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Influence Research of Cavity Shapes on Temperature Field of Multi-pad Hydrostatic Thrust Bearing

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Abstract

In order to compute the thermal deformation of the hydrostatic thrust bearing in the heavy type CNC equipments, a numerical research concerning temperature field of multi-pad hydrostatic thrust bearing having sector cavity, rectangular cavity, I-shaped cavity and ellipse cavity is described. Three-dimensional temperature field of gap fluid between the rotation worktable and the base has been simulated by using Finite Volume Method of CFX. This study analyzes the influence of cavity shape on the bearing temperature performance according to computational fluid dynamics and lubricating theory. It has revealed its temperature distribution. The simulation results demonstrate that an improved characteristic will be affected by cavity shape easily. Through this method, the safety of a multi-pad hydrostatic thrust bearing having different cavities can be forecasted, and the optimal design of such products can be achieved, so it can provide reasonable data for design, lubrication, experience and thermal deformation computation for hydrostatic thrust bearing in the heavy CNC equipments.

Keywords: *Different cavity shapes, Multi-pad, Hydrostatic thrust bearing, Temperature field, Simulation research*

1. Introduction

Hydrostatic thrust bearings have been used in many industrial heavy applications due to their favorable performance characteristics. These include high load-carrying capacity, zero wear of bearing surfaces, low friction at low or zero speeds, large fluid film stiffness and damping, reduced vibrations and good positional accuracy. Typical industrial applications of hydrostatic thrust bearings are in the machine tool industry, forest product industry and the slippers of axial piston pumps and motors. These have also been used in the Halle optical telescope. Hydrostatic thrust bearing systems have been extensively investigated by many researchers during the last few decals and their research efforts have been focused on various aspects concerning this class of the bearings. The following reports are important investigations concerning hydrostatic thrust bearings this time. T. A. Osman, M. dorid, Z .S. Safar and M. O. A. Mokhtar

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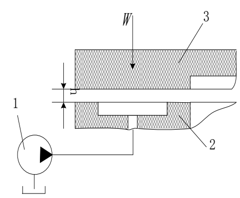
designed a test rig to study hydrostatic thrust bearing performance [1]. Good agreement has been obtained between predicted theoretical performance and that experimentally measured. J. D. Jackon and G. R. Symmos dealt with a pressure analysis of a hydrostatic thrust bearing taking into account the fluid inertia. It is shown that the same result can be obtained by a simple uni-directional flow analysis [2]. T. Jayachandra Prabhu and N. Ganesan have studied effects of tilt on the characteristics of multi-cavity hydrostatic thrust bearings under conditions of rotation and no rotation. The dimensionless load, flow, stiffness and damping were obtained and plotted for a range of the tilt parameter for experimentally useful aspects ratios. T. A. Osman, M. dorid, Z. S. Safar and M. O. A. mokhtar designed a dynamically loaded thrust bearing with as annular cavity [3-6]. They solved load capacity, bearing stiffness, damping coefficient and lubricant flow rate. Results conclude that the bearing performance characteristics are dependent on the bearing radii ratios, the sequence number, the bearing number and the tilt parameter [7]. V. K. Kapur and Kamlesh Verma studied the simultaneous effects of inertia and temperature on the performance of a hydrostatic thrust bearing. Numerical results for pressure distribution and load-carrying capacity were obtained at different step positions and film thickness ratios for several values of thermal conductivity. V. K. Kapur and J. S. Yadav studied variable viscosity and density effects in a porous hydrostatic thrust bearing. Interactions of inertia, the viscosity density variation due to temperature and the bearing material porosity were investigated [8]. The analysis results obtained are in good agreement with the experimental work. According, in recent years many studies showing the effect of surface roughness on the performance of hydrostatic circular thrust pad bearings have been reported in the literature. Sinhaasan R, Jain SC, Sharma SC. studied a comparative study of flexible thrust pad hydrostatic bearings with different restrictors [9]. C. K. Singh and D. V. Singh studied stiffness optimization of a variable restrictor compensated hydrostatic thrust bearing. Different bearing configurations were considered and it was reported that the addition of the stem enabled this bearing to support radial loads [10]. Statish C. Sharma analytically studied the performance of circular thrust pad hydrostatic bearing of various cavity shapes, i.e. triangular, square, rectangular etc. They compared results with the solutions obtained by an electrical analog technique [11]. Recently Statish C. Sharma analyzed the capillary compensated four cavities hydrostatic journal bearing with different geometric shapes of cavity. It was further reported that influence of cavity shape on the performance of capillary compensated circular thrust pad hydrostatic bearing. Statish C. Sharma used the Finite Element Method to compute the performance characteristics of a circular thrust pad hydrostatic bearing with circular, rectangular, elliptical and annular cavities. They finally gave out conclusions that the value of the fluid film pressure, the value of the bearing flow, the value of the load carrying capacity, the value of stiffness coefficient of four different kinds of cavities shapes [12]. Other researchers studied the temperature field of hydrostatic thrust bearing having circular cavity and sector cavity and researched on influence of oil cavity shapes on carrying capacity of heavy hydrostatic bearing [13-23].

Owing to rapid technological advancements in manufacturing techniques, the other cavity shape can be easily manufactured and can be used widely in the many industrial heavy applications. This paper studied that influence of cavity shape on the temperature performance of a constant flow hydrostatic thrust bearing.

2. Working principle of hydrostatic thrust bearing

A constant flow hydrostatic thrust bearing with annular cavity multi-pad is shown in Figure 1. The working principle of hydrostatic thrust bearing is that saving flow of the edge of oil cavity and worktable gap can form the loading capacity of hydrostatic bearing which can float the bearing spindle which can bear loads with the oil supplying system which can compulsively inject the lubricating oil into oil cavity between frictions [24, 25].



1—pump; 2—worktable; 3—rotation table; h—oil film thickness

Figure 1. Sketch map of principle of work of quantitative supply hydrostatic thrust bearing

3. Mathematical Model

Flow problem of fluid between the rotation worktable and base belongs to a laminar flow problem, and its mobility must meet mass conservation equation, momentum conservation equation and energy conservation equation [26, 27].

3.1 Mass conservation equation

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0. \qquad (1)$$

Where ρ is density (kg/m^3); t is time (s); u , v and w are components of speed vector $\vec{v}$ in the x , y and z direction.

3.2 Momentum conservation equation

$$\frac{\partial(\rho U)}{\partial t}+\nabla \bullet (\rho U \otimes U)=-\nabla p+\nabla \bullet \tau + S_M. \qquad (2)$$

Where S_M is momentum source; τ is pressure tensor.

3.3 Energy conservation equation

$$\frac{\partial(\rho T)}{\partial t}+div(\rho u T)=div\left(\frac{k}{c_p} gradT\right)+S_T. \qquad (3)$$

Where c_p is special heat capacitance (J/kg·K); T is temperature (K); k is fluid transfer heat coefficient; S_T is heat source term.

4. Cavity Shapes

In order to study the cavity shape impacting on the film temperature field, hydrostatic thrust bearing with rectangular cavity, sector cavity, ellipse cavity and I-shaped cavity are researched, the cavity shapes are shown in Figure 2.

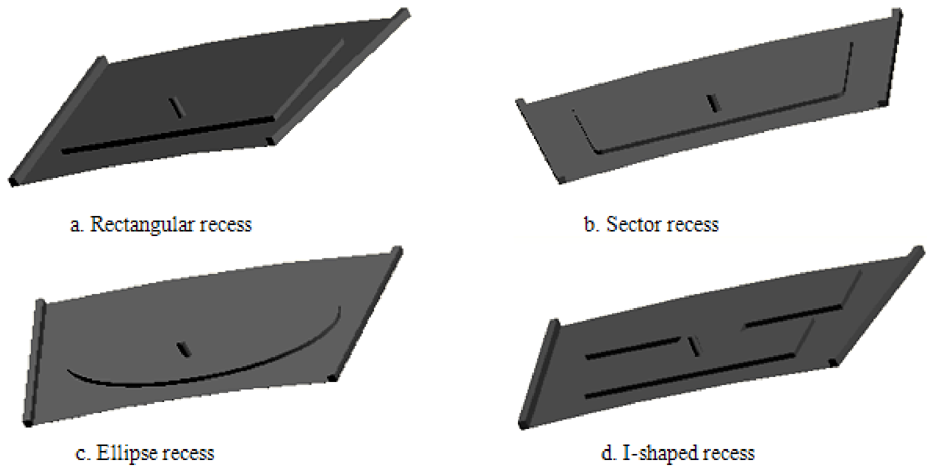


Figure 2. Clearance fluid model of four kinds of recess shapes

5. Grid Partition

The total number of the grid is 265376, and the quality distribution below 0.55 is 0, grid number between 0.55~0.9 is 4446, it accounts for the total 1.675%, 0.9~1.0 is 260930, it accounts for the total 98.325%.

6. Boundary Conditions

The boundary conditions used for the solution of temperature field are following; At the external boundary, temperature of oil is temperature of surrounding atmosphere; Temperature of lubricant through the hole is temperature of the oil tank; At the external boundary, pressure is 0.1MPa; The pressure for nodes on the pocket boundary is equal; The flow of lubricant through the hole is equal to the bearing input flow.

7. Results and Discussions

In order to study the cavity shape impacting on the film temperature field, when the inlet flow capacity is 100 kg/s, rotation velocity is 6rpm and choose viscosity of lubricating oil μ equals 0.0288 Pa·s, density ρ equals 900 kg/m^3, the cavity shape assign respectively rectangular cavity, sector cavity, ellipse cavity and I-shaped cavity, the three-dimensional temperature fields are obtained in CFX to be as Figure 3, Figure 4, Figure 5, Figure 6. The maximum temperature value of four kinds of shaped cavity hydrostatic bearings is shown in Table 1.

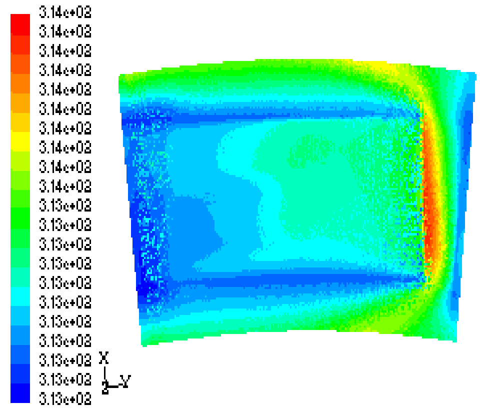


Figure 3. Temperature field of rectangular cavity

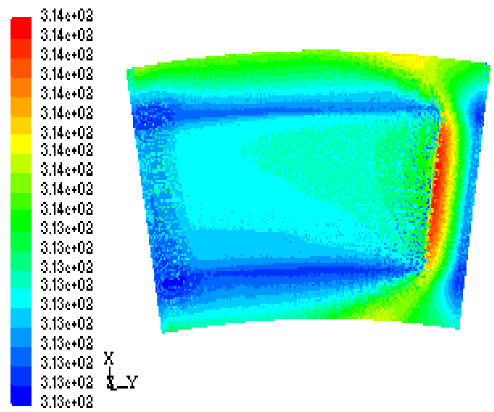


Figure 4. Temperature field of sector cavity

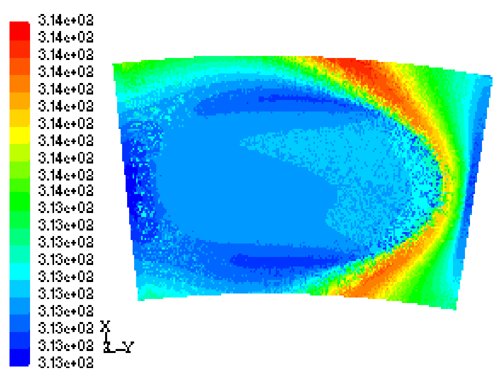


Figure 5. Temperature field of ellipse cavity

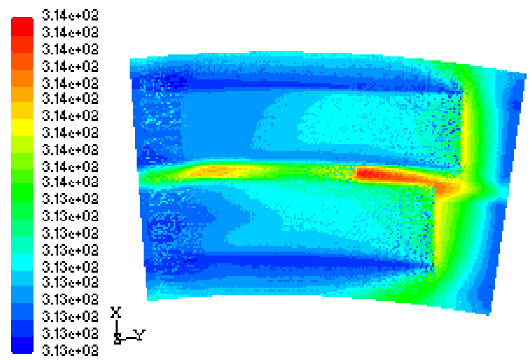


Figure 6. Temperature field of I-shaped cavity

Table 1. The maximum temperature value of four kinds of shaped cavity hydrostatic bearings (K)

	rectangular cavity	sector cavity	ellipse cavity	I-shaped cavity
maximum temperature	314.0432	314.0836	314.1451	314.1856

8. Conclusions

Numerical analysis of temperature field of multi-pad hydrostatic thrust bearing having rectangular cavity, sector cavity, ellipse cavity and I-shaped cavity reveals the following conclusions:

1) Three-dimensional temperature field of multi-pad hydrostatic thrust bearing having different cavity shapes is achieved through Computational Fluid Dynamics and the Finite Volume Method.

2) It solves the problem that temperature field cannot be measured directly hydrostatic thrust bearing in the heavy type CNC equipments because oil film is very thin in the fact project.

3) The results demonstrate that oil cavity temperature field is affected easily by oil cavity shape. The temperature of I-shaped cavity is the maximum.

4) The safety of a multi-pad hydrostatic thrust bearing having rectangular cavity, sector cavity, ellipse cavity and I-shaped cavity can be forecasted by using this model, and lay a foundation for thermal deformation of hydrostatic thrust bearing in the heavy type equipments, and the optimal design of such products can be achieved.

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