The Influence of Moment Load on Fatigue Life of Thrust Ball Bearing

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***Abstract*—The influence of moment load on the fatigue life of thrust ball bearing is no considered in existing international standard. In order to solve the problem an increment of axial load is put forward, which is equivalent to the moment load in the meaning of bearing life. Based on this a new equivalent load related to axial load and moment is obtained and the bearing life can be calculated.**

Keyword-Thrust ball bearing, Moment load, Rating fatigue life

I. INTRODUCTION

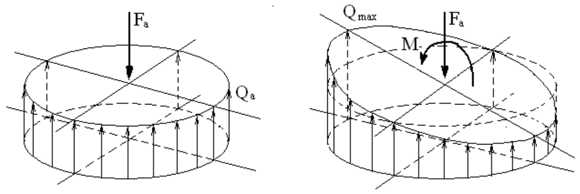
The basic rating life of thrust ball bearing can be calculated as follows according to the Standard of rolling bearings dynamics load ratings and rating life [1],

$$L_s = (C_a / P_a)^3 \tag{1}$$

The unit of L_s is 10^6 revolution, where C_a is rating dynamics load, P_a is equivalent load. Usually only axial load is supported by the thrust ball bearing, at this time

$$P_a = F_a \tag{2}$$

Equation (2) indicates that the equivalent load is independent of moment load, that is the moment load is no influence on bearing fatigue life. In practice, although the moment can not change the total equivalent load, but it will change the load distribution on balls (see Fig. 1) and hence will reduce the bearing life. In the paper we will consider the influence of moment load on bearing life.



a. Pure axial load
b. Momemt and axial load

Fig. 1 Load distribution on balls

II. CONTACT LOAD DISTRIBUTION ON BALLS

Under the axial load F_a and moment M, the thrust ball bearing will produce an axial displacement δ_a and rotation θ. Because of the two displacements the curvature center O_i of inner groove at the place with azimuth angle φ will produce an axial movement δ_{ai} relative to curvature center O_e of outer groove as showed in Fig. 2, and

$$\delta_{ai} = \delta_a + 0.5 d_m \theta \cos\varphi \tag{3}$$

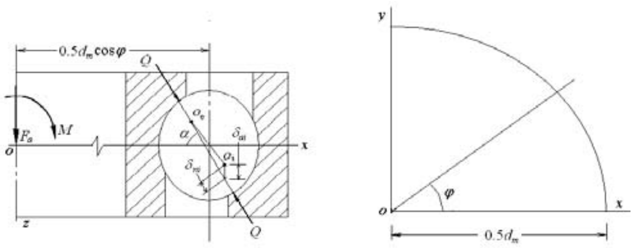


Fig. 2 Contact load and deformation

where d_m is pitch diameter of ball center. Assume contact angle α does not change, the deformation in direction of contact normal is

$$\delta_{ni} = \delta_{ai} \sin\alpha \tag{4}$$

According to Hertz theory [2] the contact load on ball is

$$Q = K\delta_{ni}^{1.5} = K(\delta_{ai} \sin\alpha)^{1.5} \tag{5}$$

where K is contact stiffness coefficient. The equilibrium equation of bearing can be expressed as follows

$$\begin{cases} F_a = \sum_{i=1}^{Z} Q_i \sin\alpha \\ M = \sum_{i=1}^{Z} (0.5 d_m \cos\varphi) Q_i \sin\alpha \end{cases} \tag{6}$$

where Z is the number of balls. Equation (6) is a nonlinear equation group with unknown variables δ_a and θ. To solve it the ball contact loads $Q_i (i = 1,2,...,Z)$ can be determined.

III. BEARING FATIGUE LIFE CALCULATION BASED ON CONTACT LOADS

The theory of rolling bearing fatigue life had been built by Lundberg and Palmgren [3,4] as early as in 1947. According to L-P theory, the rating life of bearing rings can be expressed as

$$L_r = (Q_c / Q_e)^3 \tag{7}$$

where Q_c and Q_e is rating dynamics load and equivalent load of rings respectively. To the thrust ball bearing,

$$Q_c = 88.2(1-0.33\sin\alpha)\left(\frac{2f}{2f-1}\right)^{0.41}\frac{(1\mp\gamma)^{1.39}}{(1\pm\gamma)^{1/3}}\left(\frac{\gamma}{\cos\alpha}\right)^{0.3}D_w^{1.8}Z^{-1/3} \tag{8}$$

where $\gamma = D_w \cos\alpha / d_m$, $f = r/D_w$, r is curvature radius of ring groove, D_w is ball diameter, the above operator is adapt to inner ring and the below to outer ring.

For the rotation ring relative to exerted load the equivalent load is

$$Q_{e\mu} = \left(\frac{1}{Z}\sum_{j=1}^{Z} Q_j^3\right)^{1/3} \tag{9}$$

where Q_j is contact load of balls. The fatigue life of rotating ring is

$$L_\mu = \left(\frac{Q_{c\mu}}{Q_{e\mu}}\right)^3 \tag{10}$$

For the stationary ring relative to exerted load the equivalent load is

$$Q_{e\nu} = \left(\frac{1}{Z}\sum_{j=1}^{Z} Q_j^{10/3}\right)^{0.3} \tag{11}$$

and the fatigue life of stationary ring is

$$L_\nu = \left(\frac{Q_{c\nu}}{Q_{e\nu}}\right)^3 \tag{12}$$

Like this, the rating life of bearing can be expressed as

$$L_{LP} = (L_\mu^{-1.11} + L_\nu^{-1.11})^{-0.9} \tag{13}$$

Example 1. A thrust ball bearing with data $\alpha = 90^\circ$, $D_w = 22.225mm$, $Z = 16$, $d_m = 140mm$, $f_i = f_e = 0.535$, $c_a = 142kN$ supports the axial load $F_a = 20kN$ and moment $M = 300kNmm$ and inner ring rotating. Determine the rating life L_{LP} and L_S.

The contact load distribution of balls can be obtained as follows by solving Eq.(6):

$\varphi(°)$	0	22.5	45	67.5	90	112.5	135	157.5	180
Q(N)	1804	1758	1629	1441	1230	1031	871	770	735

In the table only half number of balls are included because of symmetry. According to L-P method,

$$Q_{c\mu} = Q_{c\nu} = 10790N,\quad Q_{e\mu} = 1356N,\quad Q_{e\nu} = 1371N$$

$$L_\mu = 539.6,\quad L_\nu = 512.1,\quad L_{LP} = 279$$

And according to the Standard method (Eq.(1)) ,

$$c_a = 142kN,\quad P_a = F_a = 20kN,\quad L_S = 358$$

Obviously, L_S is 28% higher than L_{LP}. So that it is incorrect not to consider the influence of moment load in calculating bearing rating life.

IV. RELATIONSHIP BETWEEN MOMENT AND INCREMENT OF AXIAL LOAD

Let's consider the contact load of balls caused by moment only, it can be written as follows according to the moment equilibrium equation in Eq.(6) ,

$$M = Zd_m J Q_{\max}\sin\alpha \quad \text{or} \quad Q_{\max}\sin\alpha = \frac{4.37M}{Zd_m} \tag{14}$$

Where $Q_{\max} = K(0.5d_m\theta\sin\alpha)^{1.5}$

$J = \frac{1}{Z}\sum_{\phi=0}^{\pm\pi/2}(\cos\phi)^{2.5} = 0.2288$[5] when Z is large enough.

For the thrust ball bearing supported combined axial load and moment, it is always possible to find a axial equivalent load P_a' under which the bearing rating life is equal to that under combined loads. P_a' can be expressed as follows (see Fig. 3)

$$P_a' = F_a + \Delta F_a = F_a(1+\lambda) \tag{15}$$

where ΔF_a is an increment of axial load, it is equivalent to M in the meaning of bearing life and

$$\lambda = \Delta F_a / F_a \tag{16}$$

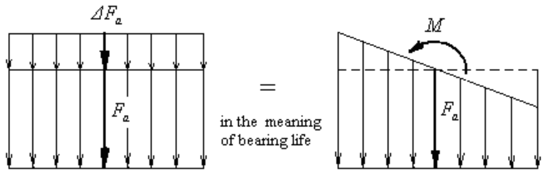


Fig. 3 Increment of axial load

It is reasonable to assume that the contact load caused by ΔF_a have similar relationship with Eq.(14), that is

$$\Delta F_a / Z \propto M/(Zd_m) \quad \text{or} \quad \lambda = \frac{\Delta F_a}{F_a} \propto \frac{M}{d_m F_a}$$

In order to determine the relationship, calculate the bearing life L_{LP} by L-P method and the parameter λ by Eq.(16) under various moment load. The results are showed in Table 1 and Fig 4.

TABLE1 CALCULATED RESULTS

$F_a(kN)$	$M(\times 10^5 Nmm)$	$L_{LP}(\times 10^6$	λ	$M/(d_m F_a)$
	1.5	337.3	0.020	0.054
20	3.0	279.0	0.087	0.107
	4.5	215.9	0.184	0.161
	6.0	162.9	0.300	0.214

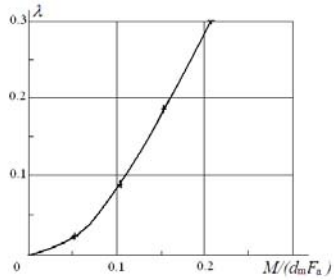


Fig. 4 Curve of $M/(d_m F_a)$ and λ

By means of curve-fitting we can get follows relationship

$$\lambda = 5.14\left(\frac{M}{d_m F_a}\right)^{1.84} \qquad (17)$$

Now the λ can be calculated by Eq.(17) when M and F_a are known and a new equivalent load P_a' can be gotten by Eq.(15) , finally a new ratting life L_S' will be obtained by Eq.(1) which includes the influence of moment load.

Example 2. For the bearing in Ex. 1, calculate its new ratting life L_S' and compare with L_{LP}. The calculating results are showed in table 2.

TABLE 2. CALCULATING RESULTS

$F_a(kN)$	$M(10^5 Nmm)$	$M/(d_m F_a)$	λ	$P_a'(kN)$	L_s'	L_{LP}	$\varepsilon(\%)$
	1.5	0.054	0.024	20.48	333.2	337.3	-1.2
20	3.0	0.107	0.084	21.68	281.0	279.0	0.7
	4.5	0.161	0.178	23.56	218.9	215.9	1.4
	6.0	0.214	0.301	26.02	162.5	162.9	-0.2

Example 3. A thrust ball bearing with data $\alpha = 60^\circ$, $D_w = 15.875mm$, $Z = 15$, $d_m = 85mm$, $f_i = f_e = 0.535$, $c_a = 142kN$ supports the axial load $F_a = 20kN$ and moment $M = 150kNmm$ and inner ring rotating. Determine the rating life L_{LP} and L_S'.

According to the condition above $M/(d_m F_a) = 0.088$, from Eq.(17) $\lambda = 0.059$, from Eq.(15) $P_a' = 21.18kN$, from Eq.(1) $L_s' = 34.2$.

According to the L-P method , $L_{LP} = 35.0$. The error between L_{LP} and L_S' is only 2.2%.

V.DISCUSSION

(1) The maximum load of ball determined by Eq.(14) must satisfy the condition as follows

$$Q_{max} \sin\alpha = \frac{4.37M}{Zd_m} \le \frac{F_a}{Z} \qquad (18)$$

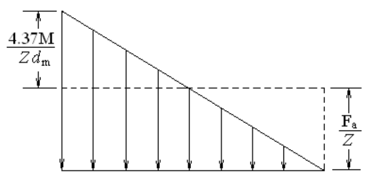


Fig. 5 Critical moment load

If take the equals sign in Eq.(18) a critical load condition of balls whill occur, in which one of the balls may be unloaded as showed as Fig. 5. If the Eq.(18) don't be satisfied there will be no load on some balls and this is not allowed for thrust ball bearing.

(2) It is not considered in the paper that the bearing

suppots combined loads of radial, axial and moment.

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