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Short Communication

A new method for calculating the static performance of hydrostatic journal bearing

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ABSTRACT

A new analytical method is proposed to calculate the static performance of hydrostatic journal bearing. Analytical expressions of recess pressure and flow are deduced through analyzing flow continuity equation and utilizing Gauss–Legendre integral formula. To study the computational accuracy and the application range of the new method, recess pressure and flow of a four-pocket capillary compensated hydrostatic bearing under different eccentricity ratios and wrap angles of oil recess are calculated using three methods (the new method, the old analytical method and the finite difference method). The results indicate that new analytical method has the advantage of simplicity and high computational accuracy.

1. Introduction

Multirecess hydrostatic journal bearing has been widely applied to machine tools and other devices because of its good rotation accuracy, excellent damping property[1,2], and other advantages. Many researchers[3,4] study hydrostatic bearing's application to different machines (such as large vertical boring mills, planer milling machines, cylindrical grinders, etc). The static and dynamic performance parameters of hydrostatic bearing exert great effects on its application. The usual methods for calculating static and dynamic performance parameters are concentric theory, finite difference method (FDM) and finite element method (FEM), etc.

The concentric theory [5] ignores hydrodynamic effect on bearing land. The concentric theory is an analytical method, while finite difference method and finite element method are both numerical methods. Ghosh [6] gives a study on the influence of circumferential sill length of four-pocket hydrostatic journal bearing on load carrying capacity and the flow requirement by using FDM. Liang et al. [7] give a quantitative analysis to hydrodynamic effect on bearing land using the finite difference method. The literature [8] adopts FDM to research the effect of size and number of recess on load capacity and oil flow. Ghosh et al. [9] study load capacity and bearing flow of hydrostatic journal bearing under different L/D ratios with the help of the finite difference method. By using FEM, Singh et al. [10,11] conducted a study on the load capacity of hydrostatic bearing at different eccentricity ratios. Jain et al. [12] research deformation coefficient's influence on bearing performance using FEM, finding that proper restrictor and deformation coefficient can improve bearing performance. Using the finite element method, researchers [13,14] study the impacts of restrictor and offset factor on bearing performance.

The concentric theory is simple, but has low precision. Numerical methods (FDM and FEM) are accurate, but have complicated algorithm and have to resort to computers. Therefore, it is necessary to seek out an easy and accurate method to calculate the performance parameters of hydrostatic journal bearing. Based on the previous study [7], the new analytical expressions of recess pressure and flow are deduced through analysis of flow continuity equation and application of the Gauss–Legendre integral formula. The simulation results indicate that this new analytical method is simple, fast and accurate compared with the other two methods (the old analytical method and FDM). The purpose of this paper is to provide such a new method to quickly calculate the static performance parameters of hydrostatic journal bearing.

2. Analysis

2.1. Fluid film thickness

As shown in Fig. 1(b), O_b is bearing center, $O_J(x_J, y_J)$ is journal center, θ is circumferential coordinate, e is eccentricity, and ϕ is attitude angle. By using geometric knowledge the film thickness of

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Nomenclature

c	radial clearance, mm
e	eccentricity, mm
h	fluid film thickness, mm
p	pressure, N mm^{-2}
θ, z	circumferential coordinate, axial coordinate
D	journal diameter, mm
r	journal radius, mm
L	bearing length, mm
L_1	pocket length , mm
Q_{ir}	flow of lubricant from the ith pocket ($i=1,2,3,4$), mm^3 s^{-1}
Q_{ic}	flow of lubricant through the ith restrictor, mm^3 s^{-1}
d_c	diameter of capillary restrictor, mm
l_c	length of capillary restrictor, mm
a_b	bearing land width in axial direction, mm
a_t	bearing land width in circumferential direction, mm
X, Y, Z	Cartesian coordinates
x_J, y_J	coordinates of steady-state equilibrium journal center
p_{ir}	the ith recess pressure, N mm^{-2}
ε	eccentricity ratio
p_s	supply pressure, N mm^{-2}
N	journal speed, r min^{-1}

Greek symbols

θ_1	wrap angle of oil recess
θ_2	wrap angle of bearing land in circumferential direction
θ_3	wrap angle of circumferential return oil chute
η	dynamic viscosity of lubricant, N s m^{-2}
φ	attitude angle
ρ	density of lubricant, kg mm^{-3}
ω_J	journal rotational speed, rad s^{-1}
O_J, O_b	journal center, bearing center

Non-dimensional parameters

$\overline{C}_{sR}$	design parameter of capillary restrictor, $3\pi d_c^4/(32c^3 l_c)$
$\overline{X}, \overline{Y}$	$(x, y)/c$
$\overline{Z}$	z/L
H	h/c
$\overline{Q}$	$(12\eta/p_s c^3)Q$
$\overline{Q}_{ic}$	$(12\eta/p_s c^3)Q_{ic}$
$\overline{Q}_{ir}$	$(12\eta/p_s c^3)Q_{ir}$
Λ	speed parameter, $(6\eta r^2/p_s c^2)\omega_J$
$\overline{P}_{ir}$	p_{ir}/p_s
$\overline{P}$	p/p_s

Subscripts and superscripts

s	supply
—	corresponding non-dimensional parameter
c	capillary
r	recess
J	journal
b	bearing

point A can be expressed as

$$h = c + e\cos(\theta - \phi) \tag{1}$$

According to the geometrical relationship, there exist $\sin\phi = x_J/e$ and $\cos\phi = y_J/e$, and H is dimensionless oil film thickness, $H = h/c$, i.e.

$$H = 1 + \overline{X}_J \sin\theta + \overline{Y}_J \cos\theta \tag{2}$$

where dimensionless coordinates of the journal center can be written as

$$(\overline{X}_J, \overline{Y}_J) = \left(\frac{x_J}{c}, \frac{y_J}{c}\right) \tag{3}$$

2.2. Flow continuity equation

The non-dimensional flow of lubricant through the ith capillary restrictor is

$$\overline{Q}_{ic} = \overline{C}_{sR}(1 - \overline{P}_{ir}) \tag{4}$$

Fig. 2 is the schematic diagram of boundary flow of bearing pocket. The flow of lubricant flowing from pocket consists of two parts, i.e. circumferential flow (Q_1, Q_2) and axial flow (Q_3, Q_4). Γ_1 and Γ_2 represent circumferential boundaries of pocket, and Γ_3 as well as Γ_4 represent axial boundaries of pocket. The flow of lubricant from the ith pocket can be expressed as

$$Q_{ir} = Q_1 + Q_2 + 2Q_4$$
$$= \int_{\Gamma 1}\left(\frac{h^3}{12\eta r}\frac{\partial p}{\partial\theta}\bigg|_{\Gamma 1} - \frac{\omega_J r h}{2}\right)dz + \int_{\Gamma 2}\left(\frac{h^3}{12\eta r}\frac{\partial p}{\partial\theta}\bigg|_{\Gamma 2} + \frac{\omega_J r h}{2}\right)dz$$
$$+2\int_{\Gamma 4}\left(\frac{h^3}{12\eta}\frac{\partial p}{\partial z}\bigg|_{\Gamma 4}\right)r d\theta \tag{5}$$

If the bearing land is narrow, the hydrodynamic effect on bearing land can be ignored (i.e. the pressure on bearing land between the pocket and circumferential return oil chute decreases linearly [7]). Then the pressure gradient can be written as

$$\begin{cases} \frac{\partial p}{\partial\theta}\Big|_{\Gamma 1} = \frac{\partial p}{\partial\theta}\Big|_{\Gamma 2} = \frac{p_{ir}}{\theta_2} \\ \frac{\partial p}{\partial z}\Big|_{\Gamma 4} = \frac{p_{ir}}{a_b} \end{cases} \tag{6}$$

Therefore, the formulae of circumferential flow (Q_1, Q_2) are

$$Q_1 = \left(\frac{h_{il}^3}{12\eta}\cdot\frac{p_{ir}}{r\theta_2} - \frac{\omega_J r h_{il}}{2}\right)L_1 \tag{7}$$

$$Q_2 = \left(\frac{h_{it}^3}{12\eta}\cdot\frac{p_{ir}}{r\theta_2} + \frac{\omega_J r h_{it}}{2}\right)L_1 \tag{8}$$

where h_{il} and h_{it} represent the oil film thicknesses on circumferential boundaries (Γ_1 and Γ_2).

From Eq. (1), the equation $h = c + x_J\sin\theta + y_J\cos\theta$ can be obtained. Substituting it into the expression of Q_4 gives

$$\int_{\Gamma 4}\left(\frac{h^3}{12\eta}\frac{\partial p}{\partial z}\bigg|_{\Gamma 4}\right)r d\theta = \frac{r p_{ir}}{12\eta a_b}\int_{\theta_{il}}^{\theta_{it}}(c + x_J\sin\theta + y_J\cos\theta)^3 d\theta \tag{9}$$

where θ_{il} and θ_{it} represent the circumferential coordinates of circumferential boundaries (Γ_1 and Γ_2). From the geometrical relationship represented by Fig. 1, the following equations can be