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ANALYSIS OF TEMPERATURE EFFECT ON THE LUBRICATING STATE OF HYDROSTATIC BEARING

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ABSTRACT

Setting the effect of oil states (sufficient state and deficient state) on temperature field distribution and temperature rise of heavy hydrostatic bearing as the starting point, simulation research is conducted with the FLUENT 6.5, which is popular in current field of scientific research all over the world. The results show that the temperature of heavy hydrostatic bearing has a linearly increase in both oil state with the spinal velocity speeding up. However the temperature rise is lower in sufficient oil state than that in the opposite state. In addition, the oil state has an effect on the distribution of temperature filed at the same rotational speed. The obtained data supply the theory basis for the safe operation of the hydrostatic bearing.

Keywords: *Hydrostatic bearing, Finite volume method, Sufficient and deficient states of lubricant, Temperature field, FLUENT*

1. INTRODUCTION

The fluid lubrication technology was applied as a high-tech applied in the 19th century, and people didn't attach importance to this technique until the mid-20th century. Hydrostatic bearing is a sliding bearing, using liquid as lubricant. And it developed with the advance of atomic energy, space technology, microelectronics and other emerging science and technology.

Hydrostatic bearing is the key part of heavy CNC lathe, of which performance directly decides the processing quality and operational efficiency of equipment. How to improve the spinal speed, processing efficiency and processing accuracy is one of critical issues to be solved currently. Therefore, national experts and scholars conducted deep research on the object. Indian scholar J. S. Yadav and V. K. Kapur studied the effect of variable viscosity and density on the pressure distribution and load carrying capacity of hydrostatic bearing [1]; on the theory basis, Suresh Verma, Vijay Kumar and other people analyzed the property of hydrostatic bearing with multi-recess and constant-flow, using minimal lubricant as working medium [2]; I. S. Durazo Cardenas and others discussed the characteristic of porous ceramic hydrostatic bearing, produced with starch consolidation craft [3]; Manish Kumar and Daejong Kim conducted research on the loading performance of aerostatic foil bearing with higher stiffness [4]; Foreign scholar James Howard and David Ashby made the analysis on the performance of hydrostatic bearing of the huge binocular telescope [5]. E. Rajasekhar Nicodemus and Satish C. Sharma researched the effect of wear parameter on four-chamber, micropolar lubricant and capillary compensation of hydrostatic bearing [6]; Udaya P. Singh, Ram S. Gupta and Vijay K. Kapur analyzed the performance of external load hydrostatic bearing using Rabinowitsch fluid as working lubricant [7]; A. N. Bolotov and A. Strelnikov carried out experiments to determine the molecular and mechanical components of the specific friction force under the effect of hydrostatic pressure of up to 140 MPa [8]; In 1995, Paranjpe and Hanm were first to devote attention to the temperature and heat effect of hydrostatic bearing[9]; In 1982, Indian scholar Zeinab S.Safa analyzed the effect of heat on the tilting hydrostatic bearing by solving energy equation under adiabatic condition using finite element method [10]; Fillon did study on the effect of heat, elastic deformation, tile contact deformation and other factors on the performance of radial bearing [11]; Foreigner Monmousseau and Fillon conducted TEHD analysis by applying steady and static load on hydrostatic bearing considering the effect of heat and tile contact deformation [12].

The heavy hydrostatic bearing model is shown in Figure 1. In the operation of hydrostatic bearing, it is found that the oil state determines the spinal speed of CNC lathe. Aiming to explain this phenomenon, two oil states are modeled in solidworks2009, with simulating in FLUENT6.5. From the simulation results, it is concluded that the oil states determines the temperature distribution of hydrostatic bearing.

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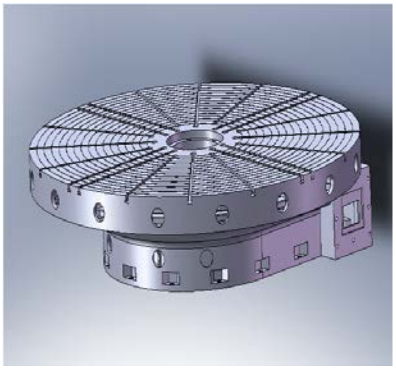

Figure 1: The Heavy Hydrostatic Bearing

2. THEORY OF HYDROSTATIC BEARING

In this simulation with sector chamber, it will usually lead to great error in various calculation of performance parameter that simplifying this model as two parallel rectangle planes, which doesn't include the flow in four corners. Aiming at decreasing error and improving accuracy of theory calculation, parameter L1、L2、B1、B2 are set as shown in Figure 2.

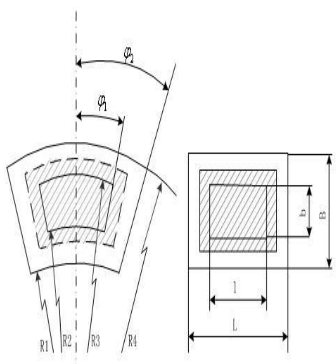

Figure 2: Sketch Map Of Separate Oil Pad With Sector Chamber

The effective area A_e of single pad (shadow area shown in Figure 2) is:

$$A_e = (L-l)(B-b) \tag{1}$$

where the following relations exist:

$$L = (R_1 + R_4) \times \varphi_2 \tag{2}$$

$$B = R_4 - R_1 \tag{3}$$

$$l = (R_2 + R_3) \times \varphi_1 \tag{4}$$

$$b = R_3 - R_2 \tag{5}$$

The total flow of one single oil pad is:

$$Q = Q_1 + Q_2 + Q_3 \tag{6}$$

where, Q is the total flow; Q_1 is the flow caused by shear flow; Q_2 is the flow caused by differential pressure; Q_3 is the flow caused by Centrifugal force.

The calculating formula of each flow is shown as followed:

$$Q_1 = \frac{1}{2}uhb = \frac{1}{2}w(\frac{R_1+R_4}{2})h(B-b) \tag{7}$$

$$Q_2 = \frac{h^3 \Delta p}{6\mu l}[\frac{B-b}{l} + \frac{L-l}{b}] \tag{8}$$

$$Q_3 = \frac{(\frac{\pi\rho\omega^2 R_4{}^2 h^3}{20\mu} - \frac{\pi\rho\omega^2 R_1{}^2 h^3}{20\mu})}{2\pi} \cdot \varphi_2 = \frac{\varphi_2 \rho\omega^2 h^3 (R_4{}^2 - R_1{}^2)}{40\mu} \tag{9}$$

3. THEORY OF FINITE VOLUME

FVM, which is called Finite Volume Method, widely studied and applied by national experts and scholars. The basic idea of this method is that at first step, discrete the calculate region as individual compute nodes, which is surrounded by nonoverla-pping control volumes; make integral operations for each control volume using differential equations to be solved; thus, a set of discrete equations, whose unknown quantities are characteristic variables of the mesh nodes, are obtained; assuming that there exists a variation law of characteristic variables between grid nodes, we will get the integrals of control volumes. The physical meaning of discrete equations is Characteristic variables observe the conversation law in finite control volume. The most important feature of the finite volume method is it is asked to observe conversation when characteris-tic variables run integrals for an arbitrary set of control volume, similarly to the whole calculating region. The main equations used in finite volume method are given in the following.

Mass conservation equation is that:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} + \frac{\partial \rho w}{\partial z} = 0 \tag{10}$$

Where, ρ is the density; u , v , w are velocity components.

Momentum conservation equation is that:

$$\frac{\partial(\rho u)}{\partial t} + div(puu) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + F_x$$

$$\frac{\partial(\rho v)}{\partial t} + div(pvu) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + F_y$$

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$$\frac{\partial(\rho w)}{\partial t}+div(pwu)=-\frac{\partial p}{\partial z}+\frac{\partial \tau_{xz}}{\partial x}+\frac{\partial \tau_{yz}}{\partial y}+\frac{\partial \tau_{zz}}{\partial z}+F_z$$

(11)

Where, ρ is the density; u , v , w are velocity components; p is the pressure; F_x , F_y , F_z are mass force components; τ is the shear stress.

4. MODEL & MESH

Numerical simulation of interior flow field in heavy hydrostatic bearing is based on computational fluid dynamics theory. In this paper, all of the models are developed in solidworks2007, which are shown in Figure 3 and Figure 4, with the mesh generating in Gambit. Because of the complexity of model, the model is cut into several parts in order to get a better mesh. The mesh is consisted of hexahedral and tetrahedral grids. In order to improve the mesh quality and decrease mesh number, the regular zone is divided by hexahedral grids, and the irregular zone is done by tetrahedral grids, in which case can raise the accuracy of the simulation results and shorten the computer convergent cycle. After the mesh operation, the node number of oil pad in sufficient state is 1630916, that in other state is 2024357.

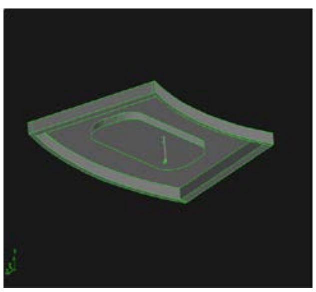

Figure 3: Oil Pad In Sufficient State

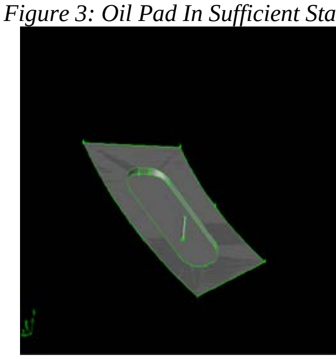

Figure 4: Oil Pad In Deficient State

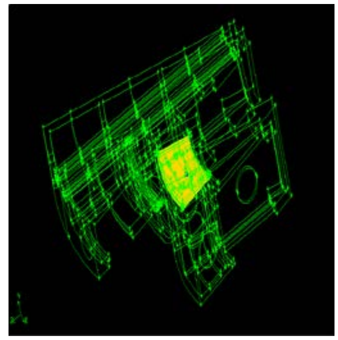

Figure 5: Mesh Grid In Sufficient Oil State

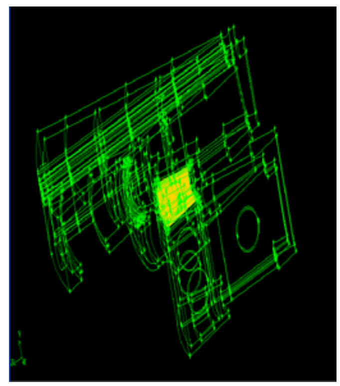

Figure 6: Mesh Grid In Deficient Oil State

5. SIMULATION&ANALYSIS

Nowadays, the temperature field distribution of heavy hydrostatic bearing is attractive to international experts and scholars. With the improvement of rotational speed of hydrostatic bearing, lubricate temperature rises and thermal deformation of friction pairs intensifies, which limits the rotational speed, Rotary precision and Processing accuracy. Thus, in this paper, simulation research is conduct to find the relationship between oil state and temperature field. The sufficient oil state is that the leaking groove is full of lubricant; while, the deficient state is that the oil doesn't fill the leaking groove, which has no effect on the oil in hydrostatic bearing. The boundary condition of this analysis is that: inlet velocity is 2 m/s; outlet boundary is outflow; Initial oil temperature is 290 K; oil density is 890 kg/m3; thermal conductivity is 0.151 W/(m · K); viscosity is 0.058 kg/(m · s); the material of friction pairs is steel. Convective heat transfer happens on the touch faces of air and friction pairs, of which parameter is 5 W/(m^2 · K) , in the 290 K environment. Both of the states are conducted respectively at the spinal speed 20rpm, 30rpm, 40rpm, 50rpm, 60rpm, 70rpm, 80rpm.

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5.1 Temperature Data in Sufficient Oil State

It is concluded that the high temperature zone is on the one side when rotating at 20rpm in Figure 7. While, when the spinal is 50rpm, which is shown in Figure 8, the temperature zone is changed to the outer side of bearing. In a word, the sufficient oil state will affect the temperature distribution of hydrostatic bearing.

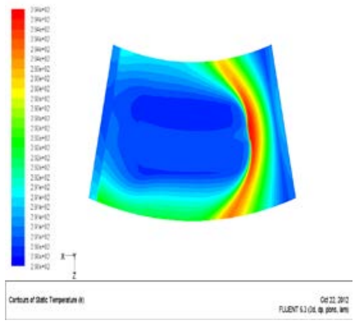

Figure 7: Temperature Field At 20rpm In Sufficient State

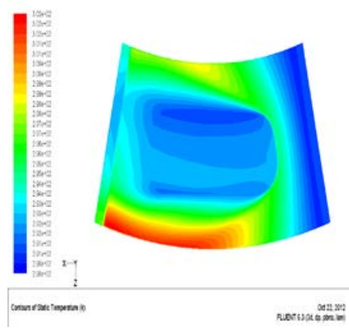

Figure 8: Temperature Field At 50rpm In Sufficient State

5.2 Temperature Data in Deficient Oil State

Figure 9 and Figure 10 display the temperature distribution contour, respectively at 20rpm and 50rpm. We can see that the high temperature zone almost has no change.

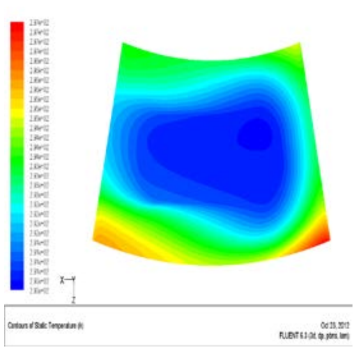

Figure 9: Temperature Field At 20rpm In Deficient State

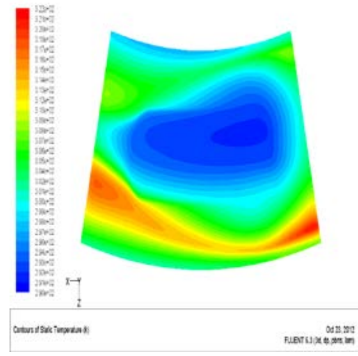

Figure 10: Temperature Field At 50rpm In Deficient State

5.3 Comparison of Both Oil States

In Figure 11, it can be seen that the temperature rise goes up with the spinal speed increasing along an approximate linearity. And the temperature in sufficient state is lower than that in deficient state at each spinal velocity. According to the results from the simulation, it is also known that the sufficient oil state determines the temperature distribution, which is different from the other oil state.

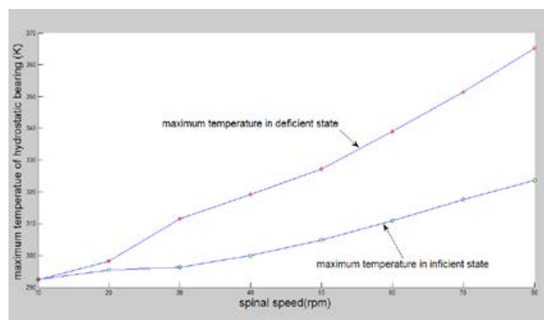

Figure 11: Comparison Curve Of Both States

6. CONCLUSION

In this paper, FLUENT6.5 is used to simulate the temperature field of hydrostatic bearing. According to the results we acquired, it is concluded that the oil state will affect the temperature distribution and temperature rise, which has never been found before. And this conclusion will support the theory basis of the security of hydrostatic bearing operation.

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