Numerical analysis of sliding bearing dynamic characteristics based on CFD

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Abstract. According to the characteristics of the flow field of the sliding bearing, the CFD numerical calculation model of the sliding bearing was established. The CFD method was used to simulate the flow field of the sliding bearing, and the pressure distribution of the sliding bearing flow field was obtained. Based on this, the stiffness and the damping coefficient of the dynamic characteristics were obtained by the dynamic grid technique. The influence of the rotational speed on the dynamic characteristic coefficient was further studied. The results show that the difference between the stiffness coefficient and the damping coefficient is less than 5%, and the accuracy of the model is verified. The absolute value of the oil film stiffness increases non-linearly with the increase of the rotational speed, and the influence of the rotational speed on the damping coefficient is small.

1. Introduction

The rotor-support system is at the core of the entire rotor system, and sliding bearings are the most important part of the system, and its operating conditions will directly affect the performance of the entire mechanical system [1]. The sliding bearing has the characteristics of simple structure, strong carrying capacity, and high rotation precision and long life. It is widely used in steam turbine, internal combustion engine, compressor, large motor and blower [2]. Important, the dynamic characteristics of sliding bearings are mainly described by the stiffness coefficient and the damping coefficient, and the dynamic characteristic coefficient is directly related to the stability of the rotor and the flow field.

The Reynolds equation is the theoretical basis for studying the sliding bearing. The basic way to calculate the bearing characteristics is to solve the corresponding Reynolds equation for different sliding bearings. Chen Boxian, Su Hong et al given the oil film in the three-dimensional stability of the two main ways to get the corresponding three-dimensional stability parameters from the theoretical analysis of three-dimensional oil film work conditions [3-4]. Yang Jinfu et al used numerical methods to study the journal radial offset and skew when the dynamic characteristics of sliding bearings, derived power coefficient matrix expression, and discussed the physical meaning of the elements [5]. Swift, H, W, GUO Zeng lin et al conducted theoretical and experimental studies on tilted tile bearings from different perspectives [6-7]. It is gradually unable to meet the increasing demand for industrial technology and is gradually replaced by the higher accuracy CFD method.

CFD technology has been widely used in aviation, aerospace, automobile manufacturing and other high-end areas, CFD technology using Nervier-Stokes (N-S) equation and the establishment of appropriate models to solve the bearing incompressible oil film, and dynamic solution is usually used
rotor micro-eddy method [8]. CFD technology has the advantage of being able to calculate the complex mathematical model to solve the complete N-S equation, the oil film pressure and other parameters of the specific distribution for the bearing selection, design, etc. to provide important data basis. The effects of aspect ratio, density, dynamic viscosity and rotational speed on the dimensionless damping coefficient were analyzed by fluid calculation software. The results show that the CFD method has been studied in these aspects of sliding bearing. A certain superiority, we can see that CFD technology for a variety of flow field calculation has a high degree of fit [9-11].

2. Model establishment and parameters
In order to make the calculation result accurate, this paper uses the model in [12], its geometric dimensions are shown in Table 1, and Figure 1 shows the axial structure of the cylindrical plain bearing.

| Bearing radius (R/mm) | Rotor radius (r/mm) | Bearing width (l/mm) | Eccentricity ratio (ε) | Eccentricity angle (θ) |
|----------------------|---------------------|----------------------|------------------------|------------------------|
| 25                   | 24.95               | 25                   | 0.5                    | 49.8°                  |

Figure 1. The model of the axial structure of the model.

The model of sliding bearing pressure is established by using fluent tool. For simplicity of comparison, the structural parameters of the model are the same as those in [12]. The model of ordinary cylindrical bearing is taken as the object of study. Bearing diameter D=50mm, bearing width B=25mm, speed n=9550r/min, relative clearance Ψ=0.175%, Eccentricity ratio ε=0.5, bearing level in the surface of the two into the oil tank. Lubricants are selected according to Zhang Zhiming's "hydrodynamic lubrication theory of plain bearings". The lubricating oil grades selected in this calculation are HU-20, dynamic viscosity µ=0.0125Pa.s, average operating temperature 50 °C, in order to simplify the neglect of viscosity With the temperature change. Boundary conditions: set the oil pressure P=103000Pa, the oil pressure P=0Pa, from both sides of the oil tank into the oil, bearing both ends of the oil, journal speed n=9550r/min, the other part of the solid wall boundary. Figure 2 shows the resulting grid structure. The iterative residual graph shows the convergence, save the calculation result, and post-process the calculation result. Figure 3 shows the eccentricity of 0.5, speed 9550rpm, oil pressure 103000Pa under the conditions of the sliding bearing pressure.
From this figure, it is clear that the pressure distribution of the oil film in the sliding bearing is clearly seen. The space within the bearing can be divided into convergent oil wedge and divergent oil wedge. The maximum pressure is generated in the convergent oil wedge region, which is 2.347MPa and the load capacity is 1256N. The calculated results in the literature [12] are 2.352MPa maximum pressure and 1160N load. The results show that result error is small and the calculation result is accurate. See Table 2 for specific data.

|                          | Maximum pressure (MPa) | Load capacity (N) | Sump angle (deg) |
|--------------------------|------------------------|-------------------|------------------|
| Foreign language data    | 2.352                  | 1160              | 49.8             |
| Data for this article    | 2.347                  | 1256              | 49.8             |
3. Dynamic characteristic coefficient calculation

Sliding bearings in normal work, the static balance of the journal position is O0(x0, y0), the oil film on the journal of the force Fx0 and Fy0. When the journal moves slightly in the vicinity of its static equilibrium position Δe, its position is O(x, y) when it deviates from the static equilibrium position, and the force applied to the journal is Fx and Fy. Then the change in oil film force can be expressed as:

\[
\begin{align*}
\Delta F_x &= k_{xx} \Delta x \\
\Delta F_y &= k_{yy} \Delta y
\end{align*}
\]  

(1)

\[
\begin{align*}
F_{x0} - F_x &= k_{xx}x + k_{xy}y + c_{xx}x + c_{xy}y \\
F_{y0} - F_y &= k_{xy}x + k_{yy}y + c_{yx}x + c_{yy}y
\end{align*}
\]  

(2)

Where kxy and cxy represent the stiffness and damping coefficients of the bearing, the first subscript indicates the direction of the force increment, and the second subscript represents the direction of the displacement increment. x, y, x, y Respectively, that the journal in the horizontal and vertical direction of the small displacement and speed. So that the crest in the horizontal direction produces a small displacement disturbance (Δx, 0), then, y=0, then each equation has only one stiffness unknown. Calculate the difference between the force of the oil film force in the horizontal and vertical directions before and after the migration, ie, ΔFx and ΔFy, and substituting the equation (2) to obtain the stiffness coefficients kxx and kyx of the oil film. Similarly, so that the journal in the vertical direction of a small displacement (0, Δy), It can get the oil film stiffness coefficient kxy and kyy.

3.1. Calculation of stiffness coefficient

The stiffness coefficients kxx and kyx of the oil film can be obtained by calculating the difference between the forces in the horizontal and vertical directions before and after the offset, ie, ΔFx and ΔFy. Similarly, the journal in the vertical direction of a small displacement, it can get the oil film stiffness coefficient kxy and kyy. Calculate the journal to produce a slight offset x/h0 and y/h0 (0.0005mm, 0.00025mm, and 0.0001mm), calculate the change of oil film force in two states, and obtain the stiffness coefficient of oil film. Figure 4 the pressure distribution of the oil film under different horizontal disturbances is shown.

(a) x/h0 = 0.01 when the pressure distribution
Figure 4. Oil pressure distribution under different horizontal disturbances.

In Table 3 the CFD single-phase flow model in different disturbance position under the journal in the horizontal and vertical force is shown. It can be seen from the table, when the journal to the x-axis positive direction, the horizontal direction of the oil film force is less than the equilibrium position, and in the vertical direction is greater than the equilibrium position, with the journal to the x-axis direction of the increase, The force in the horizontal direction is gradual decline and the vertical direction increases gradually. When the journal is shifted in the negative direction of the y axis, the oil film has more force on the journal in both directions than the equilibrium position and it increases linear relationship as the offset increasing.
Table 3. CFD single-phase flow model in different disturbance Position horizontal and vertical direction of the oil film on the journal (N).

| Disturbance displacement | $F_x$  | $F_y$  | Disturbance displacement | $F_x$  | $F_y$  |
|--------------------------|--------|--------|--------------------------|--------|--------|
| $x/h_0=0$                | 40.0   | 1172.2 | $y/h_0=0$                | 40.0   | 1172.2 |
| $x/h_0=0.01$             | 58.5   | 1217.1 | $y/h_0=-0.01$            | 54.4   | 1200.5 |
| $x/h_0=0.002$            | 42.5   | 1180.9 | $y/h_0=-0.002$           | 44.3   | 1178.2 |
| $x/h_0=0.005$            | 47.0   | 1192.8 | $y/h_0=-0.005$           | 48.8   | 1186.3 |

Table 4. Stiffness Coefficient of Oil Film for Different Models (106N/m).

| Calculation method                        | $k_{xx}$ | $k_{xy}$ | $k_{yx}$ | $k_{yy}$ |
|-------------------------------------------|----------|----------|----------|----------|
| VT-FAST                                   | 40.0     | -19.4    | 87.2     | 59.1     |
| CFX-TASCflow(x/h_0=y/h_0=0.01)            | 41.2     | -21.9    | 88.0     | 60.0     |
| CFX-TASCflow(x/h_0=y/h_0=0.005)           | 41.1     | -22.1    | 88.1     | 58.0     |
| CFX-TASCflow(x/h_0=y/h_0=0.002)           | 38.9     | -21.3    | 85.0     | 55.0     |
| FLUENT Single phase flow (x/h_0=y/h_0=0.01) | 43       | -22.8    | 88.0     | 59.3     |
| FLUENT Single phase flow (x/h_0=y/h_0=0.005) | 40       | -23.8    | 87.8     | 56.4     |
| FLUENT Single phase flow (x/h_0=y/h_0=0.002) | 37       | -23      | 86       | 54       |

In Table 4 the results of CFD single-phase flow model and other models are shown. It can be seen that the stiffness coefficient of the single-phase flow model calculated by fluent software is less than 5% compared with the CFX software.

3.2 Damping coefficient calculation

So that the crest in the horizontal direction of the small disturbance speed, then the oil film force in the vertical direction of the disturbance rate and the two directions of the disturbance displacement is zero, type (2) can be simplified as:

$$\begin{align*}
\Delta F_x &= c_{xx} \Delta x \\
\Delta F_y &= c_{yx} \Delta x
\end{align*}$$

(3)

The stiffness coefficients $c_{xx}$ and $c_{yx}$ of the oil film can be obtained by calculating the difference between the forces in the horizontal and vertical directions ($\Delta F_x$ and $\Delta F_y$), in the two states $c_{xx}$ and $c_{yx}$.

The damping coefficients $c_{xx}$ and $c_{yx}$ of the oil film can be obtained by calculating the difference between the forces in the horizontal and vertical directions, ie, $\Delta F_x$ and $\Delta F_y$, in the two states. The pressure distribution of the oil film at four time is shown during the movement of the journal from the eccentric position to the static equilibrium position at a disturbance speed of -0.0005m/s in Figure 5.
Figure 5. Oil pressure distribution at different times at the horizontal disturbance velocity.
Table 5. CFD single-phase flow model at different disturbance Speed horizontal and vertical direction of the oil film on the journal (N).

| Disturbance speed | $F_x$ | $F_y$ | Disturbance speed | $F_x$ | $F_y$ |
|-------------------|-------|-------|-------------------|-------|-------|
| $\dot{x}/Nh_0=0$  | 40.0  | 1172.2| $\dot{y}/Nh_0=0$  | 40.0  | 1172.2|
| $\dot{x}/Nh_0=-0.01$ | 72.1 | 1143.4| $\dot{y}/Nh_0=0.01$ | 73.0 | 1155.6|
| $\dot{x}/Nh_0=-0.005$ | 56.7 | 1157.4| $\dot{y}/Nh_0=0.005$ | 54.6 | 1158.4|
| $\dot{x}/Nh_0=-0.002$ | 46.5 | 1165.9| $\dot{y}/Nh_0=0.002$ | 47.6 | 1163.4|

The above table data into the formula (3) to obtain the oil film damping value, Table 4.5 shows the different models of oil film damping coefficient of the calculation results. This article references [12]. Use $\dot{x}/Nh_0=\dot{y}/Nh_0=0.005$ corresponding data for follow-up comparison.

Table 6. Oil film damping coefficient (104Ns/m).

| Calculation method | c_xx | c_yy | c_x | c_y |
|--------------------|------|------|-----|-----|
| VT-FAST            | 5.75 | 4.93 | 5.41 | 16.7|
| CFX-TASCflow($\dot{x}/Nh_0=\dot{y}/Nh_0=0.01$) | 6.92 | 5.90 | 6.60 | 18.2|
| CFX-TASCflow($\dot{x}/Nh_0=\dot{y}/Nh_0=0.005$) | 7.16 | 5.92 | 6.40 | 18.4|
| CFX-TASCflow($\dot{x}/Nh_0=\dot{y}/Nh_0=0.002$) | 6.86 | 5.82 | 6.50 | 18.0|
| FLUENT Single phase flow ($\dot{x}/Nh_0=\dot{y}/Nh_0=0.01$) | 6.8  | 5.8  | 6.5  | 18.3|
| FLUENT Single phase flow ($\dot{x}/Nh_0=\dot{y}/Nh_0=0.005$) | 7.1  | 5.67 | 6.2  | 18.5|
| FLUENT Single phase flow ($\dot{x}/Nh_0=\dot{y}/Nh_0=0.002$) | 6.75 | 6.0  | 6.3  | 18.6|

Table 6 shows the results of CFD single-phase flow model and other model damping. It can be seen that the damping coefficient of the single-phase flow model calculated by fluent software is not much different from that calculated by CFX software. All the results are less than 5%.

3.3. Damping coefficient calculation

Figure 6, It shows the CFD model of sliding bearings in the bearing dynamic characteristics of the impact. In the vicinity of the working speed, the absolute value of the oil film stiffness increases with the speed increase in Fig. 6 (a). It can be seen that the rotational speed has little effect on the oil film damping near the working speed in Fig. 6 (b).
Figure 6. Influence of Speed on Dynamic Characteristics of Sliding Bearing

4. Conclusion

(1) CFD method can directly solve the N-S equation, more accurately reflect the bearing dynamic characteristics, and be used for complex sliding bearing model to solve, this paper established a sliding bearing CFD solution model and the relevant literature results are less than 5% error, The accuracy of the method is verified, which provides the theoretical basis for the design of sliding bearing.

(2) The calculation results of the dynamic characteristics of the sliding bearing show that the calculated results of CFD and the related articles CFX are similar, which is different from the calculation results of the related articles Reynolds equation. This is because the CFD and CFX methods directly solve N-S equation, Reynolds equation method simplifies N-S equation, so the error is large.

(3) The results show that the oil film stiffness coefficient increases with the increase of the rotational speed, and the rotational speed has little effect on the damping coefficient.
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