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ANALYSIS OF FACTORS AFFECTING PERFORMANCE OF MECHANICAL SEAL'S END-FACE CHARACTERISTICS

Xinhuan Zou[1], Jun Wang[2], Qing Chen*

[1]School of Power Engineering and Engineering Thermo physics, Jilin Institute of Chemical Technology, Jilin 132022, China
[2]Valve and Fitting department, Jilin Petrochemical Co. material purchasing company Petrochina Company LTd.
**Corresponding Author Email: chenqing0708@126.com*

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ABSTRACT

Mechanical seals are widely used due to their excellent stability and low leakage rate. As for mechanical seal end-face characteristics and end-face specific pressure have crucial influence on the operating state of mechanical seal and its service life. This article analyzes the influence of spring pressure and friction characteristics on end-face specific pressure and studied the variation of friction characteristics in equipment operation through the force state of rotating ring and stationary ring.

KEYWORDS

Mechanical seal, end-face specific pressure, spring pressure, friction characteristics

1. INTRODUCTION

Mechanical seal is a kind of common shaft seal device, which is used widely in a variety of rotating equipments such as: military, shipbuilding and other fields [1]. In developed industrial countries the excellent reliability and sealing of mechanical seal have higher usage rate than others. China, for example, started to use mechanical seal in 1966, which started relatively lately but has already reached advanced level in this field.

In chemical enterprises the problem of equipment leakage happens frequently which is the main problem of non-plan shutdown. Annular parts are usually used in mechanical seal when minor failure equipment leads to shut down for maintenance. And major failure causes equipment damage even serious accident. Leakage is a bad phenomenon that will not only cause waste energy but also reduce economic benefits. When mechanical seal failure happens, the failure parts should not be replaced simply because it cannot solve the problem of leakage fundamentally. Analyzing the reason of failure of sealing equipment and improving it can effectively increase service life of equipment and dramatically reduce the risk of leakage.

The working environment of mechanical seal is very complex. There are many reasons of equipment failure. The author analyzes the results of the previous reasons for the leakage of mechanical seal and reaches the following conclusion: besides design, installation and machining the main leakage factors are concentrated on the end face.

2. END-FACE SPECIFIC PRESSURE

End-face specific pressure plays a very important role in mechanical seal parameters. It not only determines the sealing performance, but also affects the service life of the sealing device. Frictional heat generated at the end-face pressure causes the reduction of the liquid membrane at the end face increasing the wear. The small end-face specific pressure causes axial force reduction and leakage. End-face specific pressure is a contact pressure which works on micro-bulge. The force way can be shown like Figure 1.

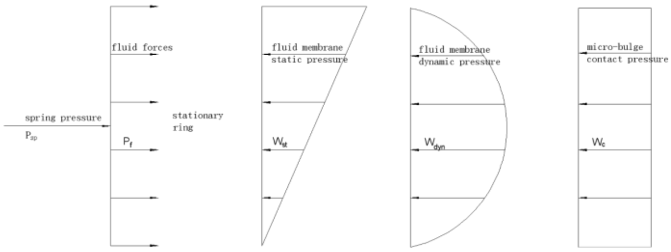

Figure 1: Schematic diagram of axial load and total bearing capacity of the sealing surface.

Total load acting axially on the sealing surface P:

$$P = P_s + P_f = p_{sp}A + p_s A_e$$

Total carrying capacity W:

$$W = W_{st} + W_{dyn} + W_C = P_{st}A + P_{dny}A = P_m A + P_c A$$

In stable running the total load P is equal to total carrying capacity W:

$$P_{sp} + P_s \frac{A_e}{A} = P_m + P_c$$

Let $\lambda = \frac{P_m}{P_s}$ $k = \frac{A_e}{A}$ The formula can be drawn:

$P_c = P_{sp} + (c - \lambda)P_s$ (1)

formula:

P_{sp} is spring pressure （MPa）, P_s is medium pressure （MPa）, P_m is film pressure （MPa）, P_c is end-face specific pressure （MPa）, λ is film pressure coefficient, c is area ratio, A_e is effective area （m^2）， P_m is average membrane pressure （MPa）， and P_s is sealing fluid pressure（MPa）. Formula (1) is universally applied in internal mechanical seal and external mechanical seal during actual working. Generally speaking, continuous operation rotating equipment must have instability and axial movement and wear of end face affect the end-face specific pressure. Therefore, the end-face specific pressure will be between $[P_{sp} + (c - \lambda)P_s - P_{fr}]$ and $[P_{sp} - (c - \lambda)P_s - P_{fr}]$ at steady condition P_{fr} friction ratio pressure (MPa) [2].

3.THE RELATIONSHIP BETWEEN SPRING PRESSURE AND END-FACE SPECIFIC PRESSURE

The elastic force acting on the sealing end face is called the spring pressure. In general, the main role of the elastic element in the mechanical seal is to provide an axial force to assist the device seal in Figure 2. In other words, a proper distance can be provided by spring pressure when some wear happens on the stationary ring and rotating ring. Therefore, the spring pressure will change the contact state of the micro-bulge between the rotating ring and the stationary ring and will also change the leakage passage between the end faces.

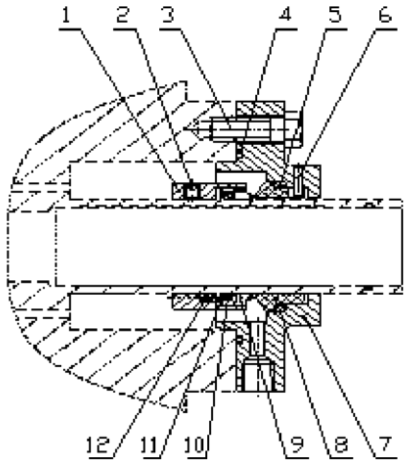

Figure 2: Schematic diagram of a mechanical seal

Transmission sleeve: 2-Set screws: 3-hexagon head bolts; 4,5,10-O-ring; 6-Anti-return pin: 7-end caps; 8—Rotating ring; 9—Stationary ring;11-pisher12-Spring

The spring pressure plays a key role in end-face specific pressure of mechanical seal. The area ratio （c < 1）of the balanced mechanical seal is generally used in production. Film pressure coefficient is between 0.3~0.7 [3]. When c and λ have a small value end-face specific pressure which is determined by spring pressure. In an ideal state Navier-Stokes equation (after simplifying is Reynolds equation):

$$q_v = \frac{\pi h^3 (p_2 - p_1)}{6\mu \ln \frac{r_2}{r_1}} \qquad (2)$$

q_v is sealing face leakage （mL/s）， , μ is Fluid dynamic viscosity （MPa · s）， h is seal gap mm, r_1 and r_2 are respectively diameter and external diameter of seal circle (mm), p_2 *and* p_1 are Medium pressure on the diameter and external diameter of the sealing face (MPa). It is not difficult to notice from the formula that the leakage rate is proportional to the end face gap. As the spring pressure increase causes the end-face specific pressure increasing and results in close contact between the micro-bulges between rotating ring and stationary ring. And the end face gap decreases increases friction raises temperature leading to lubrication fluid volatilization, causing the thickness of liquid membrane smaller and increasing wear. On the other hand, spring pressure decreases and the end-face specific pressure decreases, which leads to increase in end face gap forming a fluid friction and increasing the leak rate. When the spring pressure decreases to zero, the device fails completely. It can also be analyzed by working condition parameter. The working condition parameter is expressed by the following formula:

$$\mathrm{G} = \frac{\eta v b}{w} = \frac{\eta v b}{P_g} \qquad (3)$$

ηfluid viscosity （Pa · s）, v is average linear velocity （m/s^{-1}), Chen Guohuan expresses the frictional characteristics of the end face with g-values [4]. In general, $\mathrm{G} > 1 \times 10^{-6}$ is fluid friction, $5 \times 10^{-8} < \mathrm{G} < 1 \times 10^{-6}$ is mixed friction, $2 \times 10^{-8} < G < 5 \times 10^{-8}$ is boundary friction. We know $p_g = A$ （$P_s C + P_{sp}$）. From the formula it can be concluded that the spring pressure has an effect on the frictional characteristics of the end face. The spring pressure will change the wear condition of the end face, and the leakage rate will not be a stable value any longer.

4. SEALS' END-FACE FRICTION CHARACTERISTICS

End wear mainly occurs on the micro-bulge between the rotating ring and the stationary ring. Wear can also change the frictional characteristics of the face gap. Friction torque, friction coefficient, wear amount and wear rate are called friction characteristics of the mechanical seal face. The friction coefficient (f) of the end face plays a decisive role in the frictional state. The coefficient of friction is determined by many factors. The friction coefficient is usually studied together with working condition parameter. f-g friction characteristics method is commonly used to analyze the frictional state of the end face. In the case of experimentally measuring the friction torque, the following formula is used:

$$f = M/\left(p_g R_m A\right) \quad (4)$$

In the formula, M is friction torque （N · m）, p_g is seal face load （ Mpa）, R_m is seal face average radius （m）, and A is sealing area（m^2） . In actual working conditions, wear loss and wear rate determine the service life and leakage of mechanical seals. Wear loss is measured by measuring weight method and measuring thickness method usually [5]. The wear rate is calculated by an empirical formula. The formula is as followed:

$$\gamma = \Delta L/t \qquad (5)$$

ΔL is wear thickness mm, t is time h, Yu Qiuping performed a large number of experiments on mechanical seal with 400N, 600N, 800N, 100N, and 1200N loads, which can be seen from Figure 3 [6].

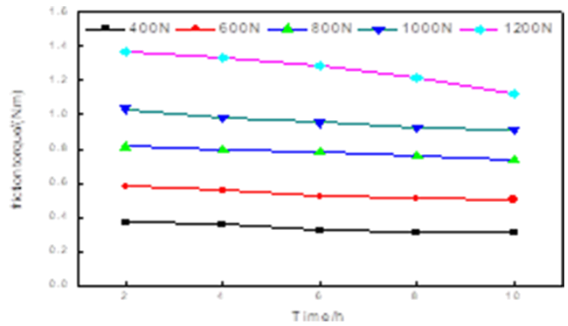

Figure 3: Friction torque changes with time

Friction torque is largely affected by the load and there is proportional relation between the friction torque and the lord. When the load increases, the end face gap decreases. The contact area of micro-bulge between rotating ring and stationary ring will increase and cause the thickness of the liquid film of the lubricating liquid to decrease and the mechanical seal requiring a large frictional torque when it is operated. Long-time operation end wear becomes severe and the surface becomes smooth because of the reduced ploughing effect -- the micro-bulge on the hard ring working on the soft ring.

From formula 3 we can know that the friction coefficient is inversely proportional to the load. From Figure 4, it is found that as the load increases, the friction coefficient increases. As the running time continues to increase, the end face becomes smooth and the friction coefficient decreases.

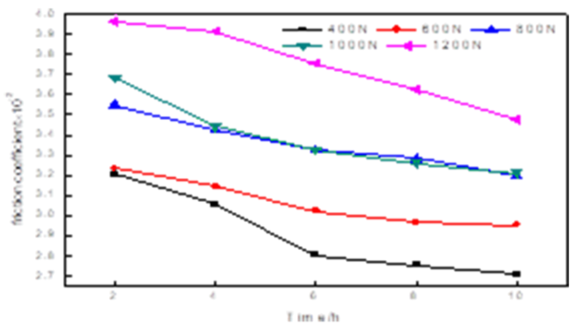

Figure 4: The coefficient of friction changes over time

From Figure 5 we know that the wear rate will increase with the more load. with the Longer running time, wear rate gradually decreases and tends to be more stable. It can be seen by formula (5) that wear loss is proportional to the wear rate.

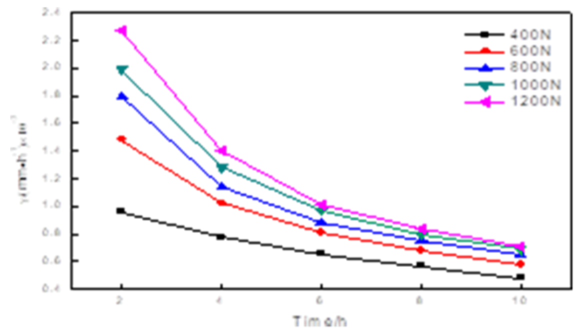

Figure 5: Change of wear rate over time

5. CONCLUSION

The role of the end-face specific pressure is very important. It often determines the working state of the mechanical seal and working state. For the current research progress, we failure to master the variation of spring pressure and end-face specific pressure, which all use the empirical formula to calculate. There are still errors compared to the actual results.

The spring pressure can change the distance between the rotating ring and the stationary ring and the wear condition of the end face. If the spring is over-compressed, the wear will be aggravated. If the spring pressure is deficiency, the degree of attaching the end face will be reduced and result in leakage. There is a suitable spring specific pressure within which the frictional properties of the end face are good and the leakage rate is significantly reduced. The working state of the mechanical seal is not considered completely.

The spring pressure is not a stable value. It can change the face shape and the leakage passage. At present, the study of the leakage passage model needs to be improved. The widely used M-B leakage model and the improved only use a simplified geometric model, and result in test results that are still larger than measured values.

The friction coefficient of the end face will change because of the load and the working time. Both the frictional torque and the friction coefficient will decrease with the increase of working time. The wear rate firstly decreases, and then stabilizes.

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