Study on water lubricated bearings of high speed pump based on numerical simulation

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Abstract. A method is presented for calculating and analyzing the performance of water lubricated bearing of high speed pump under different structure. In present work, six kinds of bearings in different radial clearance(C), which are 0.02, 0.04, 0.06, 0.08, 0.10 and 0.12 respectively, under the same minimum water film thickness, have been designed. The models are built by CREO and numerical simulated by ansys. The main content of the present work is to analyze the relationship between the pressure and the load carrying capacity with different radial clearance(C) by ansys workbench based on Fluid-Solid coupling through ansys workbench. The stress deformations of bearings are also acquired through thermal-structure coupling. From the comparing result among the numerical analysis under the six different model of water lubricated bearing, the relationship between radial clearance(C) and load carrying capacity, as well as the deformation of bearing under different radial clearance(C), are obtained. Further, results indicates that, a proper selection of radial clearance(C) is essential to enhance the bearing performance.

1. Introduction
The capability for water lubricated bearings is critical importance for efficient design and performance of high speed pump due to its good rotation accuracy, excellent damping property, and other advantages. In most cases, the water lubricated bearings determine the life of high speed pump. Over the last several decades, considerable effort from both experimental and analytical fronts has been devoted to understanding the effect of water film and journal bearing. Singh U studies the influence of rotating speed on the performance of hydrodynamic journal bearing based on two-dimension reynolds equation, energy equation and heat conduction equation [1]. Alex introduces a mix elasto-hydrodynamic lubrication model using finite element method based on relaxed iterative method to calculate the performance of water film [2]. Backar.S researches hydrodynamic journal bearing under different biolubricants through experiment [3]. GERTZOS K P gives a modified boundary condition using dynamic mesh method to obtain the distribution of flow field of lubricated bearing [4]. Gertzos obtains calculation results which is consistent with the experiment results to prove the applicability of the half Sommerfeld's boundary condition [5]. Ye Xiaoyan expresses the distribution of transient response and the best bearing clearance in water lubricated bearings of seawater-desalination pump[6-7]. But fluid lubricated bearings in high speed condition are studied in few papers. This paper studies on the optimum of radial clearance(C), which is a key parameter of load carrying capacity of journal bearing, based on fluid-solid coupling using computer fluid dynamics (CFD). In this paper, MFS(multifield solver), which based on the results of the solid domain used transient
kinetics and fluid domain used dynamic mesh, is used to achieve the date exchange through the fluid-solid interface under different radial clearance (C). The control equations of the fluid domain and solid domain are solved in the separation method to simulate the water film model. The purpose of this paper is to provide the theoretical basis and guidance of the journal bearing of the high speed rescue pump.

2. Mathematical Model

2.1. Water lubricated bearing model

The formation of Hydrodynamic Lubrication of water lubricated bearing can be divided into three stages: starting, unsteady operation and steady operation, which is shown in Fig 1. With the increasing of rotating speed, the load area of water film is larger, which will lead to the decreasing of friction force. Enough fluid under a certain rotating speed is carried to the axis gap to form water film, which separates the fluid and solid friction surface, to support external load. When steady state is reached, the journal is displaced from the bearing with a center distance (e), which is referred to the journal eccentricity ratio (\( \varepsilon \)) and the radial clearance (C).

![Fig.1 The work process of sliding bearing](image)

2.2. Model of water film

The design parameters of journal bearings based on the require of design are: diameter is 85mm, width is 100mm rotation speed is 8000r/min. For the purpose of acquiring the best radial clearance (C) of the water lubricated bearing, 6 groups of different radial clearance (C), which are 0.02, 0.04, 0.06, 0.08, 0.1, 0.12 mm respectively, under the same water film thickness, which is 0.05mm, are simulated and compared. Fig 2 shows the mesh of the water film.

![Fig.2 Structured mesh of the water film](image)
2.3. Basic equation

2.3.1. Control equation of CFD. The fluid flow and heat transfer are controlled by physical conservation law, such as law of momentum conservation, mass conservation and energy conservation law[8]. Control equation is the mathematical description of these conservation laws, the continuity equations and the motion equation of newton incompressible fluid.

Any flow question must meet mass conservation, which means the growth of mass of differential fluid in unit time is equal to the net weight of fluid flowed to the micro unit in the same time interval. Based on the mass conservation law, the former of mass conservation equation is:

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

Where \( \rho \) is density, \( t \) is time, \( u, v, w \) are the velocity component of the x, y and z direction.

Momentum conservation law is the basic law every flow system must need. This law, which can be called the Newton second law, should be expressed: the rate of change of momentum with time is equal to the sum of the external force exerted on the micro unit. Based on the law, the Navier-Stokes equation of the x, y and z direction can be deduced. Induce the vector symbol:

$$\text{div}(\mathbf{a}) = \frac{\partial a_x}{\partial x} + \frac{\partial a_y}{\partial y} + \frac{\partial a_z}{\partial z}, \text{grad}() = \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \frac{\partial}{\partial z}$$  \hspace{1cm} (2)

The former is:

$$\frac{\partial \rho u}{\partial t} + \text{div}(uu) = \mu \cdot \text{div}(\text{grad}(u)) - \frac{\partial p}{\partial x}$$

$$\frac{\partial \rho v}{\partial t} + \text{div}(vv) = \mu \cdot \text{div}(\text{grad}(v)) - \frac{\partial p}{\partial y}$$

$$\frac{\partial \rho w}{\partial t} + \text{div}(ww) = \mu \cdot \text{div}(\text{grad}(w)) - \frac{\partial p}{\partial z}$$  \hspace{1cm} (3)

Where \( \rho \) is density; \( t \) is time; \( u, v, w \) are the velocity component of the x, y and z direction; \( p \) is pressure, \( \mu \) is dynamic viscosity.

2.3.2. Fluid-Solid coupling equation. The stress formula is:

$$\sigma_{ij} = \lim_{\Delta A_i \to 0} \left( \frac{\Delta F_i}{\Delta A_i} \right)$$  \hspace{1cm} (4)

Where \( \Delta F_i \) is force application along the i direction; \( \Delta A_i \) is the force bearing along the i direction. The former of constitutive equation is

$$\sigma_{xx} = \frac{E(1-\mu)}{(1+\mu)(1-2\mu)} \left( \varepsilon_{xx} + \frac{\mu}{1-\mu} \varepsilon_{yy} + \frac{\mu}{1-\mu} \varepsilon_{zz} \right)$$

$$\sigma_{xx} = \frac{E(1-\mu)}{(1+\mu)(1-2\mu)} \left( \varepsilon_{xx} + \frac{\mu}{1-\mu} \varepsilon_{yy} + \frac{\mu}{1-\mu} \varepsilon_{zz} \right)$$

$$\sigma_{xx} = \frac{E(1-\mu)}{(1+\mu)(1-2\mu)} \left( \varepsilon_{xx} + \frac{\mu}{1-\mu} \varepsilon_{yy} + \frac{\mu}{1-\mu} \varepsilon_{zz} \right)$$
\[
\tau_{xy} = \frac{E}{2(1+\mu)} \gamma_{xy}, \quad \tau_{yz} = \frac{E}{2(1+\mu)} \gamma_{yz}, \quad \tau_{zx} = \frac{E}{2(1+\mu)} \gamma_{zx}
\]  

(5)

Where \( \sigma \) is stress component, \( \tau \) and \( \xi \) are strain components, \( \gamma \) is shear stress component, \( \mu \) is poisson ratio, \( E \) is elastic modulus.

Calculation scheme

Fig. 3 fluid-solid coupling calculation scheme

Fig. 3 shows calculation scheme of fluid-solid coupling based on CFD. When calculating transient fluid field of bearing-rotor system, bearing and fluid interact that fluid force causes structure deformation of bearing and the deformation effects fluid field which cause the change of water film pressure distribution and then its carrying capacity that in turn effects bearing structure. Finally, the laws of water film carrying capacity distribution and other parameters iterative coupling operation can be obtained.

3. Analysis and result

The pressure distribution vs. the radial clearance (C) is given in Fig. 4. The hydrodynamic water film generates the blue zones which are negative pressure zones, and the red zones which are the positive pressure zones. Hydrodynamic performance of journal bearing depends primarily on the distribution of the positive pressure zones and peak value. In the minimum film thickness of steady state condition, wedge-shaped area of convergence zone and divergence zone makes up the water film. The pressure of the convergence zone drops significantly after the positive pressure arriving the peak value. The pressure increases gradually to positive pressure after the peak of negative pressure.
C=0.02           C=0.04     C=0.06
C=0.08                        C=0.10     C=0.12

Fig. 4 The water film pressure in different radial clearance (C)

C=0.02       C=0.04          C=0.06
C=0.08                                                   C=0.10     C=0.12

Fig. 5 The water film pressure in circus direction in different radial clearance (C)

In order to show the pressure distribution more intuitive and clearly, the pressure distribution of the circus direction is presented in Fig. 5. In Fig. 5, three circus, which are based on the ratio of the current
length vs the whole length of the bearing, are extracted from the pressure of the bearing inner surface. It is obvious that, with radial clearance $(C)$ increasing, the peak of positive pressure is decreasing.

During the hydrodynamic lubrication created by water-lubricated bearing, the deformation of bearing inner surface, which is formed by the pressure of water film, changes the thickness of water film. The change has an influence on the distribution of pressure of water film. This process is fluid-solid coupling. The results obtained from coupling the interaction of flow-solid can predict and simulate the performance of bearing.

To improve the bearing performance, a new graphite alloy F50C is used to make the bearing. The property of F50C is: Rockwell hardness is 26.1; Tensile yield strength is 15.07 MPa; Young's modulus is 429.03 MPa; Tensile elongation is 94%; Coefficient of expansion is 6.24E-05.

According to the pressure of water film of the wall of bearing in Fig.6, it is inferred to cause the micro-deformation of inner surface, and then the thickness of water film changes. There is no difference on the distribution between the deformation and pressure of water film. The deformation of inner surface of bearing is in direct proportion to the radial clearance $(C)$.

![Fig.6 The deformation of bearing inner wall in different radial clearance $(C)$](image)

The film capacity, ax deformation and max pressure under different radial clearance $(C)$ are plotted in Fig.7. As is shown in Fig.7, the capacity of water film, the max deformation and pressure are in line with the same tendency of the growth of radial clearance $(C)$. Of all the radial clearance $(C)$ points, the values of the three parameters reach the peak at radial clearance $(C)$ 0.10 mm. The maximum value obtained at the point (radial clearance $(C)$ 0.10 mm) may be caused by the following reason: With the increasing of the radial clearance, the thickness of water film becomes larger which lead to greater load capacity, which refers to the effect of fluid friction is more significant. Further, when the radial clearance $(C)$ increase after radial clearance $(C)$ 0.10 mm, which may be the critical value, the hydrodynamic lubrication of water film may be damaged because of the excessive water film thickness.
4. Conclusion

In this paper, the relationship between radius clearance and performance of water film was investigated. First, six water film under different radius clearance was numerically simulated based on fluid-solid coupling and its pressure distribution were obtained. Performance of water film consists of film capacity, deformation of bearing and pressure distribution corresponding to different radial clearance reveals the critical effect of the radial clearance.

Also, this study can provide theoretical basis for water lubricated bearing designing with higher film capacity to ensure high efficiency of high speed pump.

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