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On the Contact Behavior Analysis and New Design of High Pressure Piston Seals

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In this paper, the geometry effectiveness and contact modes as functions of real contact length on a cap ring have been analyzed for high pressure sealing mechanism in reciprocating actuator. The reaction force and elastic strain energy density are very important parameters for analyzing the sealing performance of an ACGT ring seal. For the high pressure of 800bar and the maximum speed of 3m/s, the main piston is reciprocating along the linear line against the cylinder wall. The computed results indicate that the length ratio of a cap ring is more influential design parameter compared to that of the tribological contact mode. Thus, this paper recommends the discrete contact area rather than a conventional flat contact model. Especially, the sealing capacity is more improved when the length ratio of a cap ring is below 0.625.

Key words : Reaction force, Elastic strain energy density, Real contact length ratio, ACGT ring, FEM

1. INTRODUCTION

Seals are fundamental for correct operation of many pneumatic components, especially cylinders and valves. There are many parameters that must be considered in seal design such as sealing load, gland fill, frictional characteristics and shape characteristics and so on. To understand many parameters in seal design, previous research efforts on sealing concentrated mainly on the experimental aspect but unfortunately it was very difficult to understand contact mechanism of elastomeric seals with large deformations and displacement and high non-linear materials. So many researchers have been studied performance of elastomeric seals for the contact stress, the deformed shape of the seal, stress distribution throughout the cross section sealing by numerical methods.[1-2]

The leakage of elastomeric ACGT ring seals under high pressure will occur when the pressure differential across the seal just exceeds the initial peak contact stress between two contacting surfaces. It is expected that the ACGT ring seal cannot perfectly prevent the leakage of gas through the sealing interface between the surface of the ACGT ring seal and the cylinder. Thus it is necessary to improve contact force by new design for the ACGT ring seal.

From this point of view, The groove on the contact area is helpful to form lubrication film which plays important role to sealing between the seal and the cylinder. And the small contact area elevates contact force and elastic strain energy density so improves sealing performance in the limit of elasticity. So the optimization of the length ratio on the contact area must be need.

In this study, a numerical method using a non-linear FEM program MARC[3] was used to analyze the contact force and elastic strain energy density of ACGT ring according to length ratio of the contact length. They are influenced by the length ratio of contact area of the cap ring and very important parameters to predict the sealing performance of the ACGT ring seal.

2. COMPUTER SIMULATION

Fig. 1 shows the Aerospace Capped GT(ACGT) ring seal. An energizer ring supports a compression force and a cap ring protects the excessive friction force and heat source that is caused between the cylinder wall and the cap ring. Two back-up rings prevent from the extrusion of a cap ring and impose the stabilization of the energizer ring.

An elastomeric energizer ring is made of FKM that is excellent in low temperature and has high elasticity. A cap ring is made of thermoplastic and carbon filled, lublicated Polyperfluoroalkoxyethylene(PTFE), and a backup ring is made of Polyetheretherketone(PEEK).

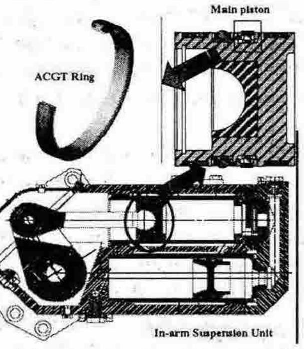
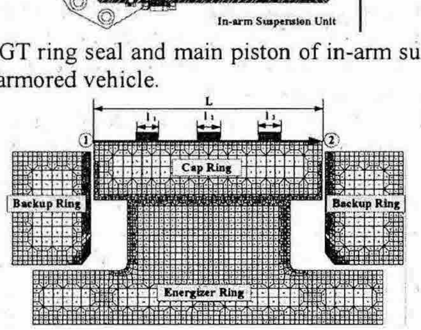


Fig. 1 ACGT ring seal and main piston of in-arm suspension unit of the armored vehicle.



Length ratio of cap ring; $\gamma = \dfrac{l}{L} = \dfrac{l_1 + l_2 + l_3}{L}$

Fig. 2 FE model of ACGT ring seal and contact spot area on the cap ring surface.

Fig. 2 shows the FE meshes for an ACGT ring seal. For analysis of the length ratio effect, the contact spot area has been modeled as shown in Fig. 2. The contact spots are rubbing against the cylinder wall as the piston is reciprocating periodically. The length ratio of a cap ring is 0.25 to 1.0 for the given contact profiles. An ACGT ring seal was modeled by using four-noded, isoparametric, quadrilateral elements for axsymmetric mesh of non-linear FEM program.

To analyze the contact mechanism of ACGT ring in detail, the cylinder and gland are modeled as a solid body and ACGT ring modeled as a deformable body. In this study, the distributions of reaction force and elastic strain energy density have been presented as sealing characteristics of an ACGT ring. A main piston reciprocates with a high speed of 3m/s and a friction coefficient is assumed as a constant, which may be occurred at each rubbing area between ACGT ring components and cylinder wall. The gas with 800bar pressure is supplied on the right side of ACGT ring seal. Thus, the gas may be leaked across the contact spot area on the cap ring surface for a reciprocating motion of a main piston. In this study, the leaked gas pressure is assumed as 160bar on the left hand side of an ACGT ring seal.

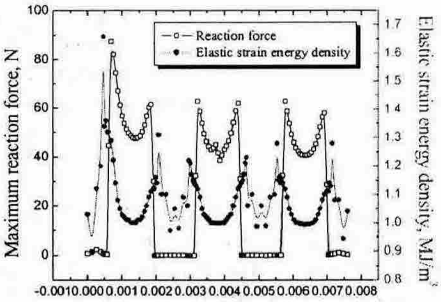
3. RESULT AND DISCUSIONS

Fig. 3 shows reaction force and elastic strain energy density distributions against the length of the cap ring. The friction coefficient between the cap ring and the cylinder wall is 0.01, which means that the thin film may be established. The speed of a piston is 3m/s and the reaction force is calculated along the line ①→② in Fig. 2. In this figure, a maximum reaction force between a cap ring and a cylinder is about 90N and a maximum elastic strain energy density is about 1.6MJ/m^3 when the length ratio of a cap ring is 0.625. The peak value for a sealing may be occurred during the return stroke of a reciprocating motion as shown in Fig. 3(a). This means that the extrusion of the first contact spot of a cap ring is more severe compared to other two contact spot areas. Fig. 3(a) shows the discrete peak values of reaction force and elastic strain energy density for the given contact spot area of a cap ring. This may increase the sealing characteristics of an ACGT ring definitely.

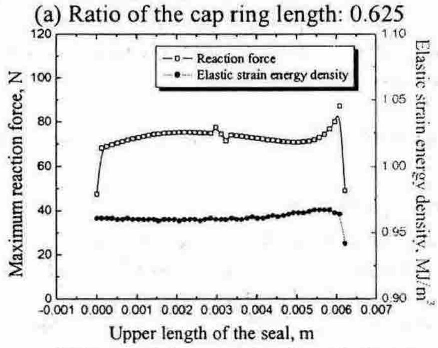
But, Fig. 3(b) shows different phenomena of sealing characteristics for the given length ratio of 1.0. This denotes that the surface of a cap ring is completely contacted against the cylinder wall at the beginning stage of a piston motion. In this figure, the maximum reaction force is about 80N and the maximum elastic strain energy density about 0.96MJ/m^3 when the length ratio of a cap ring is 1.0, which means that the rubbing surface is flat. The reaction force and strain energy are uniformly distributed on the rubbing surface of a cap ring during the reciprocating motion.

In these results, the sealing mechanism of Fig. 3(a) is more interesting compared to that of Fig. 3(b) because of concentrated high values of the reaction force and elastic strain energy density of cap ring materials. Thus, the contact spot area may improve the sealing pressure between a cap ring and a cylinder wall and the length ratio of a sealing spot area is an important design parameter for a given limit of elasticity. In this analysis, the fluid film does not included in detail but the testing result of this sample that is fabricated with a shape of Fig. 3(a) shows more extended life of a seal.

The seal designer may interest for the optimized length ratio of a contact spot as demonstrated in Fig. 4. This figure shows a maximum reaction force and elastic strain energy density as a function of the length ratio when the piston returns from the reciprocating motion. In Fig. 4, the computed results are for the friction coefficient of 0.01 and the speed of 3m/s. The friction coefficient of each contact area between rubbing surfaces is 0.01, which is in good lubrication mode.



(a) Ratio of the cap ring length: 0.625



(b) Ratio of the cap ring length: 1.0

Fig. 3 Reaction force and elastic strain energy density as a function of the contact spot area for the given cap ring length ratio.

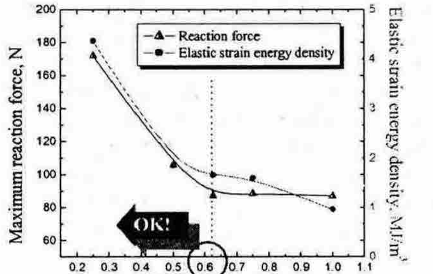


Fig. 4 Distributions of maximum reaction force and elastic strain energy density as functions of length ratio of the cap ring just after return stroke motion. The friction coefficient is 0.01 and the speed of a piston is 3m/s.

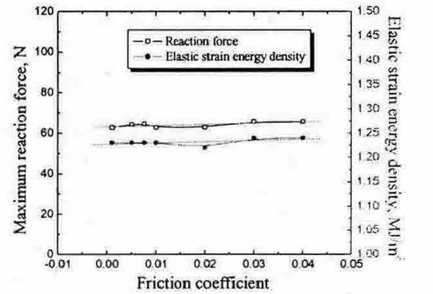


Fig. 5 Distribution of maximum reaction force and elastic strain energy density as functions of friction coefficient of a cap ring surface against the cylinder wall just after return stroke motion.

In Fig. 4, a maximum reaction force between a cap ring and a cylinder wall is about 90N for the length ratio of a cap ring from 0.625 to 1.0. The maximum strain energy density is about 1.6MJ/m^3. The maximum reaction force and elastic strain energy density are rapidly increasing below 0.625 for the given profile of a cap ring and the operation conditions. In this figure, the decreased length ratio of a cap ring is more useful parameters for a reliable sealing design of an ACGT ring seal.

And an elastic strain energy density steadily increases when the length ratio was from 1 to 0.25. a high reaction force between a cap ring and cylinder means that a sealing force is high and high elastic strain energy density means that the resistance to deformation of a cap ring is strong and rigid. So the sealing capability is improved when the length ratio of a cap ring is below 0.625.

Fig. 5 shows a maximum reaction force and an elastic strain energy density distributions for various values of friction coefficients, which are ranged from 0.001 to 0.04 along the contact area ①→② in Fig. 2. This is strongly related to the lubrication mode, which denotes fully developed fluid film. The length ratio of a cap ring is 0.625 and reciprocating speed of a piston 3m/s. As shown in Fig. 5, the sealing characteristics increases a little for the increased friction coefficient rubbing on the surface of a cap ring.

From considering the above results, the maximum reaction force and the elastic strain density have more influenced by the real contact length in comparison of the friction mode between cap ring and cylinder wall.

4. CONCLUSIONS

This study presents the FEM results, which are reaction force and elastic strain energy as functions of a contact length ratio of a cap ring and a friction coefficient between a cap ring and a cylinder wall.

From the computed results, the geometrical contact area is more important parameters compared to that of the tribological contact mode between the rubbing gap. In this ACGT seal, the optimized length ratio of a cap ring contact area is about 0.615. This study recommends the piecewise contact area rather than the conventional flat contact mode. This design may increase the sealing pressure that is strongly related to the increased reaction force and elastic strain energy density of an ACGT ring seal.

5. REFERENCES

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