Computational fluid dynamics study of magnetic liquid rotary seal for sealing liquid

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Abstract. When applied in sealing liquid, the instability of the interface between the magnetic liquid and the sealed liquid in the direct-contact magnetic liquid seal structure will occur and increase, eventually leading to the failure of the magnetic liquid seal. In order to understand the destruction process of the interface between the magnetic liquid and the sealed liquid more intuitively, the two-phase flow of the magnetic liquid and the sealed liquid was simulated numerically. Phase distribution and velocity distribution are obtained through the simulation.

1. Preface

Magnetic liquid seal has the advantages of long life, low leakage rate and high reliability. It is widely used in the fields of vacuum seal and gas seal with low pressure\textsuperscript{1}. However, when it is used to seal liquid, the relative motion between the magnetic liquid and the sealed liquid caused by the rotation of the spindle gives rise to the interface instability\textsuperscript{2,3}, therefore, the sealing performance is poor.

The performance of magnetic liquid seal for sealing liquid has been paid much attention by scholars. Rosensweig\textsuperscript{4}, Williams\textsuperscript{5}, Kurfess\textsuperscript{6}, Szydl\textsuperscript{7}, Mitamura\textsuperscript{8-10} et al carried out magnetic liquid seal tests for sealing liquid. Previous studies have shown that when the spindle speed is high, the kelvin-Helmholtz instability of the interface between the magnetic liquid and the sealed liquid in the direct-contact magnetic liquid seal structure will occur and increase, eventually leading to the failure of the magnetic liquid seal. However, the change of the interface between the magnetic liquid and the sealed liquid could not be observed in the experiment. In order to understand the destruction process of the interface between the magnetic liquid and the sealed liquid more intuitively, the two-phase flow of the magnetic liquid and the sealed liquid was simulated numerically in this paper.

2. The establishment of computational fluid dynamics (CFD) model

The hydrodynamic problems of magnetic liquid and the sealed liquid belong to the problems of two-phase flow which cannot be mixed. In this paper, the VOF model in Fluent tracks the interface between magnetic liquid and the sealed liquid. After There is the coupling problems of magnetic field magnetic field and two phase flow, and it is not easy to convergence because the simulation of magnetic liquid seal itself is a multiscale problems, which has large amount of calculation. Therefore, the following numerical simulation does not consider the magnetic field, only the computational fluid dynamics of magnetic liquid and the sealed liquid being studied. The phase distribution and velocity distribution of magnetic liquid and the sealed liquid during interface failure were investigated.

Considering the influence of rotating shaft speed on the interface between magnetic liquid and the sealed liquid, a three dimensional model as shown in Figure 1 is established. The model consists of two parts: the sealing cavity (upper part) and the sealing gap (lower part) between the pole shoes and the
rotating shaft. The sealed liquid is in the sealing cavity and the magnetic liquid is in the sealing gap. Let the horizontal plane be the X-Y plane and the vertical direction be the Z direction.

![Geometry of the magnetic liquid seal structure](image)

**Fig. 1** Geometry of the magnetic liquid seal structure

The sealed liquid is located at the interface between the seal cavity and the seal gap. The sealed liquid (water) is blue and the magnetic liquid is red, as shown in Figure 2. Liquid exchange can be carried out between the seal gap and the space in the seal cavity. The upper end of the model is the pressure inlet and the lower end is closed.

![Two phases in the model of the magnetic liquid seal structure](image)

**Fig. 2** Two phases in the model of the magnetic liquid seal structure

The physical parameters of the liquid were set according to the actual experimental conditions. The magnetic liquid selected was an incompressible liquid, with density $\rho_1 = 1.224 \times 10^3 \text{kg/m}^3$ and dynamic viscosity $\mu_1 = 3 \times 10^{-2} \text{kg/ms}$; The sealed liquid (water) is also an incompressible liquid, with density $\rho_2 = 0.9982 \times 10^3 \text{kg/m}^3$ and dynamic viscosity $\mu_2 = 1.003 \times 10^{-3} \text{kg/ms}$.

3. Simulation results and analysis

3.1 Phase distribution

The initial conditions are set as follows: the sealing gap is 0.1mm; The upper end pressure of the sealed liquid is 0.2Mpa; Shaft speed 1800r/min. At the beginning of the simulation, assuming that the initial state of the interface between the sealed liquid and the magnetic liquid is plane, the morphologic change process of the interface between the sealed liquid and the magnetic liquid and the two-phase flow are investigated. The variation of two-phase distribution in the simulation process is shown in Figure 3.

As can be seen from Figure 3, the initial state of the interface between water and magnetic liquid at the beginning of the simulation is shown in Figure (1), approximate to the plane. When the shaft rotates at a fixed speed, the water and the magnetic liquid have a speed difference in the tangential direction of the interface, and there is Kelvin-Helmholtz instability at the interface, as shown in FIG. (2). The interface is no longer a plane, resulting in ripples. With the advance of time, it is obvious that a small amount of magnetic liquid enters into the water, as shown in Figure (3). After that, more and more magnetic liquid enters into the water. As the magnetic liquid leaves the seal gap, water also enters into
the seal gap. Finally, water and magnetic liquid mix together, and more and more water enters into the seal gap until the seal fails, as shown in Figure (4).

![Figure 3 Interface change process of the interface of water and magnetic liquid](image)

Through the simulation results of the above phase distribution, the morphology change process of the interface between magnetic liquid and sealed liquid and the two-phase flow can be clearly seen.

### 3.2 Velocity distribution

As shown in Figure 4, the velocity vector diagram in the entire computational domain is obtained by simulation. The linear velocity of the magnetic liquid in the sealing gap and that of the water in the sealing chamber on the surface of the shaft are the same, both equal to the linear velocity of the shaft, which is 1.139 m/s. At the interface there exists a velocity vector from one side of the magnetic liquid to the water side, with a maximum of about 0.85 m/s.

![Figure 4 Holistic velocity vector graph](image)

It can also be seen from the partial velocity vector in the interface and sealing gap shown in Figure 4 that, within the sealing gap, there is an upward velocity vector, and the closer it is to the interface, the higher the velocity is. The velocity vector diagram verifies that the magnetic liquid is diffusing into the water.
4. Conclusion
The morphology change process of the interface between magnetic liquid and sealed liquid is obtained through the simulation. The linear velocity of the magnetic liquid in the sealing gap and that of the water in the sealing chamber on the surface of the shaft are the same, both equal to the linear velocity of the shaft. There exists a velocity vector from one side of the magnetic liquid to the water side at the interface.

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