

Lubrication Analysis of Floating Ring Bearings Considering Floating Ring Heat Transfer

Jiaqi Li, Jimin Ni, and Qiwei Wang
Tongji University

ABSTRACT

Turbochargers improve performance in internal combustion engines. Due to low production costs, TC assemblies are supported on floating ring bearings. In current lubrication analysis of floating ring bearing, inner and outer oil film are usually supposed to be adiabatic. The heat generated by frictional power is carried out by the lubricant flow. In reality, under real operating conditions, there existed heat transfer between the inner and outer film. In this paper, the lubrication performance of floating ring bearing when considering heat transfer between inner film and outer film is studied. The lubrication model of the floating ring is established and the heat transferred through the ring between the inner and outer film is calculated. The calculation results show that heat flow between the inner and outer film under different outer film eccentricity ratio and rotate ratio has a large difference. The rotate speed also has an obvious effect on the lubrication of the floating ring bearing. When heat transfer of the floating ring is considered, lubrication performance is changed obviously. There is a good agreement between the results predicted by the calculation model in this paper and some of the published experimental data.

CITATION: Li, J., Ni, J., and Wang, Q., "Lubrication Analysis of Floating Ring Bearings Considering Floating Ring Heat Transfer," *SAE Int. J. Fuels Lubr.* 9(1):2016, doi:10.4271/2016-01-0485.

INTRODUCTION

The floating ring bearing is an important part in the turbocharger which will directly affect the operational reliability and durability. Some researchers have studied the floating ring bearing. Orcutt[1] and Mokhtar[2] observed a floating bearing can decrease the frictional power loss. Trippett[3] found experimentally that ring speed ratios decrease dramatically as shaft speed rises. Clark[4] established a thermal model of floating ring under heavy load. The influence of film rupture to the frictional moment was studied by Koenke[5]. Hatakennaka[6] considered the effect of centrifugal force to the floating ring bearing. Andres[7,8] studied the lubrication performance of floating ring bearing at a given load and gained experimental the ring speed ratio versus the rotate speed in different inlet pressures. The effects of inlet port's type, oil aeration level and shaft speed on the performance of high speed turbocharger bearing were researched by Chun[9]. Dong[10] studied the effect of stability of floating bearing with the variance of floating ring thickness. Deligant[11] used 3D CFD to analyze the floating ring and found the reduction of the power loss with the changed oil viscosity. Shi [12] studied the effect of different structure size on power loss of the floating ring bearing and semi-floating ring bearing. Guo[13,14] calculated the static and dynamic state performance of the floating ring bearing under different flow state. Andres[15] analyzed the thermohydrodynamic performance of a floating ring bearing. The starved lubricating characteristics of the floating ring bearing on JFO condition was analyzed by ZHANG[16]. ZHANG[17] studied the dynamic effects of system parameters on speed ratio of the floating ring bearing.

However, the lubrication analyses of floating ring bearings were conducted under many given preconditions. For example, the inner and outer film were studied individually with a given load; the influence of the different load was not considered; only the load balance of the floating ring was considered in some papers and the floating ring heat transfer was not considered. And the inner film heat distribution under different working condition was also not gained. The lubrication performance of floating ring bearing with the outer film eccentricity ratio was not studied. Neglecting the floating ring heat transfer will cause the deviation of the inner and outer film temperature increase between the analyzing results and actual situation. The analysis is not comprehensive without considering the change of the outer film eccentricity ratio. In the actual operation of the floating ring, a portion of the heat converted by the frictional power dissipation of the inner film(or the outer film) is carried away by the lubricant flow rate, and the other portion is transferred to the outer film(or inner film) through the floating ring. Meanwhile, the lubricant flow of the outer film (or the inner film) carries away all the heat not only absorbed from the other film but also generated by its friction. Thus, the inner film, floating ring and outer film constitute a heat-transfer system. On the other side, the floating ring heat transfer maybe different under the different outer film eccentricity ratios and rotate speeds.

In this paper, the research object is a certain floating ring bearing in a turbocharger. Based on the heat balance and load balance of the floating ring, the lubrication performances of the floating ring bearing under different outer film eccentricity ratios and rotate speeds are analyzed when considering floating ring heat transfer.

MODEL

Floating Ring Balance Model

The floating ring bearing is the bearing within two films. The lubricant film between the outer surface of the floating ring and bearing block is the outer film. The lubricant film between the inner surface of the floating ring and journal is the inner film. It operates based on the heat balance equation and the load balance equation. Fig. 1 shows the schematic view of a floating ring.

Heat Balance Equation

Because the temperature increases in the journal and bearing block are approximately $\Delta T_j \approx \Delta T_i$ and $\Delta T_b \approx \Delta T_o$ (ΔT_j , ΔT_b are the journal and block temperature increases, respectively), so not only the heat transfer from the journal to the inner film but also the heat transfer from the outer film to the bearing block are neglected for brevity in this article. (see reference [7] for details).

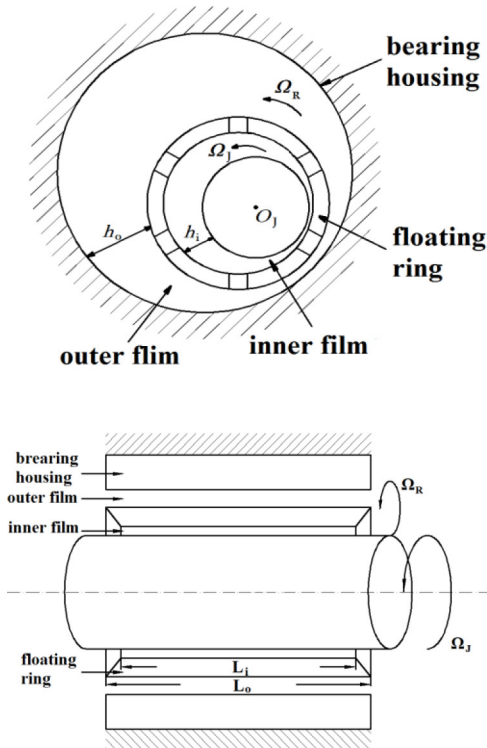


Fig 1. Schematic view of a floating ring bearing

The quantity of heat absorbed by the floating ring from the inner film is equal to that transferred to the outer film from the floating ring when the inner film temperature is higher than the outer film temperature. The heat balance equation is given below

$$A_{R_i} H_{R_i} (\Delta T_R - \Delta T_i) = A_{R_o} H_{R_o} (\Delta T_o - \Delta T_R) \quad (1a)$$

The quantity of heat absorbed from the outer film is equal to that transferred to the inner film when the outer film temperature is higher than the inner film temperature. The heat balance equation can be given by

$$A_{R_i} H_{R_i} (\Delta T_i - \Delta T_R) = A_{R_o} H_{R_o} (\Delta T_R - \Delta T_o) \quad (1b)$$

where A_{R_i} , A_{R_o} are the inner and outer film areas for heat transfer, ΔT_i , ΔT_o are the inner and outer temperature increases, ΔT_R is the floating ring temperature increase, H_{R_i} , H_{R_o} are the inner and outer heat convection coefficient, $H = 3 Pr^{\frac{1}{2}} (K/c)$ [7] and Pr is Prandtl number, $Pr = c_p \mu / K$, c_p is the specific heat of lubricant, K is the thermal conductivity of lubricant, $c_{i,o}$ is the inner or outer radial clearance of the floating ring, $\mu_{i,o}$ is the inner or outer viscosity.

Load Balance Equation

When the floating ring is stable in operation, the inner and outer film force acting on the floating ring are equal and the directions of the inner and outer film force are opposite (the film force acting on the floating ring by the inner film is vertically down in this paper). Thus, the hydrodynamic pressures generated within each film determine the inner and outer film forces, F_i , F_o , i.e.

$$F_i = F_o \quad (2a)$$

$$\begin{Bmatrix} F_{iX} \\ F_{iY} \end{Bmatrix} = \int_0^{L_i} \int_0^{2\pi} p_i \begin{Bmatrix} \cos\theta \\ \sin\theta \end{Bmatrix} R_i d\theta dz \quad (2b)$$

$$\begin{Bmatrix} F_{oX} \\ F_{oY} \end{Bmatrix} = \int_0^{L_o} \int_0^{2\pi} p_o \begin{Bmatrix} \cos\theta \\ \sin\theta \end{Bmatrix} R_o d\theta dz \quad (2c)$$

$$F_i = \sqrt{F_{iX}^2 + F_{iY}^2} \quad (2d)$$

$$F_o = \sqrt{F_{oX}^2 + F_{oY}^2} \quad (2e)$$

where F_{iX} , F_{oX} , F_{iY} , F_{oY} are the inner and outer load components at x and z coordinates, respectively, R_i , R_o are the inner and outer radius, p_i , p_o are the inner and outer oil film pressure. The inner film drag torque is equal to the outer film drag torque. The equation is

$$T_i = T_o \quad (3a)$$

$$\Gamma_i = \int_0^{L_i} \int_0^{2\pi} \left\{ -\frac{h_i}{2} \frac{\partial p_i}{R_i \partial \theta} + \frac{\mu_i}{h_i} (\Omega_J - \Omega_R) R_i \right\} R_i^2 d\theta dz \quad (3b)$$

$$\Gamma_o = \int_0^{L_o} \int_0^{2\pi} \left\{ \frac{h_o}{2} \frac{\partial p_o}{R_o \partial \theta} + \frac{\mu_o}{h_o} \Omega_R R_o \right\} R_o^2 d\theta dz \quad (3c)$$

where Γ_i, Γ_o are the inner and outer drag torques, h_i, h_o are the inner and outer film thicknesses, μ_i, μ_o are the inner and outer viscosities and Ω_J, Ω_R are the journal and ring rotational speeds, respectively.

Hydrodynamic Lubrication Model

1. Reynolds Equation

The Reynolds equation describes the inner and outer film hydrodynamic pressures, p_i and p_o , i.e.

$$\begin{aligned} \frac{\partial}{R_i^2 \partial \theta} \left(\frac{h_i^3}{12\mu_i} \frac{\partial p_i}{\partial \theta} \right) + \frac{\partial}{\partial z} \left(\frac{h_i^3}{12\mu_i} \frac{\partial p_i}{\partial z} \right) \\ = \frac{R_J \Omega_J + R_i \Omega_R}{2} \frac{\partial h_i}{R_i \partial \theta} \end{aligned} \quad (4a)$$

$$\begin{aligned} \frac{\partial}{R_o^2 \partial \theta} \left(\frac{h_o^3}{12\mu_o} \frac{\partial p_o}{\partial \theta} \right) + \frac{\partial}{\partial z} \left(\frac{h_o^3}{12\mu_o} \frac{\partial p_o}{\partial z} \right) \\ = \frac{R_o \Omega_R}{2} \frac{\partial h_o}{R_o \partial \theta} \end{aligned} \quad (4b)$$

where R_J represents the journal radius.

2. Inner and Outer Film Thickness Equation

$$h_i = c_i + e_i \cos(\theta - \varphi_i) \quad (5a)$$

$$h_o = c_o + e_o \cos(\theta - \varphi_o) \quad (5b)$$

where c_i, c_o are the inner and outer film clearances, e_i, e_o are the inner and outer film eccentric distances, φ_i, φ_o are the inner and outer attitude angles.

3. Oil Viscosity-Temperature Relationship

Vogel's equation is used to describe the variation in oil viscosity with temperature. For CD30 oil, Vogel's equation is [18]

$$\mu = 0.507610^{-3} \times \exp[3434.6 / (T - 22.29)] \quad (6)$$

where T is the temperature.

4. Frictional Power Consumption Equation

$$\begin{aligned} W_i = \int_0^{L_i} \int_0^{2\pi} \left\{ \frac{h_i^3}{12\mu_i} \left[\left(\frac{\partial p_i}{R_i \partial \theta} \right)^2 + \left(\frac{\partial p_i}{\partial z} \right)^2 \right] \right. \\ \left. + \frac{\mu_i}{h_i} (\Omega_J - \Omega_R)^2 R_i^2 \right\} R_i d\theta dz \end{aligned} \quad (7a)$$

$$\begin{aligned} W_o = \int_0^{L_o} \int_0^{2\pi} \left\{ \frac{h_o^3}{12\mu_o} \left[\left(\frac{\partial p_o}{R_o \partial \theta} \right)^2 + \left(\frac{\partial p_o}{\partial z} \right)^2 \right] \right. \\ \left. + \frac{\mu_o}{h_o} (\Omega_R)^2 R_o^2 \right\} R_o d\theta dz \end{aligned} \quad (7b)$$

where W_i, W_o represent the frictional power consumption in the inner and outer film.

5. Lubricant End-Leakage Flow Rate Equation

$$Q_{i1} = \int_0^{2\pi} \left[-\frac{h_i^3}{12\mu_i} \frac{\partial p_i}{\partial z} \right]_{z=0} R_i d\theta \quad (8a)$$

$$Q_{i2} = \int_0^{2\pi} \left[-\frac{h_i^3}{12\mu_i} \frac{\partial p_i}{\partial z} \right]_{z=L_i} R_i d\theta \quad (8b)$$

$$Q_i = |Q_{i1}| + |Q_{i2}| \quad (8c)$$

$$Q_{o1} = \int_0^{2\pi} \left[-\frac{h_o^3}{12\mu_o} \frac{\partial p_o}{\partial z} \right]_{z=0} R_o d\theta \quad (8d)$$

$$Q_{o2} = \int_0^{2\pi} \left[-\frac{h_o^3}{12\mu_o} \frac{\partial p_o}{\partial z} \right]_{z=L_o} R_o d\theta \quad (8e)$$

$$Q_o = |Q_{o1}| + |Q_{o2}| \quad (8f)$$

where Q_{i1} and Q_{i2} are respectively the lubricant flow rates from the front-end plane and rear-end plane of the floating ring bearing in the inner film, Q_{o1} and Q_{o2} are respectively the lubricant flow rates from the front-end plane and rear-end plane of the floating ring bearing in the outer film, Q_i and Q_o are the total end leakage flow rates of the lubricant in the inner and outer film.

Heat Distribution Model

One part of the heat converted from the frictional power consumption in the inner film is carried away by the inner film lubricant flow rate, and the other part is transferred to the outer film through the floating ring when ΔT_i is higher than ΔT_o . The relative equations are as follows: