Sealing Performance Analysis of Rubber O-ring in Static Seal Based on FEM

Shiwei Niu

***Abstract*— Reliability of the system relies on the sealing performance of O-ring. Sealing performance analysis of O-ring was investigated by finite element method. Effect of medium pressure and pre compression on the sealing performance analysis of O-ring were studied. The results show that the stress distribution of O-ring is dumbbell shape when the medium pressure is 0. There are three high stress locations when the medium pressure is bigger than 1MPa. The maximum von Mises stress and contact stress increase with the increasing of medium pressure. With the increasing of pre compression quantity, the maximum von Mises stress of O-ring first decreases and then increases, While the maximum contact stress increases. Those results can provide a basis for the design and safety assessment of O-ring.**

***Index Terms*—O-ring, sealing performance, finite element model, Von Mises stress, contact stress**

I. INTRODUCTION

O-ring is widely used in machine tool, ship, automobile, aerospace, metallurgy, chemical industry, railway machinery and other fields for its advantage. Such as simple structure, good sealing performance and low manufacturing cost[1]. O-ring is generally installed in rectangular groove that on the outer circle or inner circle cross section for sealing medium. It is suitable for static seal and reciprocation seal. O-ring has bi-directional dense function. Pre compression is applied on the O-ring along radial or axial direction after installed, then the initial seal ability appears. The overall sealing force can be gained by the initial seal force and seal force caused by the medium pressure. The system sealing can be realized by the overall sealing force. Usually, in order to prevent permanent deformation, the maximum compress is 30% in static seal, while it is 20% in the dynamic deal. In static seal, the highest working pressure of O-ring is 20MPa. In this paper, the sealing performance analysis of O-ring was investigated by finite element model. Effect of medium pressure and pre compression on the sealing performance analysis of O-ring were studied.

II. FINITE ELEMENT MODEL

It is difficult to determine the constitutive model of rubber material, and the experiment and calculation are also difficult for its geometric nonlinear, material nonlinear and contact nonlinear. Constitutive model researches of rubber are mainly concentrated on phenomenology theory. In this condition, assuming that rubber is isotropic material. Assume that rubber material has incompressibility for its high bulk modulus. Constitutive relationship of rubber material can be expressed in strain energy density function. Mooney-Rivlin model is the most frequently model in engineering[2]. Strain energy density is expressed as series form of deformation tensor invariant.

$$W=\sum_{i+j=1}^{N}C_{ij}(I_1-3)^i(I_2-3)^j \quad (1)$$

Where, C_{ij} is Rivlin coefficient from experiment data. When N=1, Eq.(1) can be simplified as follows.

$$W=C_{10}(I_1-3)+C_{01}(I_2-3) \quad (2)$$

For rubber material, the relationship of elastic modulus E and shear modulus G is:

$$G=\frac{E}{2/(1+\mu)} \quad (3)$$

Poisson's ratio of rubber material $\mu=0.5$. The relationship of G, E and material constants. According to the compression experiment of rubber, $C_{10}=1.87, C_{01}=0.47$.

Assumed conditions:

(1)Elastic modulus and Poisson's ratio of the rubber is constant.

(2)Tensile and compression creep properties of the O-ring are the same.

(3)Creep does not cause volume change.

(4)Effect of hydraulic oil temperature change on the O-ring is neglected.

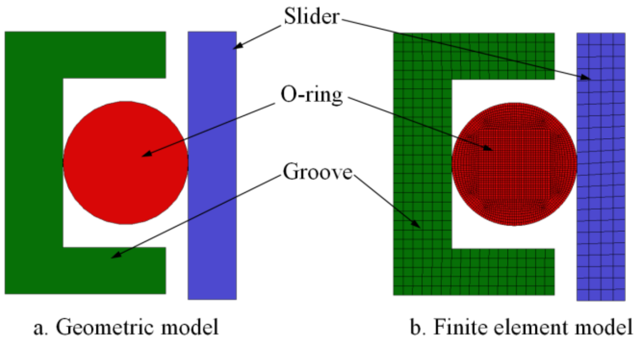

Fig.1 Geometric model and finite element model

Fig.1 shows the geometric model and finite element model of the sealing system. The material of O-ring is NBR. The size of O-ring is 150mm×5.33mm.Two-dimensional axisymmetric models of slider, O-ring and groove were established in ABAQUS. The materials of slider and groove are steel. Its elastic modulus is 206GPa, Poisson's ratio is 0.3, density is 7800kg/m^3. The friction coefficient between O-ring and steel is 0.2. Four node quadrilateral bilinear axisymmetric unit (CAX4R) was used to mesh the three parts [3].

Axis Constraints are applied on the slider and groove for the axisymmetric model [4,5]. In static seal, two steps should be given. Firstly, radial displacement 0.5mm is applied on the slider, then the pre compression appears. Secondly, medium pressure should be applied on the working surface of the O-ring.

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III. EFFECT OF MEDIUM PRESSURE

When the pre compression is 0.4mm, Von Mises stresses of O-ring under different medium pressures are shown in Fig.2. When the medium pressure is 0, the stress distribution of O-ring is dumbbell shape. The maximum von Mises stress is not on the surface of O-ring, but in the location that has a distance with the ring surface. The maximum von Mises stress is 1.483MPa.

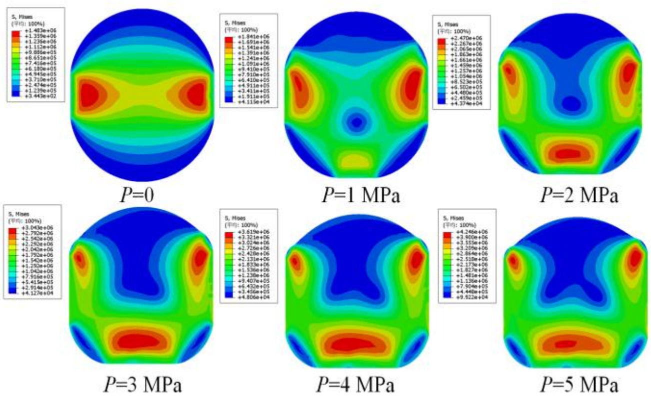

Fig.2 Von Mises stress of O-ring under different medium pressures

With the increasing of medium pressure, the stress distribution changes. There are three high stress locations when the medium pressure is bigger than 1MPa. The maximum von Mises stress increases with the increasing of medium pressure. It is more serious when the stress is bigger.

When the pre compression is 0.4mm,contact stresses of O-ring under different medium pressures are shown in Fig.3. When the maximum contact stress on the main sealing surface is bigger than medium pressure, good sealing can be achieved. Otherwise, medium leakage occurs. When the medium pressure is 0, There are two contact surfaces. The maximum contact stress in the middle part of the contact area, the contact stress is smaller on both sides of the contact area. After medium pressure is applied, there are three contact areas. And the width of contact area is bigger than it in no pressure condition.

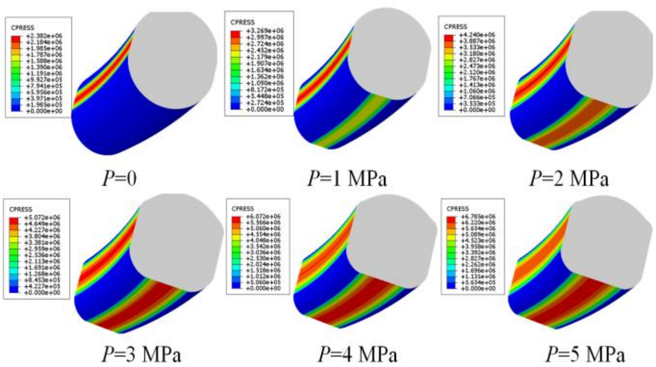

Fig.3 Contact stress of O-ring under different medium pressures

Fig.4 shows the maximum von Mises stress and contact stress of O-ring under different medium pressure. With the increasing of medium pressure, the maximum von Mises stress and contact stress increase with an nonlinear rule. When the medium pressure is smaller than 5MPa, the maximum contact stress on the main sealing surface is bigger than medium pressure. So, the sealing performance of O-ring is good in these condition. But when the medium pressure is bigger, the von Mises stress is bigger. So, O-ring in high medium pressure is prone to failure.

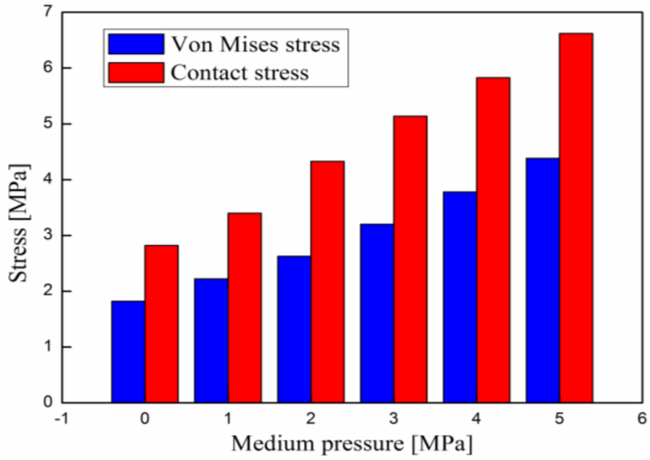

Fig.4 The maximum stress of O-ring under different medium pressures

IV. EFFECT OF PRE COMPRESSION QUANTITY

When the medium pressure is 3MPa, the maximum von Mises stress and contact stress of O-ring under different pre compression quantities are shown in Fig.5. With the increasing of pre compression quantity, the maximum von Mises stress of O-ring first decreases and then increases. But the maximum contact stress of O-ring increase. It means that the sealing performance of O-ring can be improved by increasing pre compression quantity. In those conditions, the maximum contact stress is bigger than the medium pressure. Therefore, the sealing performance of O-ring is reliable.

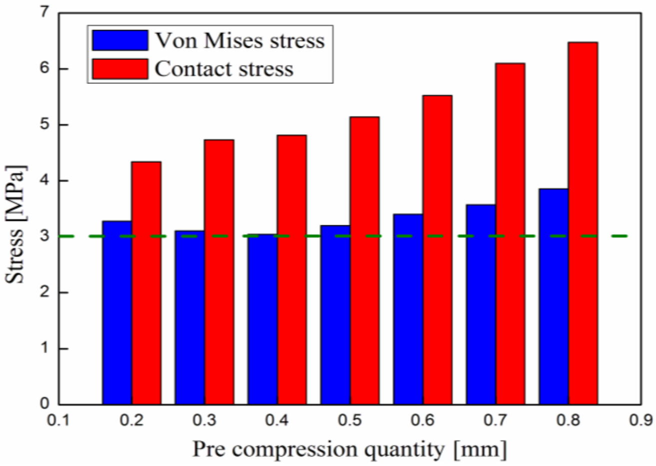

Fig.5 The maximum stress of O-ring under different pre compression quantities

V. CONCLUSIONS

(1) When the medium pressure is 0, the stress distribution of O-ring is dumbbell shape. The maximum von Mises stress is not on the surface of O-ring, but in the location that has a distance with the ring surface. There are three high stress locations when the medium pressure is bigger than 1MPa. The maximum von Mises stress increases with the increasing of medium pressure. But it first decreases and then increases with the increasing of pre compression quantity.

(2) When the medium pressure is 0, the maximum contact

stress in the middle part of the contact area, the contact stress is smaller on both sides of the contact area. There are three contact areas when medium pressure is bigger than 0. The maximum contact stress of O-ring increases with the increasing of pre compression quantity and medium pressure.

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