Gas Sealing Performance Analysis of Metal Rubber Seals

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Gas Sealing Performance Analysis of Metal Rubber Seals

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Abstract. In this paper, the gas sealing properties of the metal rubber seals is analyzed. The gas leak rate formula for metal rubber seals is derived. The gas seal performance test of metal rubber seals is conducted and the relationship between gas leakage and temperature and pressure is obtained under different test temperatures and gas pressures. The results provide the basis for the optimization and improvement of sealing performance.

1. Introduction
In the aeroengine mechanical power system, the gas sealing device is one of the important components, especially as the main flow path, the secondary flow of the air system, and the main bearing cavity sealing components. The sealing performance has an important influence on the engine performance and will have a direct impact on engine boost ratio and turbine efficiency increase[1].

For gas seals, rubber O-rings have good performance in normal temperature applications, but their working temperature range is limited. At low temperatures (below -50°C), all natural and synthetic rubbers and almost all thermoplastics are not suitable for sealing materials. In this temperature range[2]. The metal rubber material has superior performance and can be used for high temperature, strong pressure and corrosive media, high vacuum and ultra-low temperature environment[3,4]. Therefore, the use of metal rubber seals for gas sealing has a very broad practical value and application space.

In this paper, the formula of the gas seal leakage rate of the metal rubber seal is deduced, and the leakage condition of the metal rubber seal is tested under different pressures and temperatures to realize the analysis of its sealing performance.

2. Analysis of gas seal leakage rate of metal rubber seals
This paper deals with the calculation of the gas leakage rate when a metal-rubber seal is used for gas sealing. Figure 1 and Figure 2 show the installation diagrams and physical maps of the metal-rubber seals tooling used for gas-sealing test.
For the gas seal of metal rubber seals, the leakage model is simplified according to the test tooling, and the gas seal leakage model of the metal rubber seal is shown in Figure 3. In the figure, there are two fixed flanges on the top and bottom, and there is an annular groove in the middle of the lower flange, in which the metal rubber seal is placed. The initial gas pressure inside the metal rubber seal is $P_1$, and the gas pressure outside the seal is $P_2$. The average clearance between the flange surface and the rough surface of the metal rubber seal is $u$, the contact width is $l$, and the radius of the metal rubber seal is $r$. If we do not consider the change of the length of the leakage area along the direction of the contact width, the leakage rate of the gas seal of the metal rubber seal can be directly obtained according to the leakage formula of the fluid in the rectangular region of the micro element $^{[5,6]}$.$$
abla Q’ = \pi r M P_1 u^3 \Phi p (P_1 - P_2)/(6 \eta RT l) \tag{1}$$

In the formula, $R$ is the molar gas constant; $M$ is the molar mass of the gas; $\Phi p$ is the pressure flow factor; $\eta$ is the viscosity of the gas.

We consider the change in the length of the leakage area along the direction of the contact width and solve the leak rate of the gas seal of the metal rubber seal according to the following method. The minimum radius of the contact area at this time is $r_1$, and the maximum radius is $r_2$. First, at the radius $r$, select a micro element ring with a width of $dr$. The gas pressure difference between the two sides of the ring is $dP$. After the ring is unrolled, it is a rectangular leakage area with a length of $2 \pi r$ and a width of $dr$. We solve it by applying Equation (1). The gas leakage rate in this micro-region can be obtained as:

$$Q’ = -2 \pi r M P u^3 \Phi p dP/(12 \eta RT dr) \tag{2}$$

which is:

$$P dP = -6 \eta RT Q’ dr/(\pi r M u^3) \tag{3}$$

The boundary conditions are: $r = r_1$, $P = P_1$; $r = r_2$, $P = P_2$. Substituting equation (3) and performing the integral operation, the formula for calculating the gas leakage rate can be obtained as:

$$Q’ = \pi M u^3 \Phi p/[12 \eta RT \ln(r_2/r_1)] \tag{4}$$
3. Metal Rubber Seal Gas Sealing Performance Test

3.1. Test plan
According to the requirements of the experimental tooling parameters, the metal rubber seals with a relative density of 0.40 were selected to perform gas sealing performance tests at different temperatures and pressures. Pressure test interval: 0.4MPa-2.0MPa (pressure increase 0.2MPa). Temperature test interval: -60°C-140°C (temperature increase 20°C).

3.2. Analysis of test results
For metal rubber seals, the initial pressure of the test was 2 MPa, the test time was 8 hours, and the leakage at different temperatures was tested. The resulting curve of gas leakage over time is shown in Figure 4.

From Figure 4, it can be seen that as the test time continues, the amount of gas leakage gradually accumulates, but its increase rate gradually decreases, which is the result of the gas pressure gradually decreasing as the gas leaks. As the temperature increases, the amount of gas leakage gradually decreases.

![Figure 3. Gas seal leakage model of metal rubber seal.](image)

![Figure 4. Gas Leakage-Time Relationship.](image)

After the 8-hour test time is reached, the curve of the gas leakage with temperature is shown in Figure 5. From the figure, it can be found that the amount of gas leakage decreases with increasing temperature, which is consistent with the theoretical analysis result that the temperature will cause thermal expansion phenomenon and make the seal and tooling contact more closely.
The test time is shortened to 0.5 hours, and the curve of the gas leakage with time is shown in Figure 3-3. It can be seen that the gas leakage increases linearly in a short period of time, which shows that the gas leakage rate remains basically constant during a short period of time. That is, we can use the leakage amount per unit time in a short time to approximate the gas leakage rate at a certain point.

We analyze the leak rate of different pressures by keeping the test temperature constant and changing the test pressure. The curve of the leak rate with pressure at different temperatures was shown in Figure 7. It can be found that as the pressure increases, the gas leakage rate gradually increases, and as the temperature increases, the gas leakage rate gradually decreases. Analyzing the gas leak rate, we can find that the leak rate and pressure are approximately linear, and the pressure has two effects on the leak rate. For one thing, the pressure difference is the direct cause of the leak, and the pressure difference is the linear influence factor. For another thing, the contact stress between the seal and the test tooling is changed due to the pressure change, which affects the size of the contact area and the leak gap. This is a non-linear influence factor. The approximate linearity of the variation
The pressure difference, a linear term, has a greater effect on the leakage rate than the pressure-influenced contact region.

![Gas leakage rate- Gas pressure curve.](image1)

Figure 7. Gas leakage rate- Gas pressure curve.

We analyze the leak rate at different temperature by keeping the test pressure constant and changing the test temperature, and we obtain the curve of the change of leak rate with pressure at different temperatures as shown in Figure 8. It can be found that as the temperature increases, the gas leakage rate gradually decreases. From the analysis of the theoretical formula of the leakage rate, if the impact of the thermal expansion of the seal and the test fixture on the contact area is not considered, the leakage rate should show a reciprocal increase trend with the temperature, but due to the effect of temperature expansion, the leakage rate and temperature are to some extent. It appears an approximately linear relationship.

![Gas leakage rate-temperature curve.](image2)

Figure 8. Gas leakage rate-temperature curve.
According to the experimental results, the three-dimensional map of the leak rate with temperature and pressure changes is shown in Figure 9. From this figure, the relationship between the leak rate and temperature and pressure can also be observed more intuitively.

![Figure 9. Gas leakage rate-temperature-gas pressure relationship.](image)

**4. Conclusion**

1. This paper studies the sealing performance of gas seals of metal rubber seals, and derives the formula for solving the leak rate;
2. This paper studies the relationship between gas leakage rate and gas pressure. Keeping the test temperature constant, by changing the gas pressure, it was found that the leakage increases approximately linearly with gas pressure;
3. This article studies the relationship between gas leak rate and gas temperature. Keeping the gas pressure constant, by changing the test temperature, it was found that the leakage gradually decreased as the test temperature increased, and it had a certain linearity.

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