Characteristic Analysis of Water Lubricated Plain Journal Bearing under Transient Load

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Abstract. Transient load has a huge impact on the life and stability of water-lubricated bearings. In this paper work, CFD software is used to analyse the dynamic characteristic of water lubricated bearings under different transient loads of 500N, 1000N, 2000N and 3000N. The water film pressure contour distribution at different transient time was given. The time-varying relationships between the different transient loads with bearing forces, the journal displacement, the maximum value of water film pressure as well as the minimum value of water film thickness are obtained. The results show that with the increase of transient load, the effective bearing area of dynamic water pressure film decreases, and the maximum pressure increases. The bearing forces, the journal displacement, the maximum value of water film pressure as well as the minimum value of water film thickness will increase fast.

1. Introduction

As the core part of the rotating machinery, which is lubricated by a liquid with low-viscosity like water, the water-lubricated bearing has the advantages of high specific heat, low viscosity, low friction and environmental protection. The film thickness of water lubricated bearing is relatively small, it has good vibration-resistance and can improve the stability of rotor system[1]. In recent years, with the increasing application of water-lubricated bearings in Marine System, submarine, pump and other industries, water-lubricated bearings have gotten more and more attention, and many studies were done. SinghU [2] studied the variation of bearing film thickness, bearing capacity and temperature field at different rotor speeds using two-dimensional Reynolds equation. Litwin et Al [3] tested the pressure distribution of the multi-groove water lubricated bearings. Now Computational Fluid Dynamics (CFD) method is more fast and easy to solve complex geometric models than traditional Reynolds equations. By using the CFD software, Cabrera [4] analysed the pressure contour distribution of the bearing, and the verification test was done. Zhang [5] studied the influence factors of stiffness coefficients in plain journal bearings. Afterwards, a lot of CFD studies are done to find the influence factors of the relative clearance length-to-diameter ratio, diameter of bearing and journal speed on the stiffness. Tanamal and Ryan [6] used a CFD approach to simulate the fluid flow in a water lubricated journal bearing with equal spaced axial grooves. Lubricant pressure and velocity profiles were obtained and compared with available theoretical and experimental results. Liu [7] found that The CFD and FSI techniques were shown to be a useful tool for the investigation of the hydrodynamic and elasto-hydrodynamic lubrication of a rotor–bearing system. Xie[8] using the fluent software, investigated the lubrication mechanism of the water lubricated bearing through numerical
methods, focusing on the pressure and thickness distributions as well as the variations of the bearing capacity and the friction force. During the process of starting and stopping of the machine, the water lubricated bearings will suffer a great transient force. The water film pressure, water film thickness and stiffness and damping will change greatly. Ma Jinkui [9] used different type of pulses to study the variation of the Axis trajectory of the rotor, the maximum oil film pressure and the minimum oil film thickness. TICHY [10] studied the influence factors of the transverse impact load, and the time on the rotor axial trajectory. Chen [11] used the CFD method to study the liquid annular seals and its dynamic analysis under transient load.

In this paper, the Dynamic Mesh model of Fluent software is utilized to analyze the characteristic of water-lubricated bearings under different transient loads, the rotor displacement, the water film force, the minimum value of water film thickness as well as the maximum value of water film pressure are studied.

2. Theoretical Analyses

In this work, we assume that the model is completely submersed in a liquid like water. Fig.1 gives a schematic when the bearing is subjected to an unchangeable load. When the journal deviates with a small distance from the center of bearing, the water film squeezed and the dynamic pressure produced. The journal eccentricity (e) is the small distance between the center of journal the bearing. it can be decomposed into components along the X and Y direction.

![Figure 1. The bearing model](image)

In this model, the bearing forces can be expressed as:

\[ F_x = -\int_{\phi_1}^{\phi_2} \int_{r_1}^{L \frac{r}{2}} p \cos \phi rd\phi dz \]  
\[ F_y = -\int_{\phi_1}^{\phi_2} \int_{r_1}^{L \frac{r}{2}} p \sin \phi rd\phi dz \]

3. CFD Model and Results

3.1. CFD Model

In this paper, CFD models are built and meshed using ICEM CFD19.2 software. The grids are hexahedron grids. The double precision calculations are used. The CFD model of water lubricated bearing can be seen in Figure 2. Parameters of the bearing is given in Table 1, the water properties at 25°C listed in Table 2.
In this CFD analysis, we choose pressure-based solver method and pressure–velocity coupling way is built with SIMPLE Calgorithm. A second order up wind discretization is set up for the momentum equations. The residual terms use the convergence tolerance of $10^{-6}$ .One side model of the film clearance is set as pressure inlet boundary condition, the other is pressure outlet boundary condition. Both the pressure inlet and outlet are 0Pa due to the bearing completely submersed .We set the outer surface as "stationary wall" boundary condition and the inner surface as "moving wall". Both two walls are set as No-slip condition.

### 3.2. The Water Film Pressure Distribution under Different Transient Loads

Under the condition of constant journal speed of 3000r/min, when the water lubricated bearing is subjected to a load, the relative moving between bearing and rotor promotes hydrodynamic pressure film, which can avoid the direct contact between the bearing and journal.

In this analysis, we choose the same transient time of 0.05s, so as to know the influence of different transient loads.Fig.3 shows the water film pressure distribution at transient time 0.05s under different loads of 500N, 1000N, 2000N, 3000N. The dynamic water film pressure distribution shows that with the increase of transient load, the effective bearing area of dynamic water pressure film decreases, but the maximum pressure increases.
3.3. The Water Film Pressure Distribution at Different Transient Time

We choose the same transient load of 1000N. Under the journal speed of 3000r/min and transient load of 1000N, four different times like 0.025s, 0.05s, 0.075s and 0.1s are chosen for the pressure distribution, as shown in fig 4 below. It shows that the pressure of water film is relatively large at time 0.025s. With time increasing, the change of the dynamic pressure becomes smaller, and the effective bearing area of the water film comes to a balance.
3.4. Dynamic Characteristic Analysis

Fig.5 illustrates the time-varying change of bearing reaction forces when the bearing subjected to different vertical transient loads (vertical direction) like 500N, 1000N, 2000N, and 3000N, respectively. It can be seen that there is a great increase of the bearing reaction force, which mainly occurred in the vertical direction, the horizontal force is small and almost has no change. With the increase of time, the bearing reaction forces come to a balance.

![Figure 5. The time-varying change of bearing reaction forces](image)

Fig.6 shows the time-varying change of journal displacements when the bearing subjected to different vertical transient loads (vertical direction) like 500N, 1000N, 2000N, and 3000N, respectively. It can be seen that there is a great increase of the journal displacements. With the increase of time, journal displacements come to a balance. Fig.12 also show that when the load increases, the shorter time the rotor needs to come to a balance.

![Figure 6. The time-varying change of journal displacements](image)

Fig.7 illustrates the time-varying change of maximum film pressure when the bearing subjected to different vertical transient loads (vertical direction) like 500N, 1000N, 2000N, and 3000N, respectively. It can be seen that there is a great increase, when the load increases, the film pressure increases too. When rotor subjected to 500N, the film pressure finally is $1.0\times10^5$pa, when the rotor subjected to 3000N, the pressure finally is $8.9\times10^5$pa.
Figure 7. The time-varying change of maximum water film pressure

Fig. 8 shows minimum value of water film thickness changing with time-varying when the bearing subjected to different vertical transient loads (vertical direction) like 500N, 1000N, 2000N, and 3000N, respectively. It can be seen that there is a great increase. With the increasing time, minimum value of water film thickness comes to a balance. The film thickness decreases when the load increases. When the rotor subjected to 500N, it finally comes to 0.051mm, when the rotor subjected to 3000N; the value finally is 0.016mm.

Figure 8. The time-varying change of minimum water film thickness

4. Conclusions
In this paper, CFD software is taken to study the dynamic characteristic of water lubricated bearing. The results show that the transient load has a huge impact on the characteristics of water lubricated bearing. There is an "impact effect" on the water film pressure, the water film thickness and the journal displacement, all the parameters mentioned above increase rapidly and then come to a balance. With the increase of transient load, the effective bearing area of dynamic water pressure film decreases, and the maximum pressure increases.

Nomenclature:
c: radial clearance
D: journal diameter
L: bearing length
N: rotor speed
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