ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

ANALYTICAL ELASTOHYDRODYNAMIC LUBRICANT FILM THICKNESS FOR BALL BEARINGS 6007, 6207, 6307 & 6407 USING HERTZ CONTACT THEORY

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DOI: 10.5281/zenodo.160862

ABSTRACT
Elastohydrodynamic lubrication is the phenomenon that occurs when a lubricant is introduced between surfaces that are in rolling contact such as rolling bearing. Elastohydrodynamic lubrication (EHL) is an important branch of the lubrication theory, describing lubrication mechanisms in non conformal contacts widely found in many mechanical components such as various gears, rolling bearings, cams and followers, metal-rolling tools, traction drives, and continuous variable transmissions. In present work, the elastohydrodynamic (EHD) lubricant film thicknesses for bearings 6007, 6207, 6307 and 6407 are calculated by the formula based on Hertz's contact theory. The developed formula along with inexpensive measuring instruments can be used for online condition monitoring of rolling element bearings.

KEYWORDS: Elastohydrodynamic lubrication (EHL), Elastohydrodynamic (EHD), lubricant film thickness, online condition monitoring, rolling elements bearing.

INTRODUCTION
The flow of lubricant in the rolling element bearing plays an important role to reduce the friction. It is essential to maintain the lubricant film between the ball and races of the bearing for enhanced life. Hertz [1-3] derived an analytical model for concentrated contact between two isotropic, homogeneous, linear elastic solids with smooth surfaces. When the solids are pressed together with a force Q directed normal to the surfaces, an approximately elliptic or circular contact area is formed. In the present work circular contact area is assumed and the related contact radius is calculated. This is further used to evaluate the EHD lubricant film thickness. Many methods have been used by the researcher in the past to calculate the lubricant film thickness are expensive, so an inexpensive method have been developed by Matharu et.al. [4-6]. In this work, the bearing 6007, 6207, 6307 & 6407 are taken for the calculation of contact radius and area. Further it is used for evaluation of EHD lubricant film thickness.

METHODOLOGY

The contact radius, effective radius and the effective contact modulus is calculated by the Hertz contact theory of elastic circular contact [1-3]:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}, \qquad \frac{1}{E'} = k_1 + k_2 \qquad \& \qquad a = \left[\frac{3QR}{4\,E'}\right]^{1/3} \tag{1}$$

Where,

$$k_1 = \frac{1-{\nu_1}^2}{E_1} \qquad \& \qquad k_2 = \frac{1-{\nu_2}^2}{E_2}$$

Applying this theory for rolling element bearing, we have

$$a_i = \left[\frac{3Q(k_1+k_2)r_i r}{4(r_i + r)}\right]^{1/3} \qquad \& \qquad a_o = \left[\frac{3Q(k_1+k_2)r_o r}{4(r_o - r)}\right]^{1/3} \tag{2}$$

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Now, considering the bearing resistance between the ball and races of the bearing

$$R_{IR} = \frac{\rho\, h_o}{a_1} \qquad \& \qquad R_{OR} = \frac{\rho\, h_o}{a_2} \tag{3}$$

where

$$a_1 = \pi(a_i)^2 \qquad \& \qquad a_2 = \pi(a_o)^2 \tag{4}$$

Now, Total bearing resistance

$$R_T = R_{IR} + R_{OR} \tag{5}$$

Now, by equation 3, 4 & 5, we have

$$R_T = \frac{(a_1 + a_2)}{(a_1 a_2)}\, \rho\, (h_o)_T$$

So, EHD lubricant film thickness is given by

$$(h_o)_T = \frac{a_1\, a_2}{(a_1 + a_2)} \frac{R_T}{\rho} \tag{6}$$

In Table.1 useful dimensions for the bearings 6007, 6207, 6307 & 6407 are given, which have been used for the calculation of EHD lubricant film thickness.

Table 1: Useful dimensions of bearing

BEARING	r_i	r_o	r
6007	20	28.5	4.25
6207	21	32.5	5.75
6307	22	35.5	6.75
6407	23	44.5	10.75

ANALYSIS & CALCULATION

Analysis and calculations for ball bearing 6007 are shown. Values of parameters for ball bearing 6207, 6307 and 6407 are also calculated similar to the calculations for 6007, which are not shown in the paper. The total lubricant film thickness for all above bearings are shown in Table 2.

Bearing 6007

$$a_i = \left[\frac{3Q(k_1 + k_2) r_i r}{4(r_i + r)}\right]^{1/3} = \left[\frac{3Q(4.398\, X\, 10^{-6} + 4.398\, X\, 10^{-6})20\, X\, 4.25}{4(20 + 4.25)}\right]^{1/3} = 0.0285\, [Q]^{\frac{1}{3}}$$

$$a_o = \left[\frac{3Q(k_1 + k_2) r_o r}{4(r_o - r)}\right]^{1/3} = \left[\frac{3Q(4.398\, X\, 10^{-6} + 4.398\, X\, 10^{-6})28.5\, X\, 4.25}{4(28.5 + 4.25)}\right]^{1/3} = 0.0321\, [Q]^{\frac{1}{3}}$$

$$a_1 = \pi(0.0285)^2\, [Q]^{\frac{2}{3}} = 0.00255\, [Q]^{\frac{2}{3}}$$
$$a_2 = \pi(0.0321)^2\, [Q]^{\frac{2}{3}} = 0.00323\, [Q]^{\frac{2}{3}}$$

$$(h_o)_T = \frac{0.00255\, [Q]^{\frac{2}{3}}\, X\, 0.00323\, [Q]^{\frac{2}{3}}}{\left(0.00255\, [Q]^{\frac{2}{3}} + 0.00323\, [Q]^{\frac{2}{3}}\right)} \frac{R_T}{\rho} = 0.00142\, \frac{Q^{2/3}\, R_T}{\rho}$$

Similarly, formula for total EHD lubricant film thickness is derived for ball bearing 6207, 6307 and 6407.

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RESULTS AND DISCUSSION

It is clearly seen from the derived formula that EHD lubricant film thickness is directly proportional to load and bearing resistance and inversely proportional to resistivity of the lubricant. The film thickness calculated for bearing 6207, 6307 and 6407 are tabulated in Table 2.

Table 2 : EHD lubricant film thickness and other parameters

PARAMETER	$(h_o)_T$ in mm			
	6007	**6207**	**6307**	**6407**
a_i	0.0285 x $Q^{1/3}$	0.0310 x $Q^{1/3}$	0.324 x $Q^{1/3}$	0.0364 x $Q^{1/3}$
a_o	0.0321 x $Q^{1/3}$	0.0359 x $Q^{1/3}$	0.380 x $Q^{1/3}$	0.0454 x $Q^{1/3}$
a_1	0.00255 x $Q^{2/3}$	0.00302 x $Q^{2/3}$	0.00330 x $Q^{2/3}$	0.00417 x $Q^{2/3}$
a_2	0.00323 x $Q^{2/3}$	0.00404 x $Q^{2/3}$	0.00454 x $Q^{2/3}$	0.00647 x $Q^{2/3}$
$(h_o)_T$	$0.00142\ X\ \frac{Q^{2/3}\ R_T}{\rho}$	$0.00173\ X\ \frac{Q^{2/3}\ R_T}{\rho}$	$0.00191\ X\ \frac{Q^{2/3}\ R_T}{\rho}$	$0.00254\ X\ \frac{Q^{2/3}\ R_T}{\rho}$

CONCLUSION

EHD lubricant film thickness is function of bearing resistance, resistivity of the lubricant and load on bearing. The lubricant film thickness increases with increase in load and bearing resistance and decreases with increase in resistivity of the lubricant.

The total EHD lubricant film thickness increases as the bearing number increases. Larger the size of the bearing, larger will be diameter of balls with more elastohydrodynamic contact area. The larger balls entrap more lubricant than smaller balls to take up more load.

The method can be directly used for online condition monitoring of rolling element bearings with the help of resistivity and bearing resistance measuring instruments and load can be easily measured during operation.

It is found that the formula proposed by the Hertz is dependent of experimental data. So that the lubricant film thickness can also be calculated experimentally.

NOMENCLATURE

R_T	- Total bearing resistance in Ω
R_{IR}	- Minimum resistance between the ball and inner race in Ω
R_{OR}	- Minimum resistance between the ball and outer race in Ω
ρ	- Resistivity of lubricant in Ω mm
$(h_o)_T$	- Elastohydrodynamic lubricant film thickness
a_i	- Radius of deformation between inner race and ball (mm)
a_o	- Radius of deformation between outer race and ball (mm)
a_1 and a_2	- Contact area (mm^2)
r_i	- Outer radius of inner race (mm)
r_o	- Inner radius of outer race (mm)
r	- Radius of ball (mm)
k_1, k_2	- Constant = $4.398X10^{-6}$ mm^2/N
ν_1 , ν_2	- Poission's ratio for the material of ball & race ($\nu_1 = \nu_2 = 0.3$)
E_1, E_2	- Modulus of elasticity for the material of ball & race ($E_1 = E_2 = 206900$ N/mm^2)
E'	- Effective contact modulus (N/mm^2)

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