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Archard and Kirk's Lubricant Film Thickness for Deep Groove Ball Bearings 6008, 6208, and 6308 using Engine Lubricants

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***Abstract* — The service life of a machine can be seriously affected, decreasing its overall performance, if there is any defect, during operation, in the bearings of that machine. And if the machine is of rotating type, then Rolling Element Bearings becomes its most essential parts. One of the major defects arises due to the insufficient lubricant between the rolling elements of a bearing, which leads to the early failure of the bearings. In the present paper, the lubricant film thickness for the deep groove ball bearings of 6008, 6208, and 6308 series, is calculated for different engine lubricants, based on the theory proposed by Archard and Kirk. An on-line condition monitoring of the rolling element bearing can be carried out by using the developed formula (proposed by Archard and Kirk) along with inexpensive measuring instruments.**

Keywords – On-line condition monitoring, deep groove ball bearings, minimum lubricant film thickness, friction, rolling elements bearings, expected service life.

I. INTRODUCTION

In order to avoid metal to metal contact between the rolling elements of a bearing, a lubricant film, which separates the rolling elements of a bearing should be there, to prevent the damage of the bearing as well as the total failure of the associated large system. Appropriate lubrication of the rolling element bearings is necessary for the proper functioning of the machine. Hence in order to ensure smooth functioning of the machine, a sufficient amount of the lubrication is a must for the rolling element bearings. Thus, the estimation of the minimum lubricant film thickness is essential for optimum performance of the rolling element bearings. Therefore, the present work deals with the determination of the minimum lubricant film thickness for the deep groove ball bearings of series 6008, 6208, and 6308, with the engine lubricants designated as A, & B, based on the formula developed by Archard and Kirk.

II. METHODOLOGY

Archard and Kirk [1] proposed the non-dimensional minimum lubricant film thickness for ball bearing,

as,

$$H_0 = \frac{0.84(\gamma U^{'})^{0.741}}{(Q^{'})^{0.074}}, \qquad (1)$$

$$or, h_0 = \frac{0.84(\gamma U^{'})^{0.741}}{(Q^{'})^{0.074}} xR_i$$

Where,
H_0 = Non-dimensional lubricant film thickness = h_0/R,
h_0 = minimum lubricant film thickness (mm) = $H_0 x R$,
γ, $U^{'}$, $Q^{'}$ are the dimensionless parameters, which are given as below,
$\gamma = \lambda E^{'}$; $E^{'} = E/(1-\nu^2)$; $U^{'} = \eta_0 U/ 2E^{'}R$; $U = U_1 + U_2$; $U_1 = \pi d_i N/60$; $U_2 = 0$; $Q^{'} = Q/E^{'}R^2$;
$\lambda = 0.1122 (\nu_0/10^4)^{0.163}$;
Where,
λ = Pressure coefficient of viscosity, mm^2/N,
For steel, Poisson's ratio, $\nu = 0.3$, and $E = 206900\ N/mm^2$,
η_0 = Oil viscosity at atmospheric pressure, $N\text{-}s/mm^2$,
U = Entrainment velocity, mm/s,
U_1 = Entrainment velocity of Inner race, mm/s; U2 = Entrainment velocity of Outer race, mm/s,
Q = Force/ load acting on the balls, N
$E^{'} = E/(1-\nu^2)$ = Equivalent modulus of Elasticity = 227363 N/mm^2,

Thus, after the determination of the above said parameters, and the bearing dimensions, and for the known lubricant, the dimensionless lubricant film thickness can be obtained from equation no.(1). In the present work, the determination of the minimum lubricant film thickness is done for different engine lubricants, which are designated as A, & B.

The Viscosities of these lubricants [3] & [4], for the calculations of the lubricant film thickness is given in Table 1.

Table 1: Viscosities of the Lubricants A, & B.

Viscosity	Lubricant A	Lubricant B
η_0 (in cP)	69.96	111.2298
η_0 (in $N\text{-}s/mm^2$)	69.96×10^{-9}	111.2298×10^{-9}
υ_o (cSt)	79.5	125.4

The Bearing parameters/dimensions used in the analysis, for the deep groove ball bearings 6008, 6208, & 6308 is given in Table 2.

Table 2: Bearing Dimensions for different series of deep groove ball bearings.

Deep Groove Ball bearing	R_i (in mm)	R_o (in mm)	d_i (in mm)
6008 series	3.75	5.25	45
6208 series	5.091	7.908	47
6308 series	6.0307	9.9692	49

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Where,
R_i = Equivalent contact Radius of Inner Race,
R_o = Equivalent Contact Radius of Outer Race,
d_i = Contact diameter of Inner Race.

III. ESTIMATION AND ANALYSIS FOR LUBRICANT FILM THICKNESS

Estimation for the minimum lubricant film thickness for the deep groove ball bearing 6008, with the lubricant A is shown below. And in the similar way the calculations for the lubricant B, is performed by taking the bearing dimensions of 6008, 6208, & 6308 series deep groove ball bearings, which are not shown in this paper. Finally, the minimum lubricant film thickness for the lubricants A, & B, with the bearing dimensions of the ball bearing 6008,6208, and 6308, is tabulated in Table 3.

For Lubricant A,

$$\nu_{0,(A)} = 0.795 cm^2/s,$$

$$\lambda_{(A)} = 0.1122\left(\frac{0.795}{10^4}\right)^{0.163} = 0.214664 mm^2/N,$$

$$\gamma_{(A)} = 0.214664x227363 = 48806.72119,$$

$$U'_{(A)} = \frac{(69.96x10^{-9})\left(\frac{\Pi d_i N}{60}\right)}{(2x227363xR)} = 8.055613x10^{-15}\left(\frac{d_i N}{R}\right),$$

$$(\gamma.U')_{(A)} = 48806.72119x8.055613x10^{-15}\left(\frac{d_i N}{R}\right) = 3.93168x10^{-10}\left(\frac{d_i N}{R}\right)$$

$$Q'_{(A)} = \frac{Q}{(227363xR^2)} = 4.398253x10^{-6}\left(\frac{Q}{R^2}\right),$$

On substituting these values in equation no. (1), the minimum lubricant film thickness for the contact of ball elements with the Inner race is given as,

$$h_{0,i(A)} = \frac{0.84(\gamma U')^{0.741}}{(Q')^{0.074}} x R_i$$

$$h_{0,i(A)} = 2.2452203x10^{-7}\left(\frac{d_i^{0.741} x N^{0.741} x R_i^{0.407}}{Q^{0.074}}\right)(mm)$$

Similarly, the minimum lubricant film thickness for the contact of ball elements with the Outer race is,

$$h_{0,0(A)} = 2.2452203x10^{-7}\left(\frac{d_i^{0.741} x N^{0.741} x R_0^{0.407}}{Q^{0.074}}\right)(mm)$$

Hence, the total lubricant film thickness, will be,

$$h_{0,T(A)} = h_{0,i(A)} + h_{0,0(A)}$$

$$h_{0,T(A)} = 2.2452203x10^{-7}(R_i^{0.407} + R_0^{0.407})\left(\frac{d_i^{0.741} x N^{0.741}}{Q^{0.074}}\right)(mm)$$

Thus, after substituting the values of bearing dimensions for the ball bearing 6008 series,
we get,

$$h_{0,T(A)} = 1.385812x10^{-5}\left(\frac{N^{0.741}}{Q^{0.074}}\right)(mm) \quad (2)$$

This is the relationship for the total lubricant film thickness while taking the lubricant A, and the deep groove ball bearing 6008. And a similar derivation is carried out for the lubricant B, with the ball bearing 6008, and subsequently for the ball bearing series 6208 and 6308.

IV. RESULT

On observing the equation no. (2), it is concluded that the lubricant film thickness is directly proportional to the bearing speed, but inversely proportional to the load acting on the bearing. The total lubricant film thickness is calculated for the engine lubricants A, & B, with the deep groove ball bearings 6008, 6208, 6308, and is shown in Table-3

Table 3: Total lubricant film thickness for lubricants A, & B.

Deep Groove Ball Bearing	Lubricants	η_0 (in cp)	υ_o (cSt)	$h_{0,T}$ (in mm)
6008	A	69.96	79.5	$h_{0,T(A)} = 1.385812x10^{-5}\left(\frac{N^{0.741}}{Q^{0.074}}\right)$
6208	A	69.96	79.5	$h_{0,T(A)} = 1.658235x10^{-5}\left(\frac{N^{0.741}}{Q^{0.074}}\right)$
6308	A	69.96	79.5	$h_{0,T(A)} = 1.857908x10^{-5}\left(\frac{N^{0.741}}{Q^{0.074}}\right)$
6008	B	111.2298	125.4	$h_{0,T(B)} = 4.081907x10^{-6}\left(\frac{N^{0.741}}{Q^{0.074}}\right)$
6208	B	111.2298	125.4	$h_{0,T(B)} = 4.884329x10^{-6}\left(\frac{N^{0.741}}{Q^{0.074}}\right)$
6308	B	111.2298	125.4	$h_{0,T(B)} = 5.472466x10^{-6}\left(\frac{N^{0.741}}{Q^{0.074}}\right)$

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V. CONCLUSIONS

From the above analysis it may be concluded that the lubricant film thickness is a function of bearing speed and load acting on the bearing [5]. The lubricant film thickness increases with the bearing speed and decreases with the load acting on the bearing. And this is in-line with the classical theory of lubrication [2]. It can be seen that with the increase in lubricant viscosity the total lubricant film thickness for the bearings 6008, 6208, and 6308 also increases. It may be further noted that the lubricant film thickness for the bearing 6308 is more than that of the bearings 6008 and 6208 for the same lubricant. As larger the size of the bearings, the larger will be the balls size (rolling elements) with more elastohydrodynamic contact area. The larger balls will have more lubricant entrapped than that with smaller balls to take-up more loads. This validates the values obtained for the bearings with different engine lubricants.

Hence, the above method can be linked directly with the inexpensive instruments [6] for the on-line condition monitoring of the rolling elements bearing, since the speed and load can be readily measured during the operation.

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