EVALUATION OF ARCHARD AND KIRK'S LUBRICANT FILM THICKNESS FOR 6007 BALL BEARING

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ABSTRACT

Rolling element bearings are one of the most essential parts of rotating machinery. The condition monitoring of rolling element bearing is very critical. Rolling element bearings rely on the formation of a separating oil film between surfaces having relative motion for their smooth operation and long life. The main purpose of lubrication is to enhance working life of bearing by reducing the friction between balls and races. Absence of this lubricant film is one of the most common reasons for bearing failure. In the present work the lubricant film thickness is calculated for variety of lubricants based on formula proposed by Archard and Kirk. The developed formula can be used for online condition monitoring of rolling element bearings with very simple and inexpensive measuring instruments.

Keywords: *Lubricant film thickness, rolling element bearing, ball bearing, oil viscosity, condition monitoring, online condition monitoring.*

INTRODUCTION

Lubrication of machine elements, such as gears or bearings, is essential for the proper functioning of a mechanical system. Separation of contacting elements is ensured by a lubricant film and helps avoiding metal-to-metal contact, which may otherwise damage the system and lead to its failure. Therefore estimation of the lubricant film thickness in such contacts is important and thus leads to a reliable design of the operating system. In the present work the film thickness is calculated for lubricants designated as A, B, C and D for ball bearing 6007 based on Archard and Kirk'sformula.

METHOD

The non-dimensional lubricant film thickness for ball bearing is proposed by Archard and Kirk's [2], which is givenby

$$H_0 = \frac{0.84\,(\gamma U')^{0.741}}{(Q')^{0.074}}$$

or

$$h_0 = \frac{0.84\,(\gamma U')^{0.741}}{(Q')^{0.074}}\ X\ R \qquad \text{(i)}$$

where,

H_0(dimensionless film thickness) = h_o / R

h_0(minimum film thickness in mm) = H_o x R

Υ*', U'* and *Q'* are dimensionless parameters as given below:

$$\gamma = \lambda E', \quad E' = \frac{E}{1-\nu^2}, \quad U' = \frac{\eta_0 U}{2E'R}, U = V_1 + V_2, \quad Q' = \frac{Q}{E'R^2}, \quad V_1 = \frac{\pi d_i N}{60}$$

$$\lambda = 0.1122\left(\frac{\nu_0}{10^4}\right)^{0.163}, \quad \nu_0 = 2.26X10^{-3}(SSU) - \frac{1.95}{SSU}$$

where,

λ – Pressure coefficient of viscosity inmm^2/N

ν – Poission's ratio = 0.3 (forsteel)

η_0 – Oil viscosity at atmospheric temperature in Ns/ mm^2

U – Entrainment velocity in mm/s

V_1– Velocity of inner race in mm/s, V_2– Velocity of inner race in mm/s Q

– Force acting on ball in N

E – Modulus of elasticity in N/mm^2 = 206900 N/mm^2 (for steel)

$$E' = \frac{E}{1-\nu^2} = 227363\ \text{N/mm}^2$$

The non dimensional film thickness thus can be calculated. In the present work, several lubricants are selected for analysis so that comparison can be made between them for validation of concept.

The lubricants which are selected are designated as A, B, C and D. The viscosities of these lubricants [3] for the calculation of film thickness are given in Table 1:

Table 1: Viscosities of the lubricants

Viscosity	Lubricant A	Lubricant B	Lubricant C	Lubricant D
$\eta_0$in cP	111.23	173	287	348.75
$\eta_0$in Ns/mm^2	111.23 x 10^{-9}	173 x 10^{-9}	287 x 10^{-9}	348.75 x 10^{-9}
SSU	581.23	800	1330	1708.525

Useful dimensions of bearing 6007

R_i – Equivalent contact radius of inner race = 3.505 mm

R_o – Equivalent contact radius of outer race = 4.994 mm

d_i – Contact diameter of inner race = 40mm

ANALYSIS ANDCALCULATIONS

Numerical analysis and calculations are done for a single lubricant say A. Similar to the values of parameters calculated for lubricant A, values of parameters for other lubricants (B, C, andD) are also calculated which are not shown in the paper. The total lubricant film thickness for all the lubricants is shown in Table2.

Lubricant A

$$\nu_0)_A = 2.26X10^{-3}(581.23) - \frac{1.95}{581.23} \quad = 1.31022$$

$$\lambda)_A = 0.1122\left(\frac{1.31022}{10^4}\right)^{0.163} \quad = 0.026128$$

$$\gamma)_A = 0.026128\ X\ 227363 \quad = 5940.73$$

$$U')_A = \frac{111.23X10^{-9}\ \frac{\pi d_i N}{60}}{2\ X\ 227363\ X\ R} \quad = 1.28076X10^{-14}\ \frac{d_i N}{R}$$

$$(\gamma U')_A = 5940.73\ X\ 1.28076X10^{-14}\ \frac{d_i N}{R} \quad = 7.6086X10^{-11}\ \frac{d_i N}{R}$$

$$Q')_A = \frac{Q}{227363\ X\ R^2} \quad = 4.3982X10^{-6}\ \frac{Q}{R^2}$$

For contact of ball with inner race, equation (i) is written as:

$$h_0)_{i(A)} = \frac{0.84\ (\gamma U')^{0.741}}{(Q')^{0.074}}\ X\ R_i$$

After substituting the values of different parameters, we get

$$h_0)_{i(A)} = 6.6485X10^{-8}\ \frac{(R_i)^{0.407}(d_i)^{0.741}(N)^{0.741}}{(Q)^{0.074}}\ mm$$

Similarly, for contact of ball with outer race, equation (i) is written as:

$$h_0)_{o(A)} = 6.6485X10^{-8}\ \frac{(R_i)^{0.407}(d_i)^{0.741}(N)^{0.741}}{(Q)^{0.074}}\ mm$$

Total lubricant film thickness, is therefore

$$h_0)_{T(A)} = h_0)_{i(A)} + h_0)_{o(A)}$$

$$= 6.6485X10^{-8}\ ((R_i)^{0.407} + (R_0)^{0.407})\frac{(d_i)^{0.741}(N)^{0.741}}{(Q)^{0.074}}\ mm$$

Substituting the values of R_i, $R_0$and $d_i$for bearing 6007, we get, total lubricant film thickness as:

$$h_0)_{T(A)} = 3.6726X10^{-6} \frac{(N)^{0.741}}{(Q)^{0.074}} mm$$

Similarly, formula for total lubricant film thickness is derived for lubricant B, C and D.

RESULT

It is clearly seen from the derived formula that Archard and Kirk's lubricant film thickness is directly proportional to speed and inversely proportional to load. The film thickness calculated for lubricant A, B, C and D is tabulated in Table 2.

Table 2: Total Lubricant Film Thickness

Lubricant	η_0 in cP	SSU	$h_0)_T$ in mm
A	111.23	581.23	$3.6726X10^{-6} \frac{(N)^{0.741}}{(Q)^{0.074}}$
B	173	800	$5.295X10^{-6} \frac{(N)^{0.741}}{(Q)^{0.074}}$
C	287	1330	$8.1944X10^{-6} \frac{(N)^{0.741}}{(Q)^{0.074}}$
D	348.75	1708.525	$9.7588X10^{-6} \frac{(N)^{0.741}}{(Q)^{0.074}}$

CONCLUSION

The total lubricant film thickness increases with viscosity of lubricant. Also the lubricant film thickness increases with increase in speed and decreases with increase in load. This is in-line with classical theory of lubrication [1]. The lubricant film thickness is function of speed and load on bearing. The method can be directly used for online condition monitoring of rolling element bearings with inexpensive instruments as speed and load can be easily measured during operation.

A feedback control system can be used for continuous monitoring of lubricant film thickness with speed as controllingparameter.

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