Simulation Design and Numerical Analysis of Bearing Capacity of Water Lubricated Thrust Bearing

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Abstract. Thrust bearing is widely used in all kinds of rotating machines, and the lubrication capacity and bearing capacity of sliding bearing have very important evaluation parameters for the performance indexes of safety, economy and stability of the machine. With the proposal of national industrialization strategy, the development direction of all kinds of machines to high-speed and large-scale is becoming more and more clear. Therefore, the analysis of bearing capacity and lubrication performance of sliding bearing is becoming more and more important. The main goal of this paper is to carry out simulation design and optimization of bearing capacity of thrust bearing, and carry out numerical analysis of bearing capacity after optimization design. In the aspect of research methods, this paper applies the Reynolds equation and its boundary conditions to the analysis of machine bearing capacity, and discretizes the equation to a certain extent, so as to ensure that the factors that change the performance of water lubricated thrust bearing with the change of applicable conditions are taken into account. The hydrodynamic lubrication value of the water lubricated thrust bearing obtained by the experiment in this paper is consistent with the temperature field value of the finite solution, which shows that the measurement results of the water film thickness, pressure distribution and the temperature of the thrust pad in the experiment are in good agreement with the theoretical calculation results.

1. Introduction
As the main component of all kinds of rotating machinery, the water lubricated thrust bearing is a kind of bearing which uses the relative motion of converging water wedge to produce the dynamic pressure support force. Whether the thrust performance is good or not is directly related to the operation safety of rotating machinery [1-2]. In previous applications, most thrust bearings use the characteristics of oil as lubricating medium, which obviously has the risk of pollution and oil leakage [3]. If water is used as the medium, it can play a huge role in environmental protection, energy conservation and safety. At the same time, due to the non-combustibility and high availability of water, it means that the dependence on crude oil can be greatly alleviated, and the technical problems such as friction and non-functional consumption caused by relative motion can be reduced [4-5]. It is a lubricating medium with wide application prospect after replacing oil medium in many occasions [6]. How to widely use
the mechanical transmission system of water medium to achieve the purpose of high efficiency, energy saving and environmental protection have become an important development direction in the field of mechanical dynamics research [7].

As an important research area of rotational dynamics, Chinese researchers have done a lot of research in this field, and some research teams and universities have also formed special research organizations [8]. Worldwide research began in the 1970s. Researchers first conducted in-depth analysis on the bearing capacity of oil film, which directly contributed to the intersection of bearing capacity dynamics and lubrication theory [9]. We know that for the bearing capacity of the bearing rotor system, the non-linear oil film force is an important factor, but it should also be noted rationally that most of the current oil film models have obvious defects, and the numerical model value is not accurate [10]. Generally, the research on the bearing capacity of thrust bearing mainly focuses on the oil lubricated thrust bearing, but not much on the water lubrication, especially in the special application scenario. The research on these aspects also has the following defects: first, the change trend and mechanism analysis of the parameters characteristics of the water lubricated thrust bearing are not perfect; second, there are few researches on the solution and distribution of friction heat on the friction surface; thirdly, there are few researches on the elastic deformation of water lubricated thrust bearing [11-12].

In this paper, it is pointed out that the calculation of water film bearing capacity is actually to solve the Reynolds equation with the most accurate method, so as to obtain the distribution of water film bearing capacity [13]. Reynolds equation is a two-dimensional second-order partial differential equation combining continuity equation and momentum equation. Solving hydrodynamic lubrication problem is the basic application of Reynolds equation in engineering field [14]. At present, the research on the bearing capacity boundary of oil film and water film is also developing constantly. Reynolds boundary condition only retains the positive part of pressure, and takes the negative part of pressure as zero. It is considered that the negative area is the fracture cavity area of oil film, and this boundary condition is called boundary theory [15]. In order to optimize the bearing structure, improve the bearing capacity and reduce the friction, the research on the bearing capacity of water lubricated thrust bearing is carried out to explore the influence of water lubricated mechanism and geometry on the pressure and temperature fields.

2. Methods

2.1 Fluid Lubrication Theory of Sliding Bearing

Generally speaking, there are three ways of lubrication: solid lubrication, boundary lubrication and fluid lubrication. Among them, fluid lubrication is recognized as the best way. The purpose of lubrication is to separate the surfaces of two materials in relative motion with one material, so as to minimize the friction between the two surfaces in relative motion, so as to protect the two contact surfaces. It is very important to study the lubrication mechanism of sliding bearing.

The formation of hydrodynamic oil film needs two surfaces of relative motion to form convergent geometry space and relative velocity of motion, and also needs the help of fluid. The lubricating oil film pressure between the gaps supports the balanced external load, which is hydrodynamic lubrication. Because the two surfaces of relative motion do not contact directly, but only the relative interaction between the fluid molecules, therefore, the friction property of the fluid determines the dry property of the fluid.

2.2 Reynolds Equation

Reynolds equation is generally derived from hydrodynamics and navistokes equation. From the previous description, we know that in terms of stability, the stability of cylindrical bearing, oil wedge bearing, elliptical bearing and tilting pad bearing is improved in turn. The structure of cylindrical bearing is the simplest, and the bearing capacity is strong, but the stability is poor. In view of the static
load of the limited width sliding bearing, we study the pressure of the immeasurable oil film with the Reynolds equation as the research algorithm. The dimensionless form of the Reynolds equation is:

$$\frac{\partial}{\partial r} \left( \frac{h^3}{\mu} \frac{\partial p}{\partial r} \right) + \frac{1}{r} \frac{\partial}{\partial \varphi} \left( \frac{h^3}{\mu} \frac{\partial p}{\partial \varphi} \right) = 6r \omega \frac{\partial h}{\partial \varphi}$$  \hspace{1cm} (1)

Where \( p \) is the water film pressure, \( \mu \) is the dynamic viscosity of water, \( h \) is the thickness of water film, \( \omega \) is the angular velocity, \( R \) and \( \varphi \) are the polar diameter and angle of any point on the thrust pad surface.

2.3 Boundary Convergence Criteria of Reynolds Equation

Reasonable boundary conditions not only accord with the actual situation of fluid lubrication, but also deal with the boundary conditions of Reynolds equation is very important. In order to judge whether the result of each iteration has reached the expected accuracy and decide whether the iteration can be terminated, the boundary condition treatment of Reynolds equation is very important. In order to accelerate the convergence rate, it is necessary to consider not only the actual situation of hydrodynamic lubrication, but also to judge whether the result of each iteration has reached enough accuracy, usually according to whether the load and pressure converge. The pressure convergence criteria are:

$$W = k \int_0^1 \int_0^2 p r d\varphi = k \sum P_{i,j} \cdot S_{i,j}$$  \hspace{1cm} (2)

Where, \( P_{i,j} \) represents the water film pressure value of node \((i,j)\), \( S_{i,j} \) represents the area enclosed by four nodes \((i,j)\), \((i+1,j)\), \((i+1,j+1)\), and \((i,j+1)\).

For the elastic deformation of the friction pair of the thrust bearing of the submersible pump, when the force on the thrust ring and the thrust pad reach the balance, the thickness of the water film on the two friction surfaces reaches the ideal state, which has nothing to do with the geometry and material properties. The calculation in this paper does not consider the influence of the elastic change and the thickness of the water film. Its application is limited to the finite iterative method to get the Reynolds equation and the parameter distribution of the thickness, pressure and friction of the water film bearing capacity.

3. Experiments

3.1 Simulation Design of Bearing

In order to make the established objective function meet the requirements at the beginning of design, the effective strategy is to establish the optimization objective function, optimize the single objective with genetic algorithm, and then establish the objective function according to the optimization results, so as to achieve the effect of optimizing the comprehensive performance of hydrodynamic bearing. The design first analyzes the eccentricity according to the known data, then determines the viscosity of the lubricating oil, and then considers the performance of the bearing capacity from the perspective of the bearing capacity, and considers the constraints of the variables involved.

3.2 Simulation Design of Bearing

In different subjects, the most important task of researchers is to find out different codes to solve according to different mechanisms. This way can also be called to imitate the cross mutation of natural biological genetic algorithm, so as to search the optimal solution. The steps are as follows: first, select coding strategy, and set parameters as the execution space of feasible region; second, determine specific genetic strategy, specify fitness function, select cross mutation method, and solve the probability of mutation to generate random initialization population; third, calculate the initial value of each string in the initialization population. Finally, when the number of iterations reaches the preset value, judge whether the population performance has reached the specific index synchronously. If the
specific index is reached, stop the iteration. If not, return to the previous step and continue the iteration until the specific index is reached.

4. Discussion and Results

4.1 Numerical Analysis

APDL is the ANSYS parameter design language, which is a high-level language with line by line explanation. It can realize better parametric finite analysis and system optimization secondary development.

The convective heat transfer of water lubricated thrust bearing belongs to forced convective heat transfer, which will generate friction heat in the thrust bearing and eventually dissipate in the way of convective heat. Due to the lack of experimental data and experience guidance, and the different shapes of thrust bearing, it is difficult to directly determine the heat transfer coefficient. In this paper, the bearing capacity of water lubricated thrust bearing is calculated according to the empirical formula, and the calculated bearing capacity coefficient is shown in Table 1 below.

| Water temperature | Kinematic viscosity | Thermal conductivity | Planck number |
|-------------------|--------------------|----------------------|--------------|
| ℃                 | m²×s⁻¹             | w×(m²×C⁻¹)          | Pr           |
| 20                | 7.268×10⁶          | 0.598                | 7.01         |
| 25                | 7.196×10⁶          | 0.605                | 6.45         |
| 50                | 7.121×10⁶          | 0.613                | 6.17         |
| 75                | 7.117×10⁶          | 0.621                | 5.71         |
| 99                | 7.103×10⁶          | 0.636                | 5.35         |

When the bearing speed reaches the peak value, the axial thrust will tend to a stable state, and with the increase of the speed, the friction heat will gradually strengthen. The two contact surfaces will reduce the relative friction due to the increase of the surface temperature, so they will be in the state of indirect friction and boundary friction, and may even form hydrodynamic lubrication, and indirectly increase the contact surface, so that the cooling condition will be strengthened, and the friction coefficient will be reduced. After the working state of the bearing is stable, the purpose of the bearing capacity test of the water lubricated thrust is to analyze the relationship between the bearing capacity and the water film pressure between the end faces of the thrust bearing under the stable working condition. Under the condition of the shaft speed and the steering thrust, the water film depth and the external pressure are gradually improved from small to large, so as to achieve the optimized effect of the bearing capacity. The optimized bearing The load index is shown in Figure 1.
4.2 Design Application Prospect
In all kinds of working conditions, it can get better application practice. The measured data of each collection point are relatively consistent with the theoretical calculation results of bearing capacity, which is the best result of theoretical verification. In the theoretical calculation, only the friction of the thrust ring and the boundary condition of the heat flux of the thrust pad are considered, while the main factor that the experimental results are lower than the theoretical values is the lack of environmental consideration of the boundary hot spots in the convective environment.

The actual measured value of the maximum bearing capacity of the end face of the thrust bearing is lower than the theoretical value. There must be a certain distance between the water film pressure sensor and the end face of the friction pair in the thrust ring. In application, the measured data of water film pressure is often slightly lower than the actual value. By redefining the heat flux boundary, the results of measurement are basically consistent with the ideal results, which proves the correctness of calculation and the scientificity of the experimental process. At the same time, it also shows that the experimental device has a good function of measuring the bearing capacity index, and has practical application value.

5. Conclusions
In this paper, based on the finite positive solution to verify the bearing capacity of water lubricated thrust bearing, the relevant experimental research is carried out. In the application of the basic principles of fluid science, the Reynolds formula is introduced and optimized to upgrade the accuracy and convenience of the solution. The results show that the friction coefficient, water film thickness, pressure distribution and temperature distribution of thrust pad will affect the bearing capacity. Considering the bearing capacity of hydrodynamic sliding bearing from the bearing capacity, the weighting factor of single objective can be calculated, so as to achieve the improvement of comprehensive performance from single objective to multi-objective, and ensure the small temperature increase to promote the large increase of bearing capacity.
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