

The application of dichotomy in equilibrium position of journal bearing

G K Wu^{1,2}, X Q Luo²

¹ Institute of Chemical Machinery, Zhejiang University, Hangzhou, 310027, China

² Institute of Water Resources and Hydro-electric Engineering, Xi'an University of Technology, Xi'an, 710048, China

E-mail: wuguangkuan@163.com

Abstract: The fluid lubricant force in the journal bearing is an important factor for the stability and dynamic characteristics of rotating machine. In order to obtain the dynamic coefficients of journal bearing, the equilibrium position must be known for further calculation. In this paper, the Reynolds equation is solved by finite difference method and the dichotomy is applied to acquire the equilibrium position of journal bearing by means of double loop. The effects of length, radius and clearance of journal bearing on the equilibrium position are also researched. The calculated results show that the dichotomy is an effective method for the equilibrium position of journal bearing and the geometry parameters play an important effect on the equilibrium position.

1. Introduction

It is well known that the oil-film force of journal bearing plays an important role in the dynamical characteristics of modern rotating machines [1-5]. The lubricant film force is usually simplified to 8 dynamical coefficients acting on the rotating shaft. In order to obtain the dynamical coefficients, many researchers have done a lot of works in the previous literature. Klit and Lund [6] calculated the dynamic coefficients of a journal bearing by a variational approach. Zheng and Hasebe [7] calculated the dynamic characteristics and coefficients of a journal bearing using free boundary theory. They found that the numerical results worked satisfactorily compared with finite difference method. Rao et al. [8] developed the analytical expressions for accurate evaluation and predicted the post whirl orbits by computing the nonlinear journal trajectory of a cylindrical journal bearing. In order to simplify the calculating process of dynamical coefficients, Muszynska and Bently [9, 10] proposed a nonlinear fluid dynamics model to predict the dynamical coefficients on the basis of lots of experiments, but the model only could be applied on condition that the fluid film was continuous theoretically. In fact, for the finite length journal bearing, the common method for solving dynamic coefficients included finite difference method, partial derivative method and finite element method [11-13]. In addition, as one of the important



process to obtain the dynamic coefficients, the solving accuracy of equilibrium position determined the accuracy of dynamic coefficients and the vibration characteristics of rotor system.

In this paper, the dichotomy is adopted to obtain the equilibrium position of journal bearing by means of double loop. The target of inner loop is to acquire the attitude angle and the outer loop is to calculate the eccentricity. The Reynolds equation was solved by finite difference method in order to describe the pressure distribution and fluid film force of journal bearing. The effects of geometric parameters on the equilibrium position are also researched. The calculating results show that dichotomy is an effective method for the equilibrium position of journal bearing.

2. The solving of equilibrium position

2.1. The model of journal bearing

The following fig.1 shows the geometry model of a journal bearing. The lubricant region is divided into convergent wedge and divergent wedge on the basis of the change trend. The journal rotates in the bearing at the speed of Ω_j and is in equilibrium state under interaction of external load and oil film pressure.

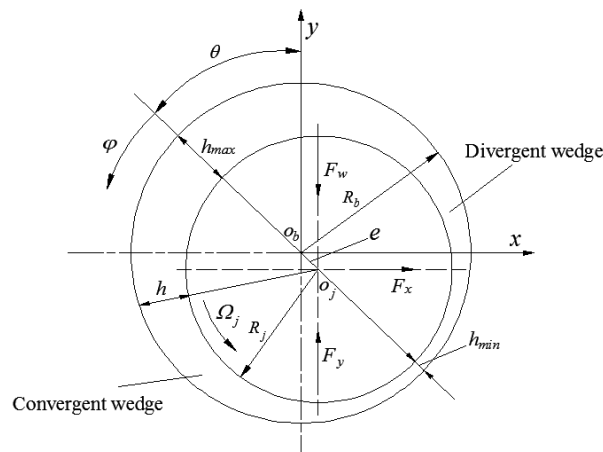


Figure 1. Geometry model of a journal bearing.

The generalized Reynolds equation of lubricant medium under turbulent condition in cylindrical coordinates for cylindrical journal bearing can be written as [14]

$$\frac{1}{R_b^2} \frac{\partial}{\partial \varphi} \left(\frac{h^3}{12\mu} \frac{\partial p}{\partial \varphi} \right) + \frac{\partial}{\partial z} \left(\frac{h^3}{12\mu} \frac{\partial p}{\partial z} \right) = \frac{\Omega_j}{2} \frac{\partial h}{\partial \varphi} + \frac{\partial h}{\partial t} \quad (1)$$

where R_b is the radius of bearing, R_j is the radius of journal, φ is the angular direction, θ is the attitude angle, h is the thickness of lubricant medium, e is the eccentric distance, μ is the viscosity of lubricant medium, p is the pressure of the lubricant film, Ω_j is the rotating angular speed, F_w is the external vertical load, F_x and F_y are x - and y - components of lubricant film force, respectively, the subscript 'max' and 'min' denote the maximal and minimum thickness, respectively.

Introducing the following dimensionless parameters for further calculations

$$\bar{z} = \frac{2z}{L_b}, \quad \bar{c} = \frac{c}{R_b}, \quad \bar{h} = 1 + \varepsilon \cos \varphi, \quad \bar{p} = \frac{\bar{c}^2}{6\mu\Omega_j} p, \quad \lambda = \frac{L_b}{2R_b}, \quad \bar{t} = \Omega_j t \quad (2)$$

where L_b is the length of bearing, c is the clearance between bearing and journal, z is the axes in axial direction, ε is the eccentricity.

Considering $d\theta/d\bar{t} = d\varepsilon/d\bar{t} = 0$ for the stable motion, Equation (1) can be further simplified as

$$\frac{\partial}{\partial \varphi} \left(\bar{h}^3 \frac{\partial \bar{p}}{\partial \varphi} \right) + \frac{\partial}{\partial z} \left(\frac{\bar{h}^3}{\lambda^2} \frac{\partial \bar{p}}{\partial z} \right) = -\varepsilon \sin \varphi \quad (3)$$

Equation (3) can be solved by FDM, once the pressure distribution of the lubricant film is obtained, the final lubricant force can be calculated by compound Simpson quadrature formula.

2.2. The static equilibrium position

The static equilibrium position is one of the important steps for dynamic coefficients. In fact, the essence of searching static equilibrium position is the eccentricity and attitude angle.

The dichotomy has been used in the computational process of static equilibrium position [15], but it was only applied to determine the eccentricity and ignored the attitude angle. In order to solve the problem, the double loop is used. In the paper, once the calculated eccentricity and attitude angle satisfy the following convergence criterions, the journal bearing is considered in the equilibrium state. The convergence criterions can be given as

$$f(\theta) = \left| \frac{F_x}{F_y} \right| < 10^{-2} \quad (4.a)$$

$$g(e) = |F_w - F_y| < 1 \quad (4.b)$$

The iterative process of static equilibrium position is shown in Fig. 2.

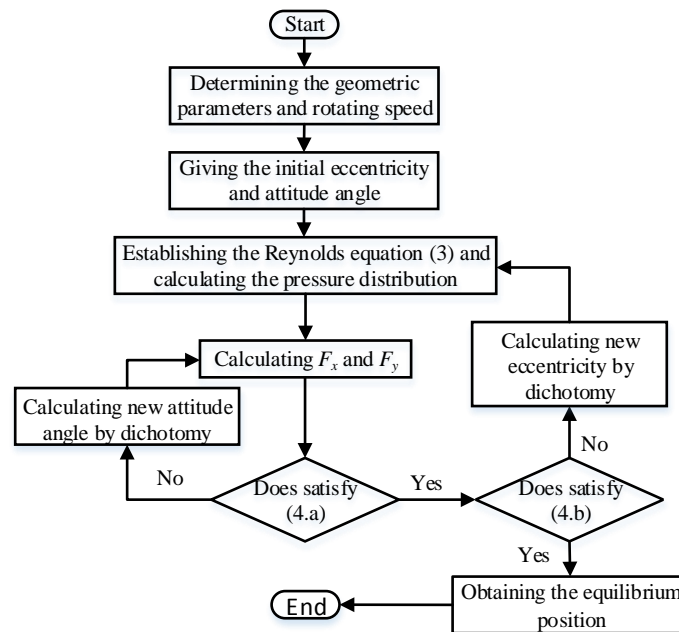


Figure 2. Iterative process of static equilibrium position.

3. Numerical results and discussions

In order to present dichotomy's effectiveness and research the effect of geometric parameters on the equilibrium position, the radius of bearing R_b , length of bearing L_b and clearance c are selected in the following calculation. The pressure distribution under different equilibrium position corresponding with the previous geometric parameters are also presented.

Assign the following parameters

$$R_b = 0.3\text{m}, L_b = 0.3\text{m}, F_w = 10000\text{kg}, \Omega_j = 3000\text{r/min}, c = 2\text{mm}$$

3.1. Influence of the radius of bearing

Figure 3(a) presents the influence of radius of bearing on the equilibrium position. The radius of bearing is selected from 0.1 m to 0.5 m and the other parameters remain the same. It can be seen that the eccentricity increases with the decrease of the radius, but on the contrary, the attitude angle increases as the radius increases. In addition, it also should be note that the changing trend becomes more obvious with larger radius values (from 0.4 m to 0.5 m) compared with smaller radius values (from 0.1 m to 0.2 m).

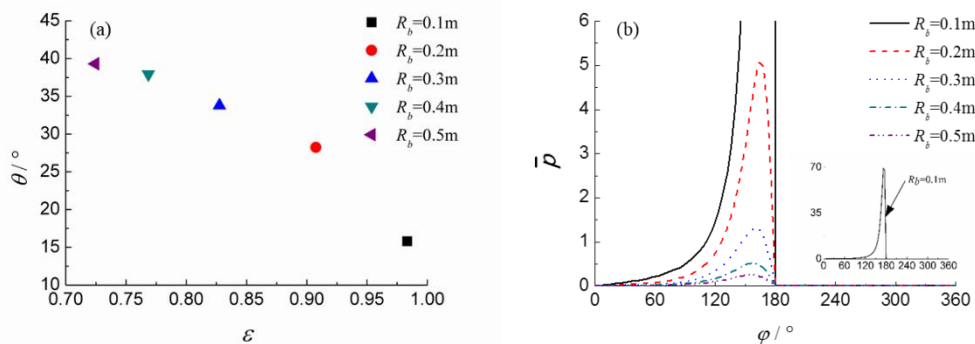


Figure 3. Influence of R_b on the equilibrium position and corresponding pressure distribution.

Figure 3(b) shows the relations of radius and pressure distribution at different equilibrium positions. From the figure, the maximal value of pressure distribution with $R_b = 0.1$ m is considerably larger than other radii and the changing trend of maximal value is the same as equilibrium position in Fig. 3(a).

3.2. Influence of the length of bearing

The influence of length of bearing on the equilibrium position is shown in Fig. 4(a). The length of bearing is employed as the variable parameter, ranging from 0.1 m to 0.5 m. The changing trend is similar to that of radius. However, the difference between adjacent equilibrium positions is more balanced compared with Fig. 3(a).

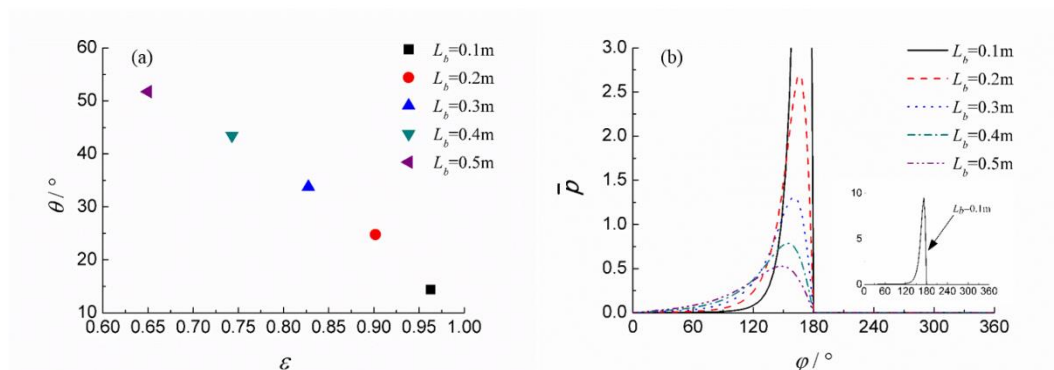


Figure 4. Influence of L_b on the equilibrium position and corresponding pressure distribution.

Fig. 4(b) presents the relations of lengths and pressure distribution at different equilibrium positions. The maximal values of pressure distribution increase as the lengths decrease. It is need to note that when the φ is less than 120° , the pressure distribution values with larger length are greater than these of smaller length.

3.3. Influence of the clearance

Figure 5(a) presents the influence of clearance on the equilibrium position. The clearance between bearing and journal is selected from 1 mm to 3 mm and other parameters also keep the same. On the contrary to the influence of radius and length, the eccentricity increases with the increase of the clearance and the attitude angle decreases as the clearance increases. Moreover, the difference between adjacent equilibrium positions with smaller clearance values (from 1 mm to 1.5 mm) is greater than the larger clearance values (from 2.5 mm to 3 mm).

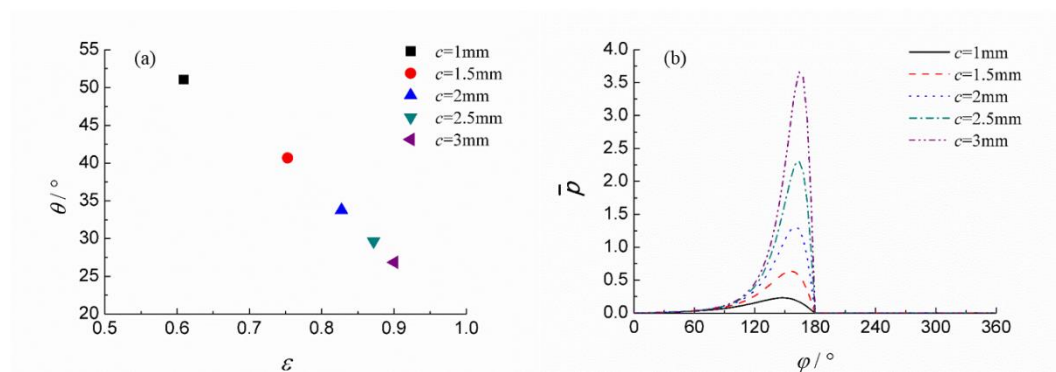


Figure 5. Influence of c on the equilibrium position and corresponding pressure distribution.

The pressure distribution at different equilibrium positions with the change of clearance is shown in Fig. 5(b). From the figure, it can be seen that the pressure values and the maximal values increase as the clearance increases, but the difference of adjacent maximal values is more average compared with that of radius and length.

Conclusions

In the paper, in order to further calculation of dynamic coefficients of journal bearing, the dichotomy with double loop is applied to acquire the equilibrium position of journal bearing. The Reynolds equation is solved by FDM and the final lubricant force is calculated by compound Simpson quadrature formula. The calculated results show that the dichotomy is an effective method for the equilibrium position of journal bearing. The changing trend of equilibrium position with different radius and length is different with that of clearance and the difference values of maximal pressure with different clearances are more average.

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