Effect of geometric cavity shape and diameter on mechanical properties of water lubricated hydrostatic stern bearing

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Abstract: In order to improve the working condition of low speed, the stern bearing friction caused by poor lubrication of abnormal vibration and noise problem, this paper starts from the influence of problem, takes the circular, elliptical, square, I-shaped and triangular cavity as the research object, establishes the water lubricated stern bearing model, and carries on the mechanical analysis of the model by using ANSYS/Workbench; and on this basis, study the effect of the diameter of the cavity on the mechanical properties of stern bearing. The results show that the displacement, strain and stress of circular cavity bearing are better than other geometric cavity bearings. Among them, the mechanical properties of 3~4mm have a better performance.

1. Introduction
Stern bearing is an important part of the ship's main power propulsion device, which supports the shaft and propeller, and is an important part of the internal and external power exchange\textsuperscript{1}. Because of its open working environment, in order to avoid the pollution of the marine environment caused by grease lubricants, sea water is used for direct lubrication. During the operation of the shaft, the fluid inside the bearing forms a certain dynamic pressure lubrication film, which offsets the stern load of part of the shaft load\textsuperscript{2}. However, in low speed and other conditions, the dynamic lubrication film between the shaft and the bearing may be damaged or even unable to form, which leads to the increase of the direct contact area between the shaft and the bearing, resulting in abnormal friction vibration and noise, which seriously affects the service life of the bearing.

In view of the abnormal friction vibration and noise caused by the large contact area between the shaft and the bearing when the water lubricated bearing system is operating in low speed, a cavity is opened at the bottom of the bearing bush to introduce lubricating water with a certain pressure from the outside to balance the self-weight of the shaft, so as to reduce the direct contact between the shaft and the bearing, improve the mechanical performance of the bearing, reduce the abnormal friction vibration and noise, and improve the performance of the shaft service life of bearing. At present, some domestic scholars have done some research on the dynamic hydrostatic lubrication. Liu Zhenglin et al.\textsuperscript{3} set the pressure water inlet from the head to end of the bearing bushing to balance the self-weight of the shaft by high pressure water, reduce the contact area and improve the initial lubrication environment. But in practice, there is no contact between the front end of stern shaft and bearing, so there is no need to set water inlet at the front of bearing. Wu Chongjian et al.\textsuperscript{4} through setting a water chamber in the bearing bush, which is connected with the accumulator through a throttle valve. When dynamic pressure
lubrication cannot be established in low speed, high pressure water is introduced from the accumulator into the bearing through the throttle valve to provide forced hydrostatic lubrication. However, this method can only be realized in a closed environment, which is not consistent with the open environment of stern bearing. Wang et al. [5] simulated the three-dimensional pressure field of oil film with different cavity shapes to ensure the safety of hydrostatic thrust bearing. VK Dwivedi et al. [6] theoretically studied the static characteristics of four cavity rectangular groove journal bearing, and studied the influence of the length and width of rectangular cavity on the bearing capacity of rectangular groove. Guo Li et al. [7] explored the influence of different cavity shapes on bearing performance parameters such as bearing capacity, stiffness and whirling frequency. The results show that angular small cavity bearing has the best performance. However, this paper only analyzes the stiffness and whirling frequency from bearing flow rate and bearing capacity, and does not analyze the mechanical properties of bearings with different cavity shapes. Narendra et al. [8] theoretically studied the influence of different groove shape, flexibility of bearing cover and compensation method on the performance of hydrodynamic and hydrostatic journal bearing. In this paper, the author uses ANSYS/Workbench to analyze the mechanical properties of different shapes of cavity and diameters of stern bearing, and studies the static performance in different shapes of cavity and size of stern bearing.

2. Model structure of the stern bearing

2.1. Basic parameters of model

The stern bearing is modeled by three-dimension software, the parameters are as shown in Table. 1

| Parameter name                  | Parameter size |
|--------------------------------|----------------|
| bearing inner diameter r_b/mm   | 60             |
| Length diameter ratio           | 2              |
| Thickness of bearing bushes h/mm| 5              |
| Bearing clearance r/mm          | 0.2            |

The circular, elliptical, square, I-shaped and triangular cavity stern bearings are drawn by SolidWorks, and a group of bearings without geometric cavity is added for comparison. In order to reduce the influence of other variables on the experiment, the area, position and other factors of the cavity should be controlled as much as possible. Fig. 1 is the schematic diagram of stern bearing.

![Fig.1 Stern bearing section](image)

2.2. Model import

The drawn model is imported into ANSYS/Workbench for analysis. Taking the non geometric cavity stern bearing as an example, the model of the stern bearing is established as shown in Figure. 2, in which the Z-axis in the coordinate system is the axial direction of the stern shaft, and the clockwise direction is the running direction of the bearing.
3. Finite element setup

According to the actual bearing situation, the ship stern bearing is mainly composed of bearing bushes and bearing sleeve. The material definition of the stern bearing is shown in Table 2.

| Name      | Material          | Density         | Young's modulus | Poisson's ratio |
|-----------|-------------------|-----------------|-----------------|-----------------|
| Bearing bushes | Hard rubber       | 1850 kg/m$^3$  | 7.48 MPa        | 0.4             |
| Shaft sleeve    | Copper tin alloy  | 8600 kg/m$^3$  | 102 GPa         | 0.324           |

In order to reduce the calculation, the geometric size of the model is scaled down. Under the action of gravity, the tail of the long shaft will contact with the bearing, and the contact area of the bottom bearing bush is the largest. Now the mesh of the bottom bearing bushes is refinement. Others are the default settings to solve the model.

Taking the no geometric cavity bearing bushes in Figure 3 as an example, it can be seen that after the bottom bearing bush is refinement, the partition result is as follows: the number of nodes is 149823 and the number of units is 71568. Because the bolt is used between the bearing bush and the bearing sleeve, there is no relative movement between the bearing bush and the bearing sleeve during the operation of the shaft, so there is no sliding between the bearing bush and the bearing sleeve, which is set as bonded. The friction contact between the bearing bush is friction contact, the friction coefficient between the shaft and the bearing is constant, and the outer surface of the bearing is set as full constraint, in order to simplify the model, a full constraint is set at the front end of the stern bearing, and the load is applied to the rear end of the shaft in the form of force in the negative direction of the y-axis, to simulate the weight of the propeller. It is assumed that the axial displacement of the bearing will not occur; the inertial force of sea water is not considered.

Figure 4 shows a three cavities hydrostatic journal bearing with three restrictors $C_1$, $C_2$ and $C_3$. Water is pumped by the same high pressure pump, so the water supply pressure is $p_e$. The high-pressure water
pressure decreases after passing through the restrictor. The load \( W \) on the journal is balanced by the vector sum of the pressure distribution generated by the three water cavity pressures.

![Diagram of Hydrostatic Radial Bearing with Three Cavities](image)

**Fig.4 Hydrostatic radial bearing with three cavities**

### 4. Result and analysis

#### 4.1. Mechanical properties of geometric cavity bearings with different shapes

When the model is imported into ANSYS / workbench, the constraint settings are the same, and the changes of displacement, strain and stress are obtained respectively.

![Displacement of No Cavity Stern Bearing Bushes](image)

**Fig.5 The displacement of no cavity stern bearing bushes**

It can be found in Fig. 5 that under the action of the gravity of the shaft and propeller, the strain of the bearing is mainly concentrated at the bottom of the bearing, and near the propeller end, the strain of the bearing increases, which is consistent with the actual situation.

In order to explore the influence of different geometric cavity shape and size on the bearing mechanical properties, the path is created to observe the displacement of the bottom bearing bush.

![Displacement of Bottom Stern Bearing Bush](image)

**Fig.6 The displacement of the bottom stern bearing bush**
As can be seen from Figure 6, the displacement near the stern end increases. The maximum displacement is mainly between 117.5mm and 120mm. In view of the closed contact surface formed by the static shaft and the bearing, through opening a small cavity at the bottom of the bearing, high-pressure water is pumped into the bearing through the small cavity, so as to realize the forced hydrostatic lubrication in the bearing, and improve the lubrication in low speed, heavy load and other environments. At present, the cavity models of circle, ellipse, square, I-shape and triangle are established respectively (as shown in Fig7). The other models have the same size and finite element settings. The changes of displacement, strain and stress are obtained respectively.

Figure 8 shows the displacement variation of stern bearing with different cavity shapes. At the same time, the maximum displacement of bearing strip caused by different cavity shapes is also different. It can be seen that the displacement near the circular cavity is 0.080 mm, the displacement near the elliptical cavity is 0.084 mm, the displacement near the square cavity is 0.085 mm, the displacement near the I-shaped cavity is 0.087 mm, and the displacement near the triangular cavity is 0.086 mm. At the same time, according to the maximum displacement of different cavity on the bearing, it can be found that the maximum displacement of elliptical cavity stern bearing is the smallest, and the maximum displacement of I-shaped cavity stern bearing is the largest.
Fig. 8 The displacement of stern bearing bushes with different geometric cavities

Figure 9 shows the strain diagram of stern bearing with different cavity shapes. It can be seen that the main strain of circular cavity is 0.0433, elliptical cavity is 0.0480, square cavity is 0.0454, I-shaped cavity is 0.0615 and triangle cavity is 0.0519. We can see that the strain of triangle and square cavity is more severe at the arc chamfer, and it is quite different from the surrounding strain value. The strain of circular cavity and elliptical cavity is smooth, and the strain transition is slow.
Fig. 10 shows the stress diagram of different cavity bearings. It can be seen that the stress value of circular cavity is mainly concentrated in 0.285 MPa, that of elliptical cavity is mainly concentrated in 0.282 MPa, that of square cavity is mainly concentrated in 0.330 MPa, that of I-shaped cavity is mainly concentrated in 0.366 MPa, and that of triangular cavity is mainly concentrated in 0.381 MPa. Among them, the stress change of the circular cavity surface bearing is the most gentle, the stress change of the triangular cavity bearing is the most violent, and the stress transition range is large. Through the comparison between bearings with different cavities and bearings without cavities, it can be seen that opening cavities on the bearing surface has a certain impact on the maximum stress on the bearing surface. The maximum stress of bearings with different cavity structures is mainly concentrated in the chamfer of the bottom bearing strip. Among them, the influence of elliptical cavity is the least, and that of triangular cavity is the most.
Therefore, it can be found that when the area and position are fixed, the mechanical properties of the bearings with different cavity shapes are different to some extent.

4.2. research on static performance of stern bearing with different bore diameter
Based on the circular cavity bearing, the models of 1.5, 2, 2.5, 3, 3.5, 4 and 4.5 mm cavity diameter stern bearing were established respectively, and the models were imported into the finite element analysis software for static analysis, and the displacement, strain and stress changes of different cavity diameter bearings were observed.
Fig. 11 Maximum displacement under different diameters

(a) Displacement

(b) Strain

(c) Stress

Fig. 11 Maximum displacement under different diameters
Fig. 11 (a) is a broken line diagram of the displacement under different diameters. It can be seen that the displacement of the cavity surface first decreases and then increases slowly with the increase of the cavity diameter, while the maximum displacement of the bearing fluctuates. When the cavity diameter is 4 mm, the displacement of the cavity surface coincides with the maximum displacement of the bearing.

Fig. 11 (b) is a broken line diagram of different cavity diameters and maximum strain. It can be seen that the strain of cavity surface fluctuates with the increase of cavity diameter, but the overall fluctuation trend is small. At the same time, the maximum strain of the bearing also fluctuates with the change of the cavity diameter. When the cavity diameter is more than 3 mm, the maximum strain of the bearing surface will slowly decrease with the increase of the cavity diameter.

Fig. 11 (c) is a broken line diagram of stress under different cavity diameters. It can be seen that the change trend of stress and strain on the surface of a circular cavity is exactly the same. The stress fluctuates slowly with the increase of cavity diameter, but the overall trend fluctuates slightly. However, different cavity diameters have great influence on the maximum stress of bearing surface. It can be seen that the maximum stress of bearing surface fluctuates with the increase of cavity diameter. When the cavity diameter is 3 ~ 4 mm, the maximum stress on the bearing surface will decrease with the increase of the cavity diameter. The reason may be that when the cavity diameter is too small, the stress on the bearing surface is uneven, which leads to the phenomenon of stress concentration. When the cavity diameter is too small, the stress change on the bearing surface is more abrupt, and the stress value increases. Therefore, if the cavity diameter is too large or too small, the stress will increase, that is to say, there is an optimal cavity diameter range, which makes the maximum stress smaller.

To sum up, too large or too small cavity diameter will lead to the increase of stress value. When the cavity diameter is 3 ~ 4 mm, the maximum strain and stress of the bearing are small, and the static performance is better.

5. Conclusion

(1) Different cavity shapes will have a certain influence on the static performance of stern bearing. In the study of stern bearing with different cavity, the stress distribution of circular cavity stern bearing is relatively gentle, and the strain and stress distribution of cavity surface are smaller than other cavities. It can effectively improve the mechanical properties of stern bearing, reduce the direct contact between shaft and bearing, and increase the service life of bearing in the process of shaft operation.

(2) In the study of circular stern bearings with different cavity diameters, the cavity diameter has little influence on the displacement, strain and stress near the cavity, but has great influence on the maximum displacement, strain and stress of the bearing. If the cavity diameter is too large or too small, the stress and strain will increase, which will affect the static performance of the bearing. It is found that when the cavity diameter is 3~4 mm, the maximum strain and stress of the bearing surface are relatively small, and the static performance of the bearing is the best.

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