Experimental study on friction coefficient of liquid film lubricated mechanical seals with laser micro-texturing

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Abstract. The friction coefficient was a key parameter for expressing the friction characteristics of the seal faces. The friction coefficient of the end faces of unbalanced mechanical seals with laser-textured micro-pores surface and spiral grooves surface were tested on the self-designed mechanical seal testing device, and compared with conventional smooth surface contacting mechanical seal. The experimental sealed medium was 25℃ water, the sealed medium pressures \( p = 0.3 \sim 0.9 \text{ MPa} \), and the rotating speeds \( n = 1000 \sim 3000 \text{ rpm} \). A series of experimental data of friction coefficient were obtained through experiments under different medium pressures and rotating speeds. The experimental results show that the friction coefficient of mechanical seals with laser surface micro-texturing were significantly lower than that of smooth surface mechanical seal, and the effect of spiral grooves end face on improve friction characteristics was better than that of micro-pores end face. Both medium pressure and rotating speed had influenced on the friction coefficient of mechanical seals with laser surface micro-texturing. The friction coefficient of micro-textured end face decreased with the increasing medium pressure, and it first decreased with the increasing rotating speed, and changes little when the rotating speed reaches a certain value.

1. Introduction

Mechanical seals play an important role in preventing leakage, saving energy and controlling environmental pollution. Whether the mechanical seal can maintain a low leakage rate and long period running depends mainly on the interface characteristics between the seal faces[1,2]. Due to the direct contact between the seal faces, the conventional contacting mechanical seal is in mixed friction or boundary friction state [3], and its operating life is short. In order to improve the lubrication condition between seal faces, surface micro-texturing technology is applied to mechanical seals. Grooves of various shapes are machined on the seal faces. By using the hydrodynamic effects of grooves, a large bearing capacity of fluid film is generated between the seal faces to realize the long period running of mechanical seals.

Laser micro-texturing liquid film lubricated mechanical seal has been successfully applied in engineering practice[4]. Friction coefficient of the end faces is a key parameter to characterize the friction characteristics between the end faces for mechanical seals, and is also a main influence factor to distinguish the friction state and decide friction power, friction heat, and temperature of the end faces. In this paper, the friction coefficient of the end faces of liquid film lubricated mechanical seals with laser-textured micro-pores surface and spiral grooves surface were tested on the self-designed mechanical seal testing device, and compared with conventional smooth surface contacting
mechanical seal, so as to provide experimental basis for the industrial application of laser micro-texturing liquid film lubricated mechanical seals.

2. Experimental procedures

2.1. Experimental device
Experiments were conducted on the self-designed mechanical seal testing device. The mechanical seal testing device is composed of mechanical system and computer data acquisition system. Its specific structure and parameters are shown in references [5,6].

2.2. Mechanical seal specimens
The specimens are three sets of unbalanced mechanical seals with single end face and single spring. The material of the rotating ring is reaction bonded SiC, the material of the stationary ring is carbon graphite M106K. The seal face parameters are inner diameter $D_i=56$ mm, outer diameter $D_o=70$ mm, balance diameter $D_b=55$ mm, and balance factor $B=1.063$. The difference of the three sets of mechanical seal specimens lies in the different types of micro-texturing on the seal face of the rotating ring, in which specimen A is a conventional contacting mechanical seals, and the seal face of the rotating ring is smooth surface; the seal face of the rotating ring of the specimen B is provided with the micro-pores; and the seal face of the rotating ring of the specimen C is provided with the spiral grooves. The micro-texturing types and parameters of rotating ring seal faces are shown in Table 1. The laser marking machine of lamp-pumped YAG-T50 is used to process the micro-texturing of the seal faces, and the PS50 3D non-contact surface topography instrument is used for measurement. In laser processing micro-texturing, the technological parameters are that effective vector step is 0.001 mm, effective vector step delay is 60 μs, Q frequency is 20 KHz and laser current is 17 A [7].

| Specimen number | Micro-texturing types | Micro-texturing parameters |
|-----------------|-----------------------|----------------------------|
| Specimen A      | Smooth surface        | —                          |
| Specimen B      | Micro-pores           | The pore diameter is 50 μm, the pore depth is 8 μm. The micro-pores are distributed in the whole seal face with an area density of 20% |
| Specimen C      | Spiral grooves        | The groove shape is logarithmic spiral, the outer diameter side grooving, the spiral angle is 20°, the groove width ratio is 0.6, the inner diameter of groove bottom is 60.1 mm, the number of grooves is 16, and the groove depth is 8 μm |

2.3. Experimental method
The comparative experiment method was used in the experiment, that is, the friction coefficient of three sets of mechanical seals with smooth surface, micro-pores and spiral grooves on the seal face of rotating ring were compared. The experimental sealed medium is water with a flow rate is $5\times10^{-4}$ m$^3\cdot$s$^{-1}$ and the average temperature is 25 ºC. Three sets of mechanical seal specimens were tested under different medium pressures and rotating speeds. The compression load of mechanical seal spring was set as 80 N. During the experiment, the medium pressure was taken as 0.3, 0.6 and 0.9 MPa respectively, and the rotating speed under each medium pressure was taken as 1000, 1500, 2000, 2500 and 3000 rpm respectively. Run smoothly for 20 min at each rotating speed.
3. Results and discussion

3.1. Comparison of friction coefficient of mechanical seals with different surface micro-texturing

The comparison of friction coefficient of mechanical seals with different surface micro-texturing is shown in Figure 1. As can be seen from Figure 1 that the friction coefficient of the mechanical seals with laser surface micro-texturing (specimen B and specimen C) are significantly lower than that of the conventional contacting mechanical seal with smooth surface (specimen A) under the same service conditions. Among them, the decrease amplitudes of spiral grooves (specimen C) on the seal face is greater than that of the micro-pores (specimen B) on the seal face. It can be seen that the friction characteristics of the mechanical seal can be improved obviously by machining the micro-texturing on the seal face, which is beneficial to the extension of the operating life of the mechanical seal.

![Figure 1. Comparison of friction coefficient.](image)

3.2. Effects of rotating speed and medium pressure on friction coefficient of mechanical seals with surface micro-pores

The mechanical seal with surface micro-pores (specimen B) is under different medium pressure, the relationship curve between the friction coefficient of the seal faces and the rotating speed is shown in Figure 2. As can be seen from Figure 2 that the friction coefficient decrease with the increase of medium pressure. When the medium pressure is low ($p = 0.3$ MPa), the friction coefficient decrease with the increase of rotating speed, and the decrease amplitudes of friction coefficient become smaller with the increase of rotating speed. When the medium pressure is high ($p = 0.6, 0.9$ MPa), the friction coefficient decreases at first and then increases slightly with the increase of rotating speed. When the rotating speed is about 2500 rpm, the friction coefficient reaches the minimum value and the lubrication state is the best.
3.3. Effects of rotating speed and medium pressure on friction coefficient of mechanical seals with surface spiral grooves

The mechanical seal with surface spiral grooves (specimen C) is under different medium pressure, the relationship curve between the friction coefficient of the seal faces and the rotating speed is shown in Figure 3. As can be seen from Figure 3 that the friction coefficient decreases with the increase of medium pressure, and the lower the rotating speed, the greater the change amplitudes of friction coefficient with medium pressure. The friction coefficient decreases with the increase of rotating speed, and when the rotating speed is large, the change of friction coefficient is small.

4. Conclusions

(1) Under the same service conditions, the friction coefficient of the mechanical seals with laser surface micro-texturing are significantly lower than that of smooth surface mechanical seal, which can effectively improve the friction characteristics of seal face and prolong its operating life.

(2) The friction coefficient of spiral grooves seal face is lower than that of micro-pores seal face, and the effect of improving the friction characteristics of mechanical seal is better.

(3) Both the sealed medium pressure and the rotating speed have influence on the friction coefficient of the mechanical seals with laser surface micro-texturing. The friction coefficient of the micro-textured end face decreases with the increase of the medium pressure, and the friction coefficient first decreases with the increase of the rotating speed, and the friction coefficient changes little when the rotating speed reaches a certain value.

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