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COMPREHENSIVE ANALYSIS OF LOAD CAPACITY IN FINITE JOURNAL BEARINGS

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Abstract: This study investigates the influence of additives on lubrication, taking into account viscosity changes and temperature effects, as published in the journal Finite Journal. A generalized Reynolds equation for a two-layer fluid is formulated and applied to finite journal bearings. The Finite Difference Method is employed to numerically solve the modified Reynolds equation for finite journal bearings. It is observed that both pressure and load capacity during the lubrication process increase with the growing impact of temperature on two-layer fluids.

Keywords: Viscosity, eccentricity, film thickness, thermal effect, and finite journal bearing.

INTRODUCTION:

In lubricated systems, typically comprised of moving or stationary surfaces separated by a thin film of lubricant, friction reduction and load support are facilitated. The characteristics of such systems, including pressure in the lubricant film and frictional forces at the surfaces, are determined by factors like surface nature and lubricant film boundary conditions. The Reynolds Equation, initially developed by Reynolds, governs the pressure within the lubricating layer and is derived by linking the equation of motion with the equation of continuity. Initially, factors such as temperature, compressibility, viscosity fluctuation, slip at the surface, inertia, and surface roughness were disregarded. However, subsequent advancements incorporated variations in viscosity and density along the fluid film into the Reynolds equation. This study focuses on analyzing the lubrication behavior of finite journal bearings under operational conditions, considering the influences of additives and thermal effects. To address lubricant additive issues, the generalized Reynolds equation is utilized. The application of the finite difference method to relevant equations enables the derivation and numerical solution of load capacity and pressure expressions. By accounting for viscosity changes and thermal impacts, the study provides load capacity graphs to visualize their effects.

Governing Equation:

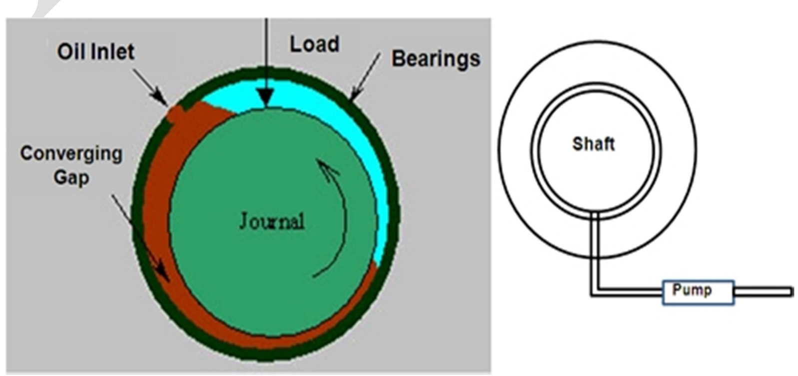

Fig 1.1: Finite Journal bearing configuration

The Physical configuration of the finite journal bearing in fig (1.1), C be the clearance of the bearing C =R-r, $\varepsilon = \frac{e}{c}$ be the eccentricity ratio and 'h' is the total film thickness, is given by $h = c(1 + \varepsilon \cos\theta)$ are shown in fig (1.1).

$$\frac{\partial h}{\partial \theta} = -c\varepsilon \sin\theta \tag{1.1}$$

Reynold's equation, which governs the flow of fluid in the bearing, is presented.

$$\frac{\partial}{\partial x}\left[\frac{h^3}{12\mu} F \frac{\partial p}{\partial x}\right] + \frac{\partial}{\partial y}\left[\frac{h^3}{12\mu} F \frac{\partial p}{\partial y}\right] = U \frac{\partial h}{\partial x} \tag{1.2}$$

$$F = \frac{(1 - \frac{a}{h})^3 (k-1) + 1}{k} \tag{1.3}$$

Considering thermal effect and viscosity, μ can be taken as $\mu = \mu_0 (\frac{h}{h_0})^q$ (1.4)

Where q is thermal factor
Then the non-dimensional parameters are

$$x = R\theta,\ dx = Rd\theta,\ \bar{y} = \frac{y}{L} \Rightarrow y = \bar{y}L,\ dy = Ld\bar{y},\ \bar{\mu} = \frac{\mu_0}{h_0^q} \tag{1.5}$$

$$\frac{\partial}{R\partial\theta}\left[\frac{h^3}{12\mu_0(\frac{h}{h_0})^q} F \frac{\partial p}{R\partial\theta}\right] + \frac{\partial}{L\partial\bar{y}}\left[\frac{h^3}{12\mu_0(\frac{h}{h_0})^q} F \frac{\partial p}{L\partial\bar{y}}\right] = \frac{U}{R}\frac{\partial h}{\partial\theta} \tag{1.6}$$

$$\frac{\partial}{R\partial\theta}\left[\frac{h_0^q}{12\mu_0} h^{(3-q)} F \frac{\partial p}{R\partial\theta}\right] + \frac{\partial}{L\partial\bar{y}}\left[\frac{h_0^q}{12\mu_0} h^{(3-q)} F \frac{\partial p}{L\partial\bar{y}}\right] = \frac{U}{R}\frac{\partial h}{\partial\theta} \tag{1.7}$$

By substituting equation (1.5) in (1.7), then the modified Reynolds equation in a non-dimensional form can be written as

$$\frac{\partial}{R\partial\theta}\left[\frac{\bar{h}^{(3-q)}}{12\bar{\mu}}\bar{F}\frac{\partial p}{R\partial\theta}\right]+\frac{\partial}{L\partial\bar{y}}\left[\frac{\bar{h}^{(3-q)}}{12\bar{\mu}}\bar{F}\frac{\partial p}{L\partial\bar{y}}\right]=\frac{U}{R}\frac{\partial h}{\partial\theta} \tag{1.8}$$

$$\text{put } \lambda^2=\frac{L^2}{4R^2},\ \bar{F}=\frac{(1-\frac{\bar{a}}{\bar{h}})^3(k-1)+1}{k},\ \bar{h}=c(1+\varepsilon\cos\theta) \tag{1.9}$$

By solving the above equation (1.7), we get the non- dimensional pressure as

$$\bar{p}=\frac{pc^2}{\mu uR} \tag{1.10}$$

Now the equation (1.7) reduced to

$$\frac{\partial}{\partial\theta}\left[\bar{F}\bar{h}^{(3-q)}\frac{\partial\bar{p}}{\partial\theta}\right]+\frac{1}{4\lambda^2}\frac{\partial}{\partial\bar{y}}\left[\bar{F}\bar{h}^{(3-q)}\frac{\partial\bar{p}}{\partial\bar{y}}\right]=-12\varepsilon\sin\theta \tag{1.11}$$

The following are the boundary conditions for fluid film pressure

$$\begin{aligned}\bar{p}&=0 \ at \ \theta=0\\ \bar{p}&=0 \ at \ \theta=\pi\end{aligned} \tag{1.12}$$

The finite difference approach is used to numerically solve the modified Reynolds equation. Grid points are used to partition the film domain under investigation, as seen in fig. (1.2). The terms of equation (1.11) can be represented as follows in finite increment format

$$\begin{aligned}&\frac{\bar{h}^{(3-q)}}{\Delta\theta}\left[\left[\bar{F}_{i+\frac{1}{2},j}\left(\frac{\bar{p}_{i,j}-\bar{p}_{i-1,j}}{\Delta\theta}\right)\right]-\left[\bar{F}_{i-\frac{1}{2},j}\left(\frac{\bar{p}_{i+1,j}-\bar{p}_{i,j}}{\Delta\theta}\right)\right]\right]+\\&\frac{\bar{h}^{(3-q)}}{4\lambda^2}\frac{1}{\Delta\bar{y}}\left[\bar{F}_{i,j+\frac{1}{2}}\left(\frac{\bar{p}_{i,j}-\bar{p}_{i,j-1}}{\Delta\bar{y}}\right)-\left[\bar{F}_{i,j-\frac{1}{2}}\left(\frac{\bar{p}_{i,j+1}-\bar{p}_{i,j}}{\Delta\bar{y}}\right)\right]\right]=-12\varepsilon\sin\theta\end{aligned} \tag{1.13}$$

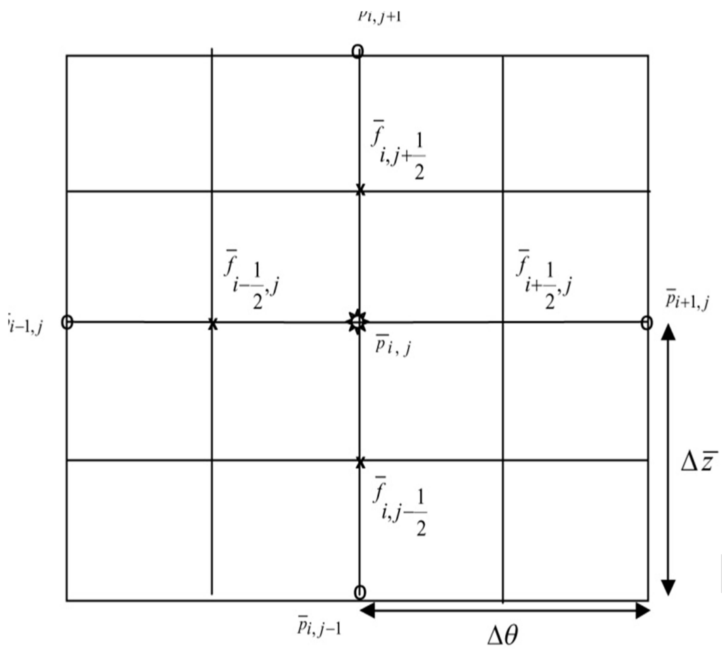

Fig 1.2: Grid point notation for film domain

By solving the equations

$$\frac{\bar h^{(3-q)}}{(\Delta\theta)^2}\left[\bar F_{i+\frac{1}{2},j}\bar p_{i,j}-\bar F_{i+\frac{1}{2},j}\bar p_{i-1,j}-\bar F_{i-\frac{1}{2},j}\bar p_{i+1,j}+\bar F_{i-\frac{1}{2},j}\bar p_{i,j}\right]+$$
$$\frac{\bar h^{(3-q)}}{4\lambda^2}\frac{1}{\Delta\bar y^2}\left[\bar F_{i,j+\frac{1}{2}}\bar p_{i,j}-\bar F_{i,j+\frac{1}{2}}\bar p_{i,j-1}-\bar F_{i,j-\frac{1}{2}}\bar p_{i,j+1}+\bar F_{i,j-\frac{1}{2}}\bar p_{i,j}\right]=-12\varepsilon\sin\theta \quad (1.14)$$

By substituting this equation in (1.11), we have

$$\bar p_{i,j}\bar h^{(3-q)}\left[4\lambda^2r^2\left(\bar F_{i+\frac{1}{2},j}+\bar F_{i-\frac{1}{2},j}\right)+\left(\bar F_{i,j+\frac{1}{2}}+\bar F_{i,j-\frac{1}{2}}\right)\right]=-48\varepsilon\lambda^2\Delta\bar y^2\sin\theta+\bar h^{(3-q)}[4\lambda^2r^2\bar F_{i+\frac{1}{2},j}\bar p_{i-1,j}$$
$$+4\lambda^2r^2\bar F_{i-\frac{1}{2},j}\bar p_{i+1,j}+\bar F_{i,j+\frac{1}{2}}\bar p_{i,j-1}+\bar F_{i,j-\frac{1}{2}}\bar p_{i,j+1}] \quad (3.15)$$

$$c_0\bar p_{i,j}\bar h^{(3-q)}=\bar h^{(3-q)}[4\lambda^2r^2\bar F_{i+\frac{1}{2},j}\bar p_{i-1,j}+4\lambda^2r^2\bar F_{i-\frac{1}{2},j}\bar p_{i+1,j}+\bar F_{i,j+\frac{1}{2}}\bar p_{i,j-1}+\bar F_{i,j-\frac{1}{2}}\bar p_{i,j+1}]$$
$$-48\varepsilon\lambda^2\Delta\bar y^2\sin\theta \quad (1.16)$$

$$\bar{p}_{i,j} = c_1 \bar{p}_{i-1,j} + c_2 \bar{p}_{i+1,j} + c_3 \bar{p}_{i,j-1} + c_4 \bar{p}_{i,j+1} + c_5 \qquad (1.17)$$

The coefficient c_0, c_1, c_2, c_3, c_4, c_5, defined as

$$c_0 = \left[4\lambda^2 r^2 \left(\bar{F}_{i+\frac{1}{2},j} + \bar{F}_{i-\frac{1}{2},j} \right) + \left(\bar{F}_{i,j+\frac{1}{2}} + \bar{F}_{i,j-\frac{1}{2}} \right) \right], \quad c_1 = \frac{4\lambda^2 r^2 \bar{F}_{i+\frac{1}{2},j}}{c_0}, \quad c_2 = \frac{4\lambda^2 r^2 \bar{F}_{i-\frac{1}{2},j}}{c_0}$$

$$, c_3 = \frac{\bar{F}_{i,j+\frac{1}{2}}}{c_0}, \quad c_4 = \frac{\bar{F}_{i,j-\frac{1}{2}}}{c_0}, \text{and } c_5 = \frac{-48\lambda^2 \Delta\bar{y}^2 \varepsilon \sin\theta}{c_0 \bar{h}^{(3-q)}} \qquad (1.18)$$

$\bar{r} = \frac{\Delta\bar{z}}{\Delta\bar{\theta}}$ The pressure p is calculated numerically with grid spacing of $\Delta\bar{\theta} = 9°$ and $\Delta\bar{z} = 0.05$

As a result of the film pressure, the bearing W's load carrying capacity is calculated by

$$W = \int_{\theta=0}^{\theta=\pi} \int_{z=0}^{z=\frac{1}{2}} p\cos\theta \, d\theta dz \qquad (1.19)$$

By using (3.12)in (3.17), we get non dimensional load as

$$\bar{W} = \frac{WC^2}{\mu UR} = \int_{\theta=0}^{\theta=\pi} \int_{z=0}^{z=\frac{1}{2}} p\cos\theta \, d\bar{\theta} d\bar{z} \qquad (1.20)$$

$$\approx \bar{w} = \sum_{i=0}^{M} \sum_{j=0}^{N} \bar{p}_{ij} \, \Delta\bar{\theta} \, \Delta\bar{z} \qquad (1.21)$$

Where M+1 and N+1 are, respectively, the grid point numbers along the 'x' and 'z' axes.

The analysis, numerical solution, and graphing of the pressure and the dimensionless load capacity are performed.

RESULTS AND DISCUSSIONS:

The mesh of the film domain in equation (1.17) for pressure contains 20 equal intervals along the bearing length and circumference. The system of algebraic equations' coefficient matrix has a pentadiagonal shape. Sci-lab tools have been used to resolve these equations.

Conclusion

- This paper analyzes the lubrication of Finite journal bearings under operating conditions while taking additive and thermal effects into account.

- Using a grid spacing of $\theta=9^0$and $\Delta\bar{z}$ =0.05., the finite journal bearing with modified Reynolds equation is numerically solved using the finite difference method.For pressure and load capacity, graphs are drawn.
- It has been demonstrated that a high viscous layer near the lubricant's perimeter layer causes an increase in pressure and load capacity, while a low viscous layer causes a drop.
- It is clear that as the thermal impact grows, pressure rises and load capacity falls.

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