well as application [9−11].

It is shown in theoretical and experimental research that hollow cylindrical roller bearing has advantages in many aspects, however, there are also some problems, especially the bending fatigue fracture is apt to occur with the hollow cylindrical rolling element under periodical alternative deformation state [12−13].

Some defects in traditional (both in solid and hollow) cylindrical roller bearings make them hard to satisfy some special mechanical requirements. Through innovative research on the structure of the cylindrical roller bearing, the design method of new structure in elastic composite cylindrical rolling element is put forward in which PTFE (Polytetrafluoroethylene) is embedded into the deep cavity hollow cylindrical rolling element, to maintain the advantages of hollow cylindrical roller bearing. The cylindrical roller bearing designed is named as elastic composite cylindrical roller bearing [14−15]. The structures of the three kinds of elements are as shown in Fig. 1. The detailed structure of the elastic composite cylindrical roller bearing is shown in Fig. 2. Because the rolling element of the elastic composite cylindrical roller bearing is easier to be deformed than
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the solid one, its anti-fatigue damage ability increases and safe service life is prolonged. In addition to lighter weight, higher precision and higher rotational speed, the PTFE in the hollow rolling element possesses extra good physical characteristics, so the new type of bearing also behaves remarkable vibration absorption effect.

The researches on structural design and bearing capacity of the elastic composite cylindrical roller bearing [16–17] show that bending fatigue fracture, caused by heavy bending stress, has become one of failure forms of hollow cylindrical roller bearing. In order to explore the effect of bending stress on the elastic composite cylindrical roller bearing, bending stress of the elastic composite roller is taken as the research object and mechanical analysis is carried out under static load state of the elastic composite cylindrical roller bearing. In addition, numerical computations are related with non-linear finite element [18–19] software, ABAQUS, to understand stress distribution of the inner wall and influence of PTFE on the stress of the inner wall.

2 Static stress analysis of elastic composite cylindrical roller bearing

Loads on the elastic composite cylindrical roller bearing and the general cylindrical roller bearing are basically the same; the load attached to the elastic composite cylindrical roller bearing can be transmitted to the outer ring and vice versa. Here, we will discuss the load distribution inside the elastic composite cylindrical roller bearing and general cylindrical roller bearing and the stress of elastic composite cylindrical rolling element under radial load.

2.1 Load distribution inside cylindrical roller bearing under static load

In most rolling bearing applications, inner ring and outer ring operate stably, rotate usually at relatively low speed, there is not big inertia force to affect load distribution between the rolling elements, and friction force and moment acting on the rolling element do not generate remarkable influence on the load distribution. So, a roller-race (linear) contact is given by [20]

\[ Q = K_1 \delta n \] (1)

where \( Q \) is the normal load of roller-race (N), \( K_1 \) is the load–displacement coefficient (N/mm), \( \delta \) is the displacement or contact deformation (mm), and \( n \) is the load–displacement index (for ball bearings, \( n = 3/2 \); for roller bearings, \( n = 10/9 \)).

Under the load, the approached value in normal direction between the two races separated by the rolling element equals the sum of approached value between rolling element and every race:

\[ \delta_n = \delta_i + \delta_o \] (2)

Then

\[ K_n = \left[ \frac{1}{(1/K_1)^n + (1/K_o)^n} \right]^{n} \] (3)

And

\[ Q = K_o \delta n \] (4)

For contact between steel roller and race, there is

\[ K_1 = 8.06 \times 10^4 I^{8/9} \] (5)

where \( I \) is the roller length.

\[ F_r = ZK_o (\delta_i - \frac{1}{2} P_d) J_r(\varphi) \] (6)

where \( F_r \) is the applied load (N), \( Z \) is number of the rolling elements, \( P_d \) is the radial internal clearance (mm), and \( J_r(\varphi) \) is integral of the radial load distribution.

\[ Q_{\max} = K_n \delta^n_{\varphi=0} = K_n (\delta_i - \frac{1}{2} P_d)^n \] (7)

where \( \varphi \) is the directional angle (°).

\[ F_r = ZQ_{\max} J_r(\varphi) \] (8)