The Simulation Analysis of Spherical Mechanical Seal of Stern Shaft

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Abstract. The simulation of spherical mechanical seal is carried out with ANSYS finite element method, and the influence of sea water pressure, shaft speed and other factors on the spherical mechanical seal performance discussed. The study shows that local contact situation of the spherical mechanical seal is closed to the outside edge of the spherical seal ring, and both maximum contact pressure and temperature are too. These research results are of important theoretical significance and engineering application value for the development of the new kind of mechanical seal and improvement of both safety and survivability of ships.

Introduction

The mechanical seal of a ship stern shaft is an important device. If the seal accident occurs, it will seriously affect the safety and survival ability of the ship.

Now plane mechanical seal device is widely used, its operation is much in mixed lubrication state [1] [2]. But because of the clearance between the stern shaft and stern bearing, the stern bearing wear and the stern shaft sink or bend, they result in overrun leakage that seriously affecting the safety of the ship.

The kind of spherical mechanical seal is suggested in order to get rid of the shortcoming of the plane mechanical seal. The structure of the spherical mechanical seal takes spherical contact instead of plane contact, which can automatically adjust the seal surface contact status, enhance the tracing ability of seal friction pair and make the spherical seal surface of rotary and stator keep in contact consistently.

Structure and composition of spherical mechanical seal

The spherical mechanical seal device is composed of rotary ring, stator ring and their seats, spring component and so on, shown in Fig. 1.

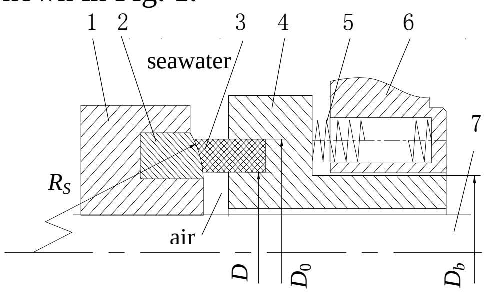

Fig.1 Spherical mechanical
Seal structure drawing

1-rotary ring seat; 2- rotary ring; 3-stator ring; 4- stator ring seat;
5- spring; 6- spring seat; 7- stern shaft

The rotary ring with cemented carbide as material is embedded in the rotary ring seat. The rotary ring seat is fixed on the shaft and rotates together with the shaft, the stator ring made of nonmetal material (FEROFORM) is fixed on the stator ring seat, and moves axially with the stator ring seat.

The contact surface between the rotary ring and the stator ring is spherical one. It plays a sealing role and has function of self-aligning. The interaction of spring force and pressure of sealed medium (seawater) ensures the consistent contact of both rotary ring and stator ring. Seawater is sealed outside of the contacting spherical surface, and air inside it.

Shaft diameter d = 185 mm; the inside diameter of seal ring D = 202 mm; the outside diameter of seal ring D_o = 218 mm; slip diameter D_b = 208 mm; sealing spherical radius of rotary or stator ring R_S =200 mm. The width of spherical seal is 8 mm.

The specific pressure of spring is 0.2 MPa. Material parameters of each component of the spherical mechanical seal device are listed in Tab.1.

Tab.1 Physical parameter of materials of stator, rotary ring and their seats

Item	Material	Modulus of elasticity E/MPa	Poisson's ratio μ	Coefficient of thermal conductivity λ/(W/m·K)	Linear expansion coefficient a/(m/℃)	Density P /(kg/m^3)	Friction Coefficient f
stator ring	feroform	300	0.48	0.5	70×10^{-6}	1.32×10^{3}	0.03
rotary ring	bronze	11.5×10^{4}	0.32	63.8	17.8×10^{-6}	8.5×10^{3}	
stator, rotary ring seat	C15	19.8×10^{4}	0.29	16.33	16.6×10^{-6}	7.9×10^{3}	

Thermal-structure coupled finite element model

Integral contact coupling method is taken to do thermal-structure solution of the spherical mechanical seal, and a finite element model (unit: N-m-s) is established [3]. The model of spherical mechanical seal rings is the type of axial symmetry. Assume that spring force and external pressure of seawater is even distributed force, liquid film reaction force between sealing spherical surfaces is in linear distribution; cooling of the sealing rings by fluid is dealt with according to convection heat transfer boundary; friction heat between sealing spherical surfaces according to heat flux boundary.

ANSYS software is applied to establish the thermal-structure coupling model of the spherical mechanical seal ring. Surface to surface contact is defined on the spherical surface of rotary and stator rings. Coefficient friction should be entered in the 'Coefficient of Friction' item and a large number should be entered in the Thermal Contact Conductance item (usually above 10^8), thus the automatic distribution of heat flux density is realized and the corresponding node temperature of the rotary, stator ring seal spherical surface is guaranteed to be basically consistent [4].

In order to improve the accuracy of the solution to contact unit, element size (ESIZE) of the spherical seal surface of rotary, stator ring and each side of the stator ring section is 0.5 mm. The unit sizes of the aft end face a certain distance from the seal spherical surface, the internal and external side faces of the stator ring seat, the acting face of the spring, the chamfer face and aft end face are all 1mm (as shown in Fig. 2). The model includes 3069 elements, 3191 nodes in all.

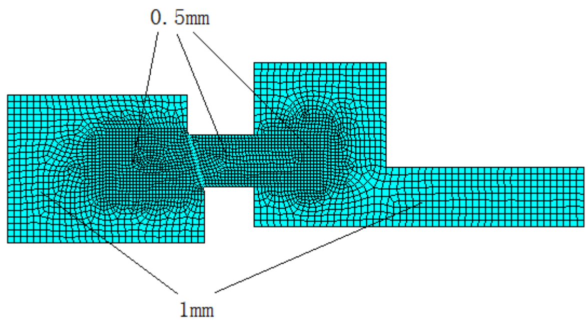

Fig.2 Section grid chart

The convective heat transfer coefficient [5] outside the seal rings is calculated in the condition that sea water or air is 25℃.

$$h_m = \frac{\lambda_f}{d} Nu_f$$

In the formula, $Nu_f = 0.023\times \mathrm{Re}_f^{\,0.8}\,\mathrm{Pr}_f^{\,0.3}$,

$$\mathrm{Re}_f = \frac{u\times d}{\gamma_f} \quad , \quad u = \sqrt{(\frac{\pi dn}{60})^2 + v^2} \; ;$$

n is rotary ring rotation speed, n=100, r·min^{-1}; v is the axial velocity of fluid, v=10 m/s; u is the linear velocity at external diameter of rotary ring seat, $u = \pi nd/60$, m/s; d is external diameter of rotary ring or internal diameter of stator ring, m; γ_f is the kinematic viscosity of the fluid, 0.01553 m^2/s for air, 1.304m^2/s for sea water; λ_f is the thermal conductivity of the fluid, 2.63 W/(m·K) for air, 60.85 W/(m·K) for seawater; Re_f is the Reynolds number; Pr_f is the Planck number, 0.702 for air, 6.22 for water; Nu_f is the Nusselt number.

Temperature displacement boundary constraint condition is shown in Fig.3, the horizontal direction is Y, the vertical direction is X, U represents constraint. The aft end surface of rotary ring seat is imposed with axial constraint UY, the fit position of the rotary ring and the shaft is imposed with vertical displacement constraint UX; the fit position of the stator ring seat and machine body is imposed with vertical displacement constraint UX, without any axial constraint between the stator ring and the stator ring seat.

Constant temperature 25 ℃ is applied on positions contacted with seawater of the rotary ring seat and the stator ring seat; in order to improve the calculation convergence of model, constant air temperature ℃ is applied on the rotary ring seat and the stator ring seat distant to the seal spherical surface.

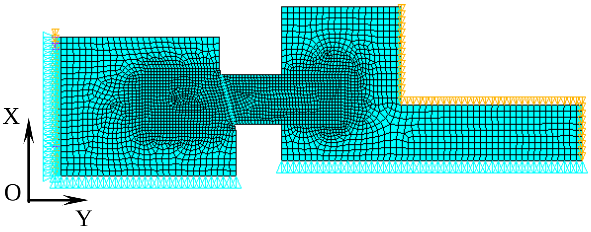

Fig.3 Temperature displacement constraint boundary condition chart

Because a nonlinear relationship shows between the contact pressure and heat flux density/seal width, node function can be used for loading in the ANSYS finite element software.

A linearly distributed load is applied on the seal spherical surface of rotary, stator ring (i.e. water film reaction), the inner air pressure is 0.10 MPa, the outer sea water pressure is 6 MPa; a resultant uniform pressure is added on the acting surface of the spring of the stator ring seat, the size is the sum of spring specific pressure and seawater pressure; uniform pressure is added for other positions marked red arrows, the size of the pressure is the same as the seawater pressure, as shown in Fig.4.

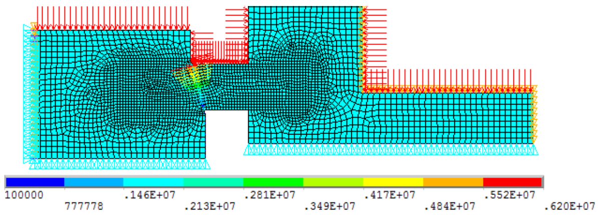

Fig. 4 Pressure load boundary condition chart

The following formula is used to calculate the heat flux q of seal rings:

$$q = \frac{2\pi n}{60} f \cdot p_c(r) \cdot r$$

In the formula, q is heat flux density, W/m^2; f is coefficient of friction; $p_c(r)$ is the contact pressure between the seal end faces, Pa; r is the radius(X direction) of seal ring, m; n is a rotary ring rotation speed, n=100, r·min^{-1}.

Calculating results and analysis

Spherical mechanical seal ring thermal-structure coupling is a typical thermal elastic problem. When the model is first calculated, the heat flow density is not applied. Contact pressure and heat flux density load between spherical seal surfaces of two rings is calculated in action of pressure generated from spring and sea water. The heat flux density model is applied on the model for the second solution to get a new contact pressure and heat flux density load. If the difference of heat flux loads calculation results before and after does not satisfy the convergence criteria, it indicates that the heat flux density load applied is not accurate enough and new heat flux density load should be imposed to calculate again. The step will be repeated until a convergence criterion is satisfied.

In order to facilitate the spherical finite element mechanical seal analysis, the rotary, stator seal spherical arc length is divided into 18 nodes. Node No.0 is located in the innermost side of the seal spherical surface, while Node No.18 is located in the outermost side of it. Axial deformation distribution of spherical mechanical seal rotary, stator ring is shown in Fig.5.

As shown in Fig.5, under external load and thermal expansion, spherical mechanical seal deformation appears, the maximum axial deformation 0.275mm appears in the inner side of the stator ring. The deformations of rotary and stator ring's contact spherical surface are not equal, the former is less than the latter. The reason is that the thermal expansion coefficient of the stator ring is larger, the elastic modulus is smaller and there is no axial constraint of stator ring.

It can be found that the spherical seal surface exists the part contact, the maximum contact pressure 4.65MPa appears at the outermost of seal ring, as shown in Fig.6. The distribution of temperature field of spherical mechanical seal is shown in Fig.7.

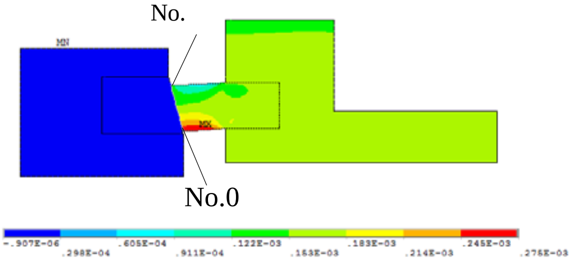

Fig. 5 Axial deformation distribution of spherical mechanical seal

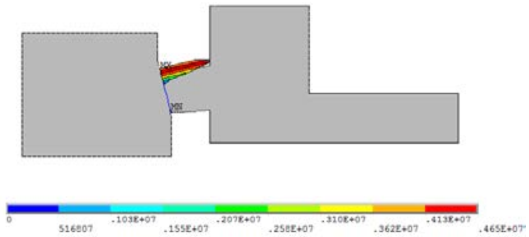

Fig.6 Contact pressure of spherical seal surface

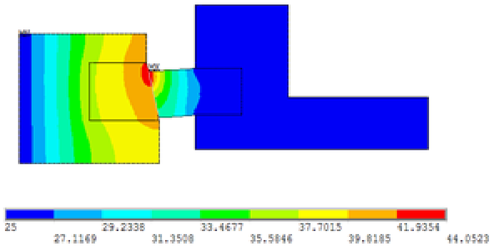

Fig.7 Temperature distribution of spherical seal

The maximum contact pressure of the spherical seal surface appears at the outermost side of seal ring, add to that the contact pressure is big, rotation line speed is high in the position, thus rapid rise of temperature is caused by the contact friction heat, up to 44.05℃. But in the area where contact pressure is 0, contact friction heat does not appear. The area is only affected by the heat transfer, so the temperature is low..

Conclusion

In spherical mechanical seal, maximum contact pressure and temperature were found near the outside of the seal ring, both are in the allowed range of the material (material Feroform) property of stator ring.

Acknowledgement

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