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Fatigue Life Calculation of Mechanical Seal Welded Metal Bellows

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Abstract. For welded metal bellows, bellows are used in mechanical seals to replace springs and other auxiliary sealing coils in seals. When the traditional rotating device rotates at a high speed, the moving ring in the mechanical sealing process will cause the axial displacement, and the bellows can compensate or reduce by relying on its own performance. For other mechanical devices, the failure of mechanical seals will directly affect their performance and life, and the failure of welded metal blowers used in mechanical seals is usually considered as fatigue damage. Therefore, studying the welding process of the bellows is extremely important to its service life. This article mainly studies the fatigue life of mechanical seal welded metal bellows. First, the characteristics of mechanical seal welded metal bellows are described by the literature research method, and then the fatigue life calculation method is summarized. Finally, the use of the experimental research method studied the fatigue life of u-shaped metal bellows and v-shaped metal bellows at temperature differences of 3°C, 4°C, 5°C, and 6°C. The experimental results show that as the temperature difference increases, the minimum fatigue life of the two types of metal bellows decreases with decline. At the same time, it can also be found that the minimum fatigue life of the v-shaped metal bellows has always far exceeded U-shaped metal bellows.

Keywords. Mechanical seal, metal bellows, fatigue life, different temperature differences

1. Introduction

With the development of science and technology and the quality requirements for environmental protection, mechanical seals are increasingly used due to their minimal leakage and good operational stability, and are widely used in various types of rotating machinery [1- 2]. Metal bellows are gradually attracting people's attention due to their strong application ability and good tensile ability [3-4]. Frequent use of mechanical seals under many extreme conditions puts forward higher requirements on the stability of mechanical seals [5-6]. In the mechanical sealing device of the metal bellows, the metal bellows plays the role of compensation, vibration reduction and noise reduction. When it ruptures, it will cause mechanical seal failure, equipment damage and medium leakage

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[7-8]. In order to ensure the stable operation of the sealing equipment and ensure the cleanliness of the environment and personal safety, it is necessary to conduct research on metal bellows [9-10].

Many related studies have achieved good results when studying the fatigue life of mechanical seal welded metal blowers. For example, some researchers conducted metallographic analysis and pressure corrosion test research on metal bellows, and obtained the formation of stainless steel bellows. The change of the metallographic structure during the process will cause the bellows to rupture [11]. The researchers also studied the dynamic characteristics of the metal U-shaped bellows under 4 working conditions, which provided a reference for the choice of bellows. Through the analysis of foreign metal bellows, the problem of capacity expansion and conversion has been solved, and the problems in actual production have been solved. The fatigue analysis of the welded metal S-shaped bellows proved the reliability of the calculation using finite element software [12].

In this paper, the fatigue life of mechanical seal welded metal bellows is studied. First, the literature research method is used to describe the characteristics of mechanical seal welded metal bellows. Then the fatigue life calculation method is summarized. Finally, the experimental research method is used to analyze the temperature difference of 3℃. The fatigue life of U-shaped metal bellows and V-shaped metal bellows at 4℃, 5℃ and 6℃ are studied.

2. Research on Mechanical Seal Welded Metal Bellows and Fatigue Life

2.1. Features of Mechanically Sealed Welded Metal Bellows

2.1.1. Features of Mechanical Seal

1) Less leakage. Compared with the traditional shaft seal, even if the mechanical seal is still leaking, as long as the mechanical seal can ensure a good fit of the sealing surface, the leakage of the entire system will be very small.

2) The mechanical seal has a long service life. During the operation of the mechanical seal, only the friction pair will be damaged, and since both the moving ring and the static ring are made of wear-resistant materials, the service life is long. Under normal circumstances, the mechanical seal can be used continuously for 1-2 years, and in individual cases it can be used for 5-10 years.

3) No need to adjust during operation. Because the working principle of the mechanical seal is based on the elastic force of the rubber element and the pressure of the fluid medium to automatically maintain the application, and does not need to be adjusted like the traditional shaft seal device.

4) It is inconvenient to assemble and disassemble. Since the mechanical seal has more components, it is more inconvenient to disassemble and reassemble.

2.1.2. Features of Bellows Mechanical Seal

Compared with the traditional mechanical seal device, the biggest feature of the mechanical blower seal is that the bellows replaces the traditional spring and auxiliary seal ring, which has stronger compensation performance and better traceability, so it can be installed during the installation process. Install the sealing pair. Compared with the traditional mechanical seal system, it has stronger applicability. Its main features are:

1) In terms of classification, the mechanical bellows seal is a balanced seal, so its range is relatively wide.

2) Because the auxiliary sealing ring is eliminated in the structure, it is equivalent to reducing the potential leakage points. On the other hand, it also reduces the frictional resistance of the compensation mechanism, so that the mechanical seal with bellows has excellent compensation and impact resistance. It also avoids problems such as shaft sleeve corrosion and seal ring aging.

3) The characteristics of mechanical bellows seals are not restricted by the sealing ring, so it can be used under many extreme working conditions, such as high temperature, high speed and high pressure. Under extreme working conditions, its performance is better than traditional mechanical seals.

2.2. Fatigue Life Calculation Method

At present, the commonly used methods for calculating the fatigue life of bellows can be roughly divided into the following three methods:

2.2.1. Formula Method

Use the empirical formula in the EJMA standard to estimate the fatigue life. This calculation method is called formula method. Under complex working conditions, the empirical formula in the EJMA standard is used to evaluate the research object of this article. The fatigue life can only be corrected by the safety factor. A small difference in the safety factor will cause a large error in the calculation result, which cannot meet the needs of engineering applications.

2.2.2. Finite Element Analysis

The fatigue module in ANSYS Workbench finite element software can solve the problems of high-cycle fatigue and low-cycle fatigue. High cycle fatigue analysis is based on linear static analysis. In finite element, the stress-life curve or S-N curve is used to express the relationship between the voltage amplitude and the number of cycles, that is, the relationship between load failure and fatigue. Among them, the S-N curve is obtained through the sample fatigue test, reflecting the uniaxial stress state. However, the ductility of the material, the processing technology of the material and the load environment will all affect the S-N curve, so the use of the finite element method has certain limitations.

2.2.3. Test Method

In addition to formula estimation and finite element software simulation, a fatigue testing machine can also be used to test the fatigue life of welded metal bellows. The fatigue test has the characteristics of high load, high frequency and low consumption. The component is full of alternating pressure in the fatigue testing machine, which leads to the phenomenon of fracture and failure, which is called fatigue correlation. According to statistics, about 70% of mechanical component failures are caused by fatigue, and most accidents are catastrophic. Therefore, it is of practical importance to use the fatigue test method to study the fatigue properties of metal materials. However, using the fatigue test method will cause problems such as a long growth cycle and high cost.

2.3. Performance Parameters of Mechanical Seal Welded Metal Bellows

2.3.1. Maximum Compression Displacement

Under the action of external force, the metal bellows is continuously compressed. When the diaphragm is compressed until the diaphragms are in contact with each other, the displacement caused is the maximum compression displacement:

$$\omega_{max} = L_0 - L'_0 \tag{1}$$

2.3.2. Resistance to Pressure and Working Pressure

The maximum static pressure that a metal bellows can withstand without plastic deformation and maintaining a constant state is called pressure resistance. Working pressure refers to the maximum pressure of the metal blower under working conditions. In order to make the metal bellows have a long service life and maintain high stability, the working pressure is required to be 40%-50% of the pressure resistance.

2.3.3. Rigidity and Sensitivity

The stiffness is the force required to make the metal bellows produce a unit displacement, and the sensitivity is the reciprocal of the stiffness. Sensitivity is the displacement required to make the metal bellows produce a unit force.

2.3.4. Elastic Characteristics

For metal bellows, the relationship between the load at a specific point on the metal bellows and its deformation is called the elasticity of the metal bellows. Its elastic properties depend on the structure and loading method of the metal bellows. The elastic properties of the metal elements of the bellows can be not only linear, but also non-linear. Non-linear characteristics have reduced and increased characteristics. Non-linearity depends on the displacement and geometry of the metal bellows.

2.3.5. Elastic Failure

The manifestation of the elasticity of the metal bellows is that the displacement produced by the metal bellows is later than the applied load.

3. Fatigue Life Test of Mechanical Seal Welded Metal Bellows

3.1. Establish the Geometric Model of the Mechanical Seal Welded Metal Bellows

For butt welding, according to the metal bellows, there is a certain proportional relationship between the wall thickness and the inner diameter. When the inner diameter of the bellows is in the range of 10~1000mm, the ratio of its wall thickness to the inner diameter should be controlled within 0.0006~0.05. Because when the wall thickness of the bellows is large, its flexibility will be poor: but if the wall thickness is too thin, its pressure-bearing capacity will be poor. For the object of this article, the inner diameter of the welded metal bellows is 39.7mm, and the thickness is 0.13mm, which conforms to the relationship between the wall thickness and the ratio of the inner diameter.

According to the structural dimensions of the welded metal bellows (as shown in table 1), the geometric model of the welded metal bellows is built using modeling software.

Table 1. Structural dimensions of welded metal bellows

Parameter	Outer diameter D /mm	The inside diameter of d/mm	Wall thickness δ/mm	Wave plate width aw/mm	Wave number	Total length
Twenty four	52	40	0.13	5.26	20	24

3.2. Mechanical Model of Welded Metal Bellows

The welded metal bellows mechanical seal analyzed and studied in this paper works under high temperature conditions, and the medium is corroded to a certain extent. At the same time, it also bears various external forces, so the stress state is more complicated. Therefore, the cross-sectional conditions of the bellows are complicated and unevenly distributed, and the wave plate itself is very thin (0.13 mm thick), which often breaks and affects the service life. Therefore, the analysis of its power in actual work can better simulate the actual working conditions in the finite element software.

Regarding the working conditions of the welded metal bellows, it is believed that when assembled on the mechanical seal, the neutrality is good regardless of the centrifugal force, and the working temperature is 180°C. The specific pressures are:

(1) The axial pre-tightening force generated by the axial compression, the pre-tightening force F_o is applied to the connection between the straight side of the bellows and the end ring (ie, the free end).

(2) The membrane voltage generated by the pressure difference between the inside and the outside, and the pressure difference between the inside and the outside OP is applied to the entire outer surface of the bellows, and the pressure difference AP = 0.3 MPa.

3.3. Add the Material Information of the Welded Metal Bellows

For welded metal bellows, different materials should be selected according to the actual conditions of use. Commonly used materials are mainly brass, tin bronze, beryllium bronze, aluminum alloy, stainless steel, and Inconel

The material of the welded metal bellows mechanical seal analyzed and studied in this paper is 316 steel, and its basic mechanical properties and physical properties are shown in table 2.

Table 2. Table of basic mechanical properties and physical property parameters

Material	Density (g/cm^3)	Yield strength Tensile strength (MPa)	Elastic Modulus (MPa)	Thermal Conductivity (W/(m.K))	Poisson's ratio
316 steel.	8.03	310	620	16.3	0.3

Allowable stress of 316 steel [σ]:

$$[\sigma] = {}^{\sigma_x}/_{n_x} \tag{2}$$

In the formula: σ_x represents the yield limit of the material, and n_x represents the safety factor. It can be seen from table 2 that the value of the yield limit of 316 steel is 310MPa, and n_x is taken as 1.5, so the allowable stress of the material is 206.7MPao.

3.4. Meshing

In ANSYS Workbench finite element software, there are four mesh methods, namely automatic division method, tetrahedron, scanning and multiple regions. Among them, the automatic segmentation method is the simplest segmentation method. The system will automatically divide the mesh, but this is a relatively crude method. In practical applications, if you don't need a precise solution, you can use this method. The tetrahedral mesh method is the most basic method. It has the advantages of fast division, automatic production, easy-to-use curvature function and approximate size, and can automatically improve the grid in key areas. The grid of the scanning method usually creates a hexadecimal grid, which can reduce the calculation time in the analysis and calculation process.

For welded metal bellows, the research object of this paper adopts hexahedral mesh. Through the mesh division, the U-shaped metal blower produces a total of 208, 134 nodes and 105, 160 units, and the V-shaped metal blower produces a total of 228, 542 nodes. Nodes are 113564 units.

3.5. Experimental Analysis Process

(1) In the fatigue analysis, the S-N curve of the material is required. The S-N curve of the material used in this article is obtained in the mechanical engineering material performance data manual. When setting the boundary conditions, it is simplified to the time-varying dynamic load.

(2) This paper studies the fatigue life of metal bellows at a temperature difference of 3℃, 4℃, 5℃ and 6℃ in sequence, and observes the minimum fatigue life position and the distribution of the safety factor with respect to the U-shaped metal bellows and V-shaped metal bellows at a temperature difference of 3℃, 4℃, 5℃ and 6℃. The change law of temperature difference, and compare and analyze the fatigue performance of the two.

4. Analysis of Experimental Results

(1) Comparative analysis of minimum fatigue life under different temperature difference conditions.

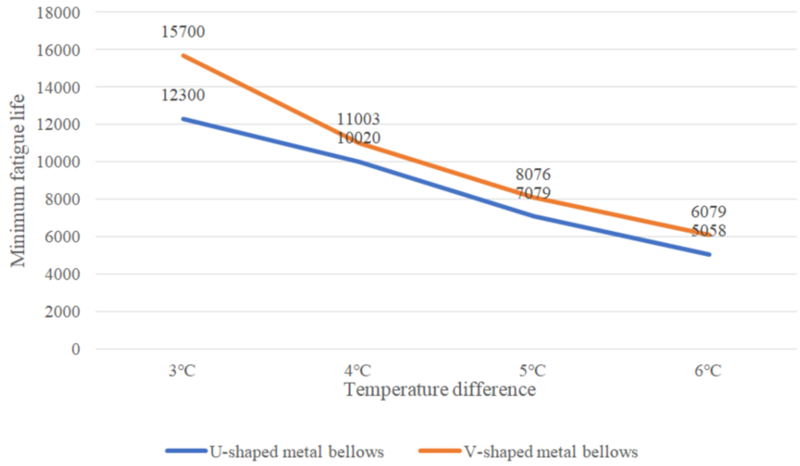

Figure 1. Comparison chart of minimum fatigue life under different temperature difference conditions.

Figure 1 is the change curve of the minimum fatigue life of U-shaped metal bellows and V-shaped metal bellows under different temperature differences. The figure shows that as the temperature difference increases, the minimum fatigue life of both types of metal blowers decreases. At the same time, it can also be found that the fatigue life of the V-shaped metal bellows is always longer than that of the U-shaped metal bellows.

(2) Comparative analysis of minimum safety factor under different temperature difference conditions.

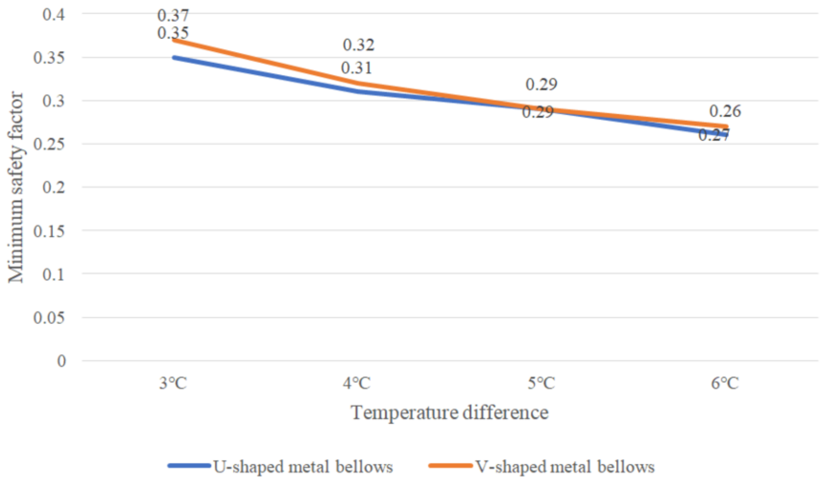

Figure 2. Comparison chart of minimum safety factor under different temperature difference conditions.

Figure 2 is a comparison diagram of the minimum safety factor of two metal bellows under different temperature differences. The figure shows that the minimum safety factor of the two metal bellows decreases as the temperature difference increases, and this part of the metal bellows needs to be reinforced. It can be seen from the figure that the minimum safety factor of the U-shaped metal bellows is always lower than that of the

V-shaped metal bellows. Compared with the U-shaped metal bellows, the V-shaped metal bellows has better fatigue performance.

5. Conclusions

Mechanical seal is a shaft sealing device for fluid rotating machinery. With the development of society, countries all over the world have higher and higher requirements for the environment, and at the same time put forward higher standards for different types of machinery. The mechanical seal system has the characteristics of less leakage, high safety, wide application range and long life. Because of these characteristics, it has been used on a large scale in the aerospace and navigation fields. In this paper, the fatigue life of the mechanically welded metal blower is tested. Experiments show that the minimum safety factor of the U-shaped metal bellows is always lower than that of the V-shaped metal bellows, and its fatigue performance is better than that of the U-shaped metal bellows.

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