Chinese Journal of Aeronautics, (2016), 29(1): 292–296

Chinese Society of Aeronautics and Astronautics
& Beihang University

Chinese Journal of Aeronautics

cja@buaa.edu.cn
www.sciencedirect.com

Analyses toward factors influencing sealing clearance of a metal rubber seal and derivation of a calculation formula

Yan Hui, Zhao Yalei, Liu Jianguo, Jiang Hongyuan *

School of Mechatronics Engineering, Harbin Institute of Technology, Harbin 150001, China

Received 18 April 2015; revised 27 May 2015; accepted 23 August 2015
Available online 19 October 2015

KEYWORDS

Elastic mechanics theory;
Elastic modulus factor;
Metal rubber;
Seals;
Temperature factor

Abstract Sealing clearance is a key factor for a metal rubber seal's sealability. The expansion coefficient and expansion deformation in the radial direction of metal rubber have been obtained through a thermal expansion experiment of metal rubber. The influence of the elastic modulus to the sealing clearance has been analyzed theoretically. By combining the temperature and elasticity factors of metal rubber with the elastic mechanics theory, the calculation formula of the sealing clearance has been derived, and the values of the sealing clearance and the leakage rate in certain working conditions have been calculated. Experimental results are consistent with calculation results in a high degree. The calculation formula of the sealing clearance can explain the influences of the temperature and elastic modulus factors of metal rubber on the sealing clearance. It can provide guidance for the study of sealing mechanism of metal rubber seals.

1. Introduction

Seals play a crucial role in many aeronautics and astronautics devices, and their failure may result in catastrophic events, such as the Challenger disaster.[1,2] Because of the easy aging of rubber, the range in which it can work in some special situations such as high temperature and high pressure is limited. A rubber seal is hardly competent for the seal in special situations of high temperature and high pressure in the field of aeronautics and astronautics.[3,4] The application of a metal seal is limited because when it works in a high-temperature situation, its springback ability will decrease, and it needs additional resilience to improve performance. Metal rubber is made of metal wire by a special process and its interior forms a space grid structure that depends strongly on the plentiful micro springs which are arranged in a certain mode, so it has many similar characteristics between metal and normal rubber. Metal rubber shows many advantages such as resistance properties of high temperature, high pressure, high vacuum, ultralow temperature, and radiation, and if metal rubber is made of a special metal wire, it can work in corrosion environment.[5] Therefore, some rubber products that could not be competent in special working conditions of aeronautics and astronautics

* Corresponding author. Tel.: +86 451 86418028.
E-mail addresses: yanhui@hit.edu.cn (H. Yan), jhy_hit@sina.com (H. Jiang).

Peer review under responsibility of Editorial Committee of CJA.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.cja.2015.09.002
1000-9361

fields can be replaced by metal rubber ones. At present, metal rubber technology has been successfully applied to many fields such as vibration isolation, sound absorption, throttling, and filtering. Furthermore, in the engineering application of special conditions in aeronautics and astronautics fields, metal rubber shows many significant advantages.[6–9] Thus, the application of metal rubber in seals is very helpful to solve the technological problem and improve the reliability of aeronautics and astronautics devices.

A metal rubber seal cladded with stainless steel is made up with metal rubber inside and stainless steel outside. When the seal is working, the stainless steel contacts with the surfaces which are needed to be sealed, so the seal clearance will be blocking.[10] The circular metal rubber core is an elastic part and it provides the contact stress between the seal and the sealing surface. The kind of seal that is studied in this paper is static seal. When the contact stress is less than the medium pressure, the metal rubber will deform under the action of the medium pressure and then the sealing clearance will increase.[11] Leakage rate is the most important index for estimating sealing effect, as the flow of fluid in the sealing clearance is complicated, and the changes of the sealing clearance have a heavy influence on the leakage rate.[12,13] As we can know from the calculation formula of metal rubber seal leakage rate, the sealing clearance has a third-power relationship with the leakage rate, so research about the change rule of the sealing clearance has a great significance for the study about the leakage rate of a metal rubber seal.[14]

In this paper, various factors influencing the sealing clearance have been analyzed, according to the theory of elastic mechanics that when the medium pressure works on a metal rubber seal, elastic deformation will occur. The calculations formula about the sealing clearance has been derived, and the values of the sealing clearance and the leakage rate in certain situations have been calculated. Then we compare the results of a test with those of theoretic calculations. This study can provide reliable theoretic basis for the stainless steel cladding metal rubber seal application in aeronautics and astronautics devices.

2. Analyses toward factors influencing sealing clearance

2.1. Influence of temperature on sealing clearance

The variation of temperature can lead to the metal rubber's thermal deformation. The experiment of thermal expansion can only measure the deformation in the axial direction, but the seal's circumferential size has been fixed when it is working in the slot, so the deformation can only happen in the radial direction. If we want to study the influence of temperature on the sealing clearance, we need to calculate the radial deformation value of the seal accurately. Based on the principle of volume invariably, we can convert the deformation in the axial direction to one in the radial direction.[15–17] Fig. 1 shows the schematic of a metal rubber cylinder specimen's volume expansion.

The relationship between the deformations in the axial direction and the radial direction can be expressed as follows:

$$\frac{\pi d_1^2}{4}(l+\Delta l)=\frac{\pi(d_1+\Delta d_1)^2}{4}l \tag{1}$$

where d_1 is the metal rubber specimen's diameter before the temperature rise; l is the metal rubber specimen's length before the temperature rise; Δd_1 is the metal rubber specimen's radial increment and Δl is its axial increment after the temperature rise.

Therefore, the relationship between the metal rubber specimen's coefficients of linear expansion in the radial direction and the axial direction can be expressed as follows:

$$\alpha_r=\sqrt{1+\alpha}-1 \tag{2}$$

where α_r and α are the coefficients of linear expansion in the radial and axial directions, respectively.

The coefficient of linear expansion can be measured through a thermal expansion experiment. The coefficient of expansion in the axial direction can be measured by a DIL 402C thermal dilatometer produced by NETZSCH. The coefficient of expansion in the radial direction and the radial increment can be calculated. The results of calculation of radial deformation are shown in Table 1, where t is the temperature of the experiment and Δd is the deformation that is converted to the radial direction.

The leakage experiments of a metal rubber seal were done in a heating cabinet and the experiment would begin when the temperature of the heating cabinet was stable. We assumed that each work temperature of the metal rubber seal was constant and didn't consider the dynamic temperature variance in system modeling.

2.2. Influence of elastic modulus on sealing clearance

When the working pressure of the seal increases, the medium which needs to be sealed will squeeze into the sealing clearance, at the same time the pressure of the medium will press the seal, and then the deformation of the seal leads to the sealing clearance increasing. As an elastomer, the metal rubber's elastic modulus can influence the sealing clearance directly. The metal rubber's elastic modulus include the friction stress modulus and the elasticity stress modulus, and because a static seal's elasticity stress modulus is more important, the friction stress modulus is the main research object of dynamic performance of metal rubber. In this paper, when we study the metal rubber seal, we only think about the elastic stress modulus. Metal rubber is a kind of anisotropic materials of which the elastic modulus doesn't remain constant and changes with the strain's change. Because the sealing clearance's variation is very small, we can use the elastic modulus under the pre-compression state instead of metal rubber's elastic modulus when it's working.

The friction stress and elasticity stress can be calculated as follow:

$$\sigma_1=\frac{\sigma_L+\sigma_{UL}}{2} \tag{3}$$

$$\sigma_2=\frac{\sigma_L-\sigma_{UL}}{2} \tag{4}$$

$$E=\frac{\sigma_1}{\varepsilon} \tag{5}$$

where σ_1 is the elastic stress, σ_2 is the friction stress, σ_L is the load stress, σ_{UL} is the unload stress, ε is the strain of the metal rubber seal, and E is the elastic modulus used in this paper.

Metal rubber's elastic modulus has a close relationship with the material, the diameter of metal wire which has been chosen,