Lubrication Simulation and Solution of Oil Film Force and the Equilibrium Position of Three-lobe Journal Bearing

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Abstract. Through the simulation of lubrication condition, the solution of the nonlinear oil film force of the three-lobe journal bearing with Difference Method and the solution of the axis equilibrium position of the three-lobe journal bearing based on Secant Method, we obtained that installation angle of the three-lobe journal bearing has a great influence on bearing capacity of bearing oil film. By use of Secant Method and Decomposition Method of position solving, the axis position can well be solved. The influence of system load on the axis equilibrium position is nonlinear, while under light load and heavy load, the axis equilibrium position can be linearized processing, which is helpful to the solution of equilibrium position.

Introduction

Three-lobe journal bearing is one of non-circular bearing. And because it still can maintain good stability under the large eccentricity, it is wide applied in engineering [1]. The studying team of East China University of Science and Technology has carried on a comprehensive research about three-lobe journal bearing which has symmetrical three oil wedge [2-7]. However, according to the research of Fredrick T. Schuller and William J. Anderson [8] and compared to the symmetric oil wedge, the whole convergent wedge has better stability and less effect during the change of oil film. Therefore, the three-lobe journal bearing with the whole convergent wedge has more wide application prospect and the study of the lubrication condition has great practical significance.

In this paper, according to the mathematical models of oil film thickness, the author has solved the lubrication equations of three-lobe journal bearing and studied the distribution of oil film pressure. In addition, the equilibrium position of the axis is solved with the Secant Method and the effects of load parameters on the axial equilibrium position are discussed.

Geometric Parameters and Lubrication Equations

Parameters of Three-lobe Journal Bearing

Fig.1 shows schematic diagram of the three-lobe journal bearing. There are three important position parameters which is axis, bearing center and oil wedge arc center (the center of the arc outline). Because of three oil wedge arc centers, it is necessary to take into account subsection when make sure the shape of bearing and the thickness of oil film. The distribution of oil film thickness along the circumference are determined jointly by shaft boundary contour and bearing contour. Obtaining the intersection point of straight line with vertical direction of the angleΦ with the arc of the oil wedge, so as to know the distance from axis to the intersection point.And in the direction of the line, oil film thickness d stands for the difference of the distance with the shaft radius r (Fig. 1). Set the angle of the eccentric direction of axis with the vertical direction is $\alpha$and the eccentricity is e. The part of oil wedge is composed of circular arcs. Then the oil film thickness can be calculated by the following equations:

$$\begin{cases} y = ctg\phi \cdot x - e\cos\alpha - ctg\phi \cdot e\sin\alpha \\ \begin{cases} \left(x - \frac{21}{32}\sqrt{3}\right)^2 + \left(y + \frac{21}{32}\right)^2 = R^2 & \frac{\pi}{3} \le \phi < \pi \\ (x-0)^2 + \left(y + \frac{21}{16}\right)^2 = R^2 & \pi \le \phi < \frac{5\pi}{3} \\ \left(x + \frac{21}{32}\sqrt{3}\right)^2 + \left(y + \frac{21}{32}\right)^2 = R^2 & -\frac{\pi}{3} \le \phi < \frac{\pi}{3} \end{cases} \end{cases} \tag{1}$$

With taking eccentricity as e,the bearing's nominal radius value *R* as 20mm and the distance from the maximize of oil wedge profile to the bearing center as 22mm.

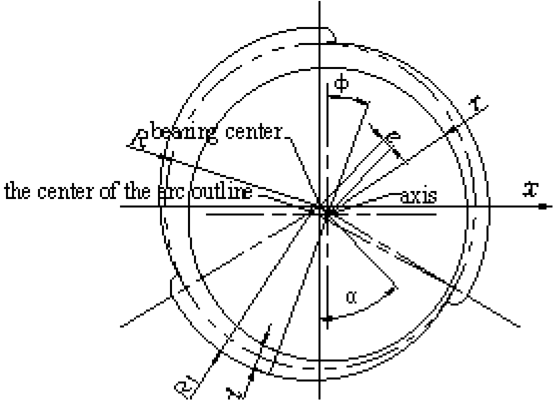


Fig.1 Schematic representation of three-lobe bearing

Reynolds Equation

Reynolds equation is used for the analysis of the lubrication condition and it is expressed as following:

$$\frac{\partial}{\partial l}\left(\frac{d^3}{\eta}\frac{\partial p}{\partial l}\right) + \frac{1}{r^2}\frac{\partial}{\partial\theta}\left(\frac{d^3}{\eta}\frac{\partial p}{\partial\theta}\right) = 6\omega\frac{\partial d}{\partial\theta} \tag{2}$$

With the axial width l ;the oil film thickness d; the lubricating oil viscosity η;the intensity of pressure p ;the radius of the shaft r; the circumferential angle of shaft θ; the rotation angular velocity of the shaft ω.

Numerical Simulation Calculation

Based on the dimensionless method and difference discrete of Reynolds equation and the algorithm of Fig.2, the relations between the various parameters and the lubrication state of bearing can be calculated through the c language programming. Oil film thickness is obtained by (1). The oil film thickness and its distribution remain unchanged in the counting process when the eccentric direction and eccentricity is determined. There is certain corresponding relationship between eccentricity and load, which is under the influence of the eccentric direction.

Through many times use of Reynolds equation, the integration of the pressure and comparing the difference between the integral value and load, the equilibrium position of axis can be calculated. But in the process above, it is need to make sure that the axial force between left and right is balanced. The author uses Secant Method solving the force of horizontal and vertical direction and the axial position respectively. It is assumed that the load acted on the axis is only on the vertical direction and the solving process is shown in Fig. 3, in which *Fx* means the force in the *x* direction and *Fy* means the force in the *y* direction. It is greatly simplified to solve the problem on the plane by means of decomposing and solving it into two directions respectively.

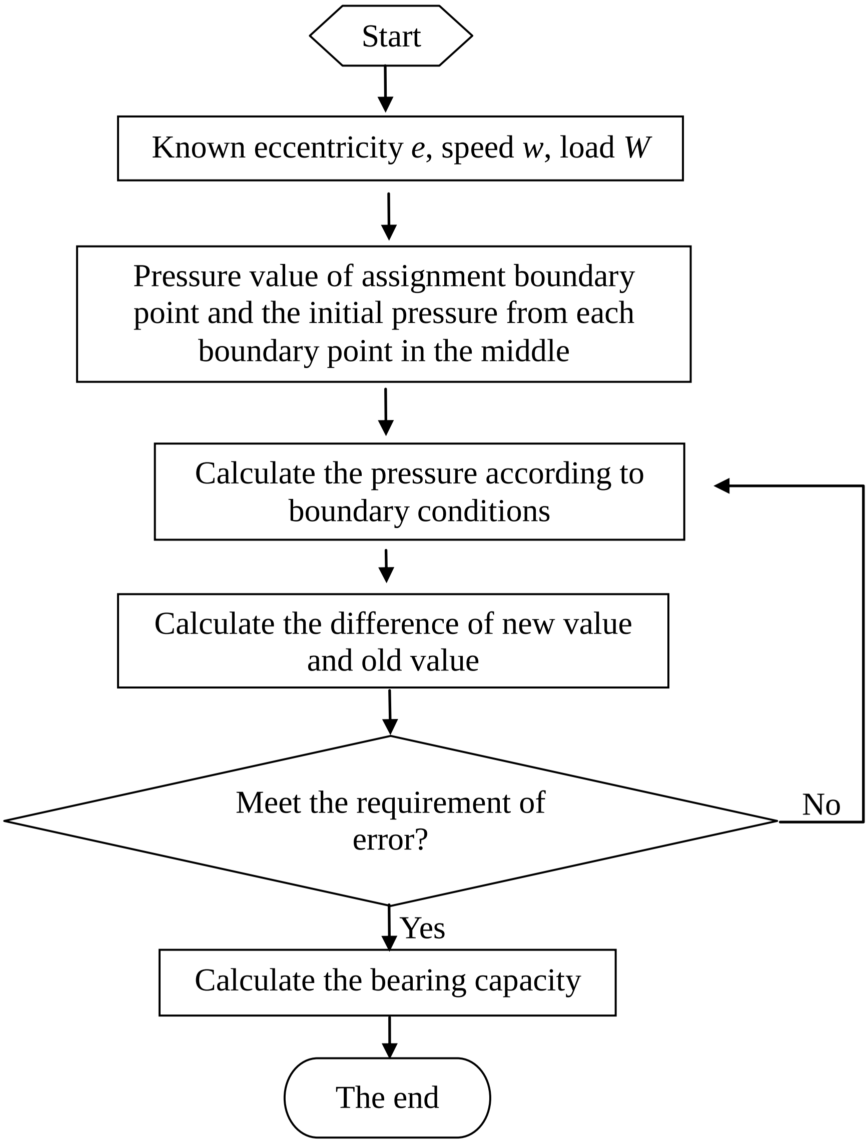


Fig.2 The flow chart of equation

Results and Discussion

In the following discussion, the parameter of dimensionless velocity is set as 0.01. Assuming that the viscosity is a fixed value and neglecting the elastic deformation of bearing during lubrication condition.

Fig.4 is the simulation of oil film thickness and pressure distribution in two different installation positions, in which the eccentric distance is of 0.3*mm* and eccentric direction is of 30°. Fig.4 (a) is the simulation of distribution in the installation position as shown in Fig. 1. It is shown that the biggest pressure is in the vicinity of 0°, which plays a role of bearing load. The rest two parts of the pressure distribution is smaller and the downward active component is smaller too. It can bear larger load when installed as shown in Fig. 1. Installation position shown in Fig.4 (b) is rotated counterclockwise 60° according to that in Fig. 1.Then the distribution of larger pressure is near area of 300° and 60°. Compared with Fig.4 (a), oil film bearing capacity decreases obviously in Fig.4 (b) and the two biggest pressure distributions are not near area of 0°.In addition,the component in the vertical direction decreases apparently and the pressure near 0° is very low, which proves that this part of oil film bearing capacity is every low. Thus from the simulation above, the installation angle has a certain impact on the oil film bearing capacity.

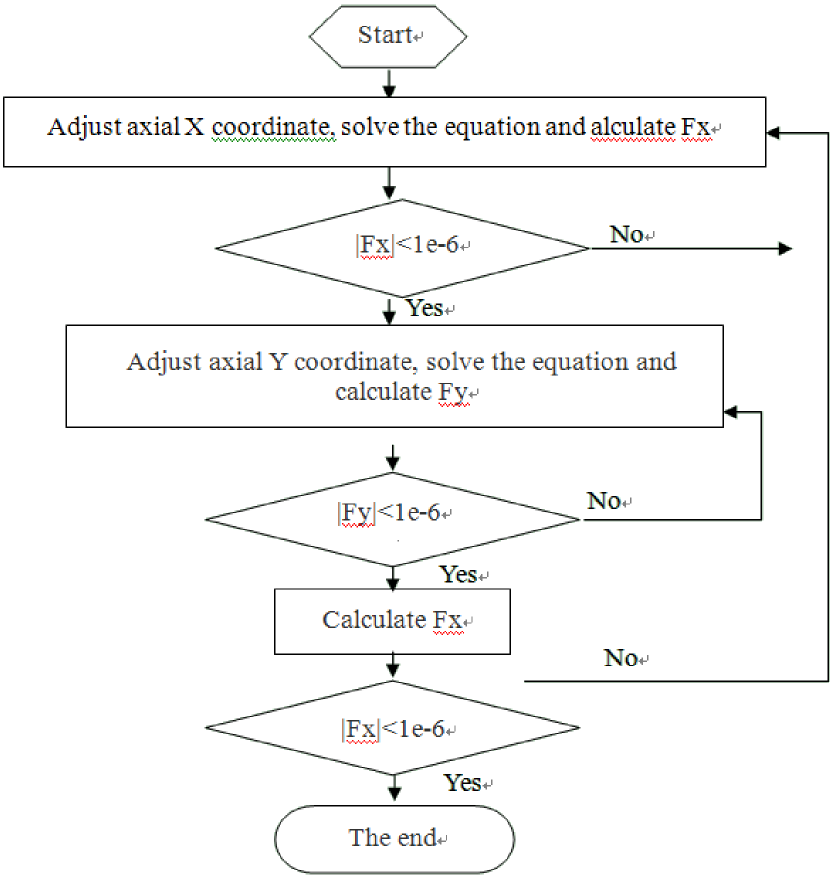
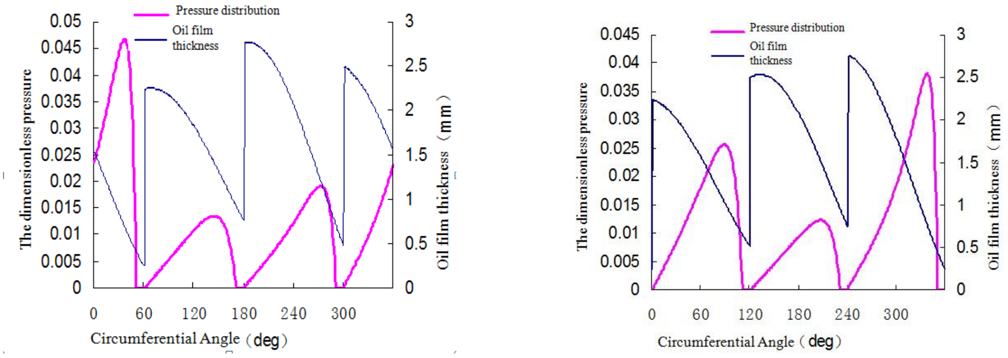


Fig.3 The flow chart of searching eccentric position



(a) (b)

Fig.4 The oil film thickness and the distribution of the dimensionless pressure calculated according to the lubrication equation.

Fig.5 is the convergence conditions of solving the equilibrium position in each time. It is shown that the convergence process is from fast to slow and then almost become unchanged finally. According to the criterion, this is the equilibrium position of the axis. And in this place, the oil film force acted on left and right axis balance. Meanwhile, the integral of pressure in the horizontal is of 0. But in the vertical direction, the oil film force is equal to load in size, opposite in the direction and the resultant force of them is zero. In the Fig.5, it is also shown that the convergence curve is basically in one direction, which proves using this method to solve equilibrium position has a good effect. If to find the solution for the points on the plane, to solve nonlinear equation and solving process is often tend to as curve model, the efficiency of solving will be reduced greatly. Thus adopting the method of this paper can solve the equilibrium position under certain load and the action of the oil film pressure efficiently.

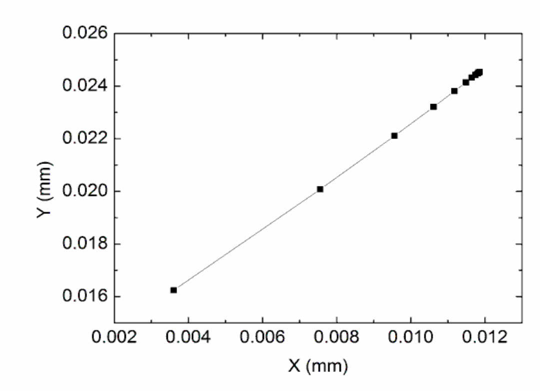


Fig.5 The convergence of solutions of the equilibrium position

Fig.6 is the relationship between the load and the equilibrium position. The equilibrium position changes with load in nonlinear way. The greater the load, the faster the movement speed of equilibrium point in the y direction, while slower in the x direction. With load increasing, the equilibrium point tends to be a limit position gradually, which ensure the axis only has a limited range of motion in the x direction. Within a small scope of the load, the changing way of the equilibrium position with the load can be approximate to a linear relationship. Thus after solving some partial load, we can give a general prediction. Then the equilibrium position can be calculated quickly based on the existing algorithm. It is known from the Fig. that the equilibrium position of the axis moves very small in the horizontal direction under a larger load. Therefore the location of axis on the vertical direction can be used as equilibrium position when under great load. The equilibrium position can be fitted with two straight lines in the image. Then the equilibrium point can be solved by the fitted lines, which will save a lot of computing resources.

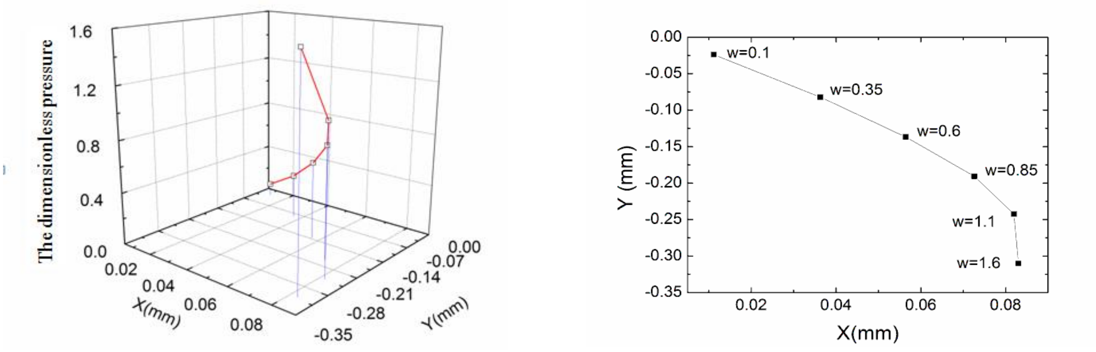


Fig.6 The relationship between the dimensionless load and the equilibrium position

Conclusions

(1) The pressure distribution in bearing oil wedges are not identical and affected by the installation angle. Under the same eccentric condition, carrying capacity is influenced strongly by the installation angle.

(2) Through using the Secant Method, the equilibrium position has been solved in horizontal and vertical directions, which can well solve the axis equilibrium position of the three-lobe journal bearing.

(3) The axis equilibrium position changes along with the load in nonlinear way. But under the effect of low loading or over loading, the path of the equilibrium position in the image can be linear processed, which will help to solve the axis equilibrium position when under the other load.

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