

Finite element analysis of the O-ring behavior used in static sealing assembly

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Abstract— This work presents a finite element analysis, using Ansys software, of the O-ring behavior inserted into a groove in a static sealing assembly. The analysis showed that mechanical clearance and friction are key parameters that have an effect on stress distribution.

The results of the numerical simulation confirm the classic form of Hertz contact pressure. The appropriate choices of the mechanical seal clearance and the friction coefficient for different pressure conditions improve the reliability of the O-ring.

Keywords— O-ring; friction coefficient; contact pressure; mechanical clearance.

I. Introduction

The O-ring is one of the most used seals in pneumatic and hydraulic systems, either in static or dynamic applications, for its low cost and ease assembly. The effectiveness of the O-ring is related to the proper groove design and the choice of its material. In hydraulic applications, for large fluid pressure and the ability of the seal to be deformed easily can facilitate the passage of a portion of the O-ring through the mechanical clearance. This phenomenon is much more likely to happen when the seal hardness is low and the sealing clearance is large.

Several researchers have investigated the O-rings sealing performance. Karaszkiwicz [1] proposed equations to determine the geometric distortion and contact forces of an O-ring. Dragoni et al. [2] Developed a theoretical model to describe the mechanical behavior of an O-ring inserted into a rectangular groove. They studied the the friction coefficient influence and the variation of the groove dimensions.

Yokoyama et al.[3] determined the effect of the contact pressure according to the fluid pressure on the behavior of the O-ring considering the thermal degradation. Diany et al. [4, 5] have shown that the equations of the classical Hertz contact theory remain valid for the relaxation by modifying the mechanical characteristics of the O-ring. There finite element model produces the same results as the analytical model. They showed that the installation of the seal in a groove reduces the compression charge needed to create a minimum contact pressure. Zhang et al. [6] compared two installations using a finite element model, one with an O-ring and the other with a D-ring. They showed that an O-ring can be replaced by a D-ring only in static applications. In dynamic reciprocating installations, the D-ring may be used longer than an O-ring when the coefficient of friction is low. Wei et al. [7] have shown that O-ring hardness changing can improve seal reliability. They confirmed that when the seal is harder, the size of the O-ring compressed into the sealing clearance is reduced and the stress distribution over the seal section is more uniform.

This work presents a finite element analysis of the O-ring behavior in a standardized groove, loaded axially by a clamping force and under the fluid pressure. The effect of mechanical clearance and friction are analyzed.

II. Finite Element Models

The assembly used in this study is composed of a cylinder and a rigid plate, Fig. 1. The O-ring is placed in a groove machined on the upper surface of the cylinder. The main role of the O-ring is to seal the assemblage. A clamping load is applied to the top surface plate in order to create a sufficient contact pressures to prevent leakage through the plate-seal-cylinder interfaces.

The diameter of the O-ring section is 2.65 mm (international standard ISO 3601/1), the geometrical parameters of the structure are presented in table 1.

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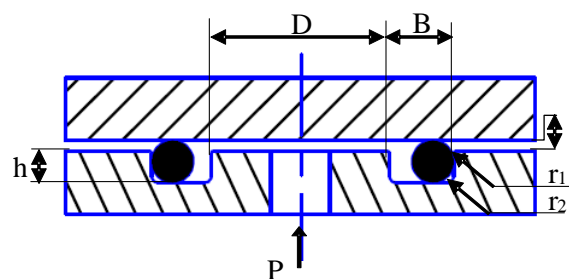


Fig. 1. Static sealing assembly.

TABLE I. STRUCTURE PARAMETERS.

Parameters	D	B	h	r1	r2
Values (mm)	11.4	3.8	2	0.3	0.6

In order to evaluate the effect of friction and mechanical sealing clearance and fluid pressure on an O-ring located in a groove, an axisymmetric finite element model was developed using Ansys software [8], Fig. 2. The O-ring is modeled by a disk with four nodes plane elements compressed between rigid plate and a groove.

In practice, the clamping load and the fluid pressure are applied simultaneously on the O-ring. In the simulation, the O-ring successively undergoes the application of two loads:

Load 1: compression of the O-ring by moving the rigid plate vertically, which represents the clamping stage.

Load 2: A fluid pressure (range 0 to 9 MPa) is applied to the inner surface of the seal.

For each variation of the mechanical clearance or the fluid pressure or the friction coefficient, the results of the simulation characterize the behavior of the O-ring and thus determine the limits of its use.

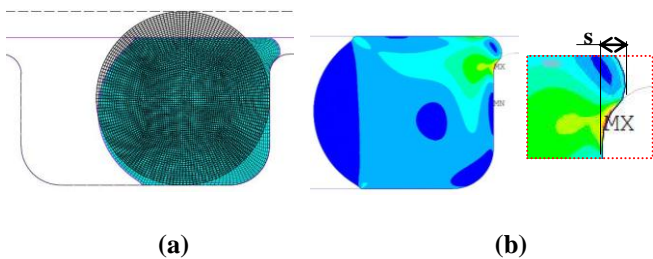


Fig. 2. (a) Progression of the O-ring deformation.
 (b) Von-Mises stress concentration area for fluid pressure of 9 MPa

III. Results and Discussions

In pressurized assembly with O-ring, leaks are caused either by the deterioration of the seal or by the loss of contact pressure at the contact interfaces. The O-ring deterioration usually occurs in areas of high stress concentration.

Fig. 3 and 4 shows the distribution of the contact pressure for the three surfaces limiting the contacts groove-O-ring-plate. The shape of these distributions confirms the classical form of Hertz contact pressure, which gives a maximum value at the center of the contact surface, and zero at the ends of the contact zone. For each position, the contact pressure increases as mechanical clearance decreases. Indeed, when the clamping load decreases, the mechanical clearance increases and consequently the contact pressure decreases. When the pressure of the fluid is applied, the contact pressure increases for all three surfaces, which increases the sealing of the assembly. However, the equivalent Von-Mises stress increases in the extrusion zone, which is an area of high stress concentration (Fig. 2 (b)), and can reach the allowable limit of seal material and thus cause leakage. Fig. 5 presents the

variation of the Von-Mises stress according to the extrusion clearance for several values of the fluid pressure. It's noted that, for low pressures, the stress decreases when the mechanical clearance increases and vice versa for pressures greater than 5 MPa. Fig. 4 can be useful to predict the couple of limit values (mechanical clearance, pressure) that must be respected to keep the Von-Mises stress everywhere inferior to the resistance stress value of the seal material and thus prevent its degradation.

Another parameter is introduced to characterize the phenomenon of the seal extrusion, which is the extrusion length, denoted "S", as used in Fig. 2 (b). Fig. 6 shows the variation of the distance " S " according to the friction coefficient for three values of the mechanical clearance of compressed O-ring in the clearance " e ". The extrusion length "S" is greater, when the sealing clearance is important and the friction coefficient is smaller.

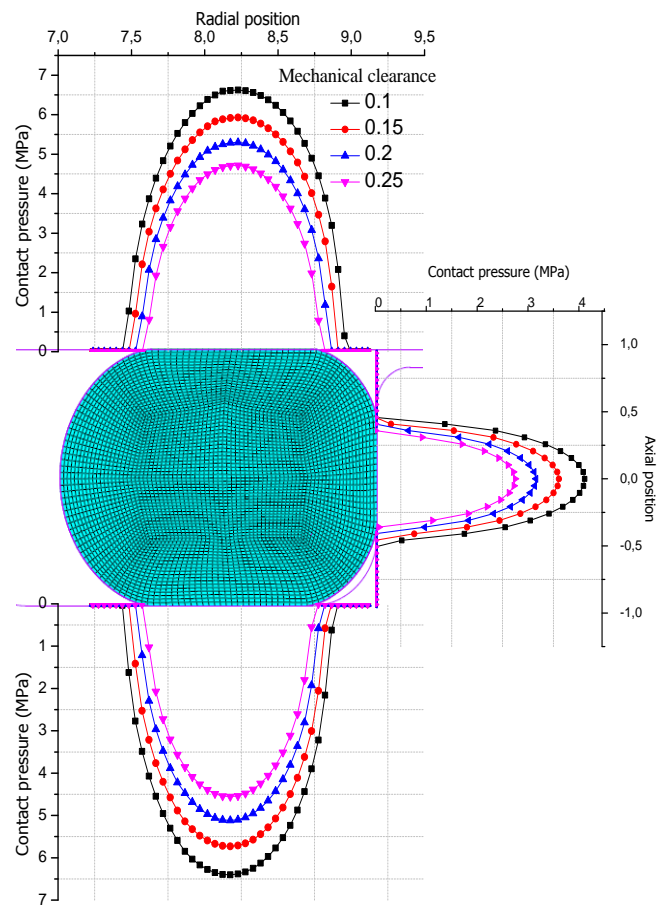


Fig. 3. The distribution of the contact pressure after the load 1.

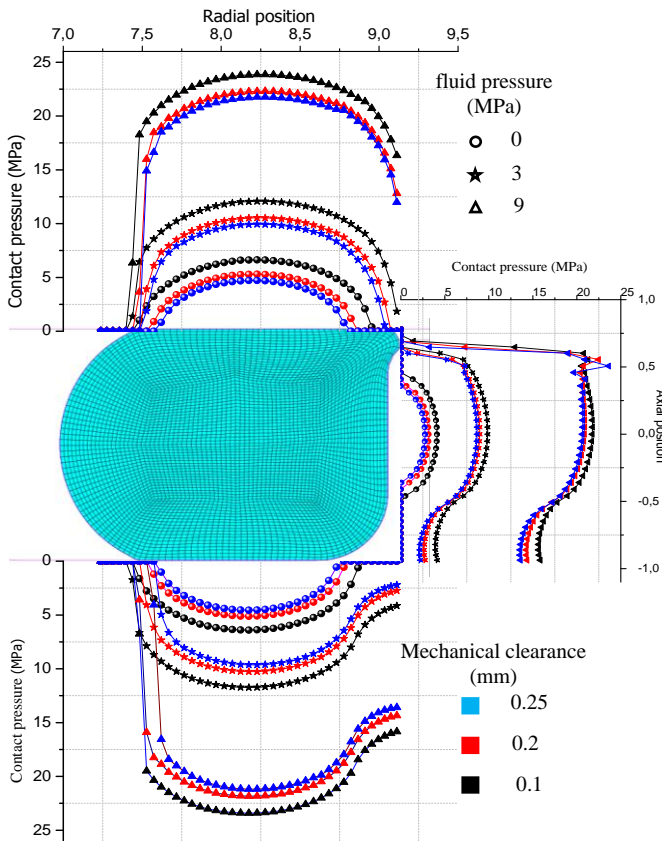


Fig. 4. The distribution of the contact pressure after the application of the fluid pressure

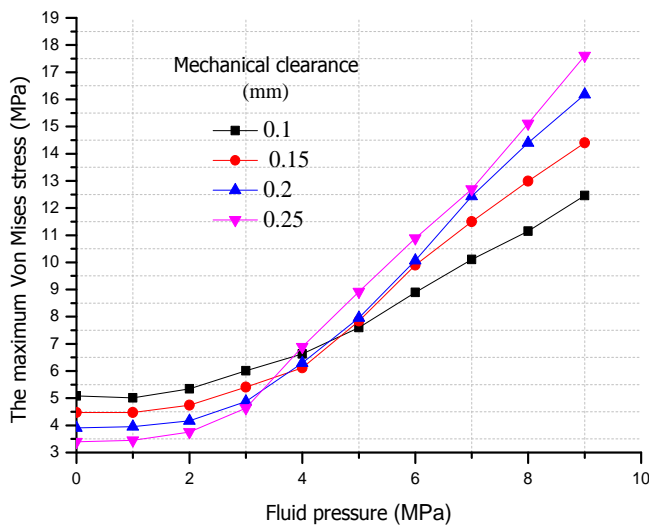


Fig. 5. The variation of the maximum stress of Von-Mises according to the fluid pressure.

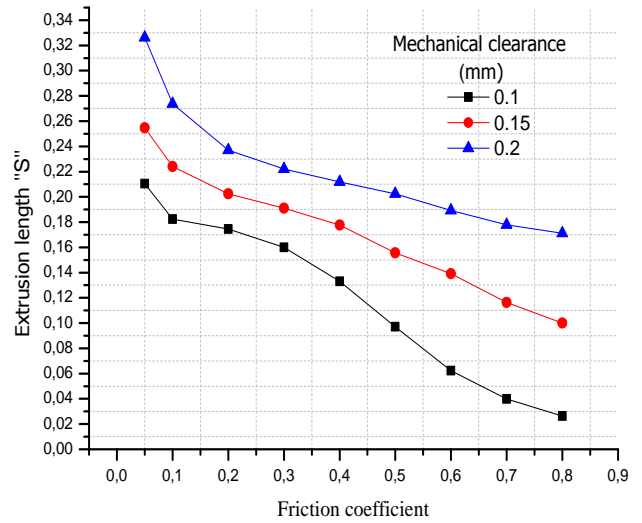


Fig. 6. Variation of " S " according to the coefficient of friction

IV. Conclusion

This study confirms the classic form of Hertz contact pressure. The application of the fluid pressure increases the values of the contact pressure in the three contact zones. When using the elastomeric O-ring seal, it is essential to choose the best value pair (mechanical clearance and friction coefficient) to avoid leaks.

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