Numerical simulation analysis of fluid-solid coupling of water-lubricated bearings

Yong Liu\textsuperscript{1a}, Xingsheng Lao\textsuperscript{1}, Chunhui Dai\textsuperscript{1} and Shiwei Yao\textsuperscript{1}
\textsuperscript{1} Wuhan Second Ship Design and Research Institute, NO.19, Yangqiaohu Avenue, Jiangxia District, Wuhan, Hubei, China
\textsuperscript{a}seasmile2004@qq.com

Abstract. The numerical simulation analysis of the fluid-solid coupling of the ship's boring water-lubricated bearing is carried out to study the influence law of the inclination and eccentricity of the rotating shaft on the pressure distribution and fluid flow state in the bearing. The results show that the tilt of the rotating shaft changes the shape of the inner flow passage of the water-lubricated bearing, resulting in unstable flow in the bearing. When rotating shaft is in normal, the pressure value in the water-lubricated bearing decreases first and then increases in the axial direction. However, after the rotation of the shaft is tilted, the change of the pressure value is the opposite; the stress of the rubber layer generally shows an increasing trend with the increase of the inclination angle.

1. Introduction
Water-lubricated bearings have the advantages of low cost, simple structure and convenient maintenance. Using water as working medium can save a lot of strategic resources such as oil and precious non-ferrous metals, and can fundamentally avoid oil pollution to water resources. It has broad application prospects in ships, hydraulics and deep-sea machinery [1] [2]. Therefore, water-lubricated bearings have attracted a great deal of attention as important objects in the fields of environmental science, materials science and mechanical engineering. However, due to the particularity of its structure and the complexity of the operating environment, it is relatively difficult to use finite element software for simulation research. Most of the current researches focus on analyzing its elastohydrodynamic lubrication mechanism and discussing it as a steady state problem. Little attention is paid to the flow field distribution characteristics in the gap of water-lubricated bearings under non-steady-state conditions. Wang Jiaxu et al. [3] proposed a research method for numerical simulation of water-lubricated bearings. Lu Lei et al. [4] carried out two-dimensional numerical simulation of six-groove water-lubricated rubber alloy bearings and obtained some meaningful conclusions. Wang Youqiang et al. [5] carried out numerical calculations on eight longitudinal groove water-softened rubber bearings, and obtained the variation law of friction coefficient with speed and load. Liu Yu et al. [6] and Tian Yuzhong [7] studied the influence of internal water tank structure on lubrication performance by means of MATLAB.

In this paper, the structure of the water-lubricated bearing of the ship is used as the object, and the computational fluid dynamics method is used to study the relationship between the internal pressure distribution characteristics of the water-lubricated bearing, the fluid flow and the groove structure, and the bearing deformation by numerical simulation. Interrelationships, these simulation results have important reference value for guiding material design and structural improvement.

2. Analysis model
The structure of the water lubricated bearing is shown in Figure 1. The rubber bearing is embedded in a steel sleeve. The rubber bearing has an outer diameter of 156 mm and the shaft has a diameter of 100
mm. The bearing material is a new type of polymer material, which is pressed from ultra-high molecular weight polyethylene powder and polyimide. The properties of the polymer materials are shown in the table 1. In the calculation, the shaft speed is 145 rad/s, the friction coefficient between the shaft and the bearing in the seawater is 0.0663, and the shaft inclination angles are 0.0917°, 0.183°, 0.275° and 0.367°, respectively.

| Table 1. Properties of the polymer materials. |
|----------------------------------------------|
| Density (g/cm³) | Hardness (HD) | Water absorption rate (%) | Young’s modulus (MPa) | Poisson’s ratio |
| 0.95           | 72.8          | 0.0289                  | 58.3                  | 0.49          |

![Diagram of water lubricated bearing structure.](image)

**Figure 1.** Schematic diagram of water lubricated bearing structure.

### 3. Results and discussion

(a) Pressure distribution equivalent map at h=0.8mm.  
(b) Pressure distribution equivalent map at h=0.6mm.  
(c) Pressure distribution equivalent map at h=0.4mm.  
(d) Pressure distribution equivalent map at h=0.2mm.

![Pressure fluctuation](image)

**Figure 2.** Equivalent diagram of pressure change at different tilt angles.
The water pressure bearing pressure cloud diagram is shown in Figure 2 at different tilt angles. It can be seen that as the inclination angle increases, the maximum pressure value in the water-lubricated bearing also increases, and the maximum value appears at the groove-to-bearing transition. When h=0.4mm, the upper end of the groove of the water-lubricated bearing fluctuates. When h=0.2mm, there is more obvious fluctuation, which indicates that the flow field fluctuation in the water-lubricated bearing increases with the increase of the inclination angle.

**Figure 3.** Pressure changes in the water lubrication x=0 section.
Figure 3(a)-(e) show the pressure changes in the water lubrication x=0 section under different inclination angles of the rotating shaft. It can be seen that in the water-lubricated bearing, the pressure at any radial height is consistent with the change in the axial direction. Moreover, when the rotation axis does not tilt, that is, h=1.0, the pressure value of the bearing at the same radial height decreases first and then increases in the z direction; and when the rotation axis is inclined, that is, h=0.6 mm, h=0.4 mm and h=0.2 mm, the pressure values of the bearings at the same radial height increase first and then decrease in the z direction. Figure 3(f) is a summary of the maximum pressure values for different angles of inclination. It can be seen that as the angle of inclination increases, the pressure inside the bearing increases. The maximum pressure value at h=0.2 mm indicates that the fluid fluctuation in the bearing is the most severe.

Figure 4 shows the comparison of fluid flow velocity between the shaft and the bearing in the case where the shaft is tilted and eccentric. As can be seen from the figure, the fluid flow velocity grows as the inclination angle of the shaft increases. However, it does not change significantly with the change of the axis eccentricity. At the same level, the fluid velocity in the water-lubricated bearing when the shaft is tilted is greater than the fluid velocity when the shaft is eccentric.

![Graph](image1)

Figure 4. Comparison of maximum speed when the axis is tilted and eccentric.

Figure 5(a)-(d) are the deformation and stress clouds of the water lubricated bearings at different tilt angles of the rotating shaft, respectively. It can be seen that the deformation amount of the rubber layer in the water-lubricated bearing has a maximum value of 1.1475 μm when the inclination is 0.183°, and a minimum value of 0.8695 μm when the inclination is 0.275°. As the tilt angle increases, the amount of deformation of the rubber layer gradually concentrates toward the bottom of the bearing, and the stress of the rubber layer increases first, then decreases and then increases.
4. Conclusions

Through the numerical analysis of the fluid-solid coupling of the ship's boring water-lubricated bearing, the following conclusions are obtained:

(1) The inclination of the rotating shaft changes the shape of the flow passage of the water-lubricated bearing inner cavity, so that the instability of fluid flow in the bearing increases;

(2) When the shaft is not tilted, the pressure value in the water-lubricated bearing first decreases and then increases in the axial direction, and after the shaft is tilted, the pressure value in the water-lubricated bearing changes in the opposite direction;

(3) Under the same degree, the fluid velocity in the water-lubricated bearing when the shaft is tilted is greater than the fluid velocity when the shaft is eccentric.

Figure 5. Deformation and stress clouds of the water lubricated bearings
(4) The stress of the rubber layer increases first, then decreases and then increases with the increase of the inclination angle. Generally, the stress increases gradually.

5. References
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