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RESEARCH ARTICLE

STUDY ON FRICTION CHARACTERISTICS BETWEEN SEAL RING AND CYLINDER

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ABSTRACT

Friction characteristics between seal ring and cylinder in pneumatic balancer have great significance to the optimization and upgrading of the working state. The variation law of lubricating grease film thickness and contact stress in space is solved by MATLAB. The results show that the dynamic load of pneumatic balancer has little effect on the friction characteristics of cylinders in the main contact area, and the relative motion speed can be increased. The method of rheological index can increase the thickness of lubricating grease film. In order to further study the lubrication performance of sealing rings, a two-dimensional finite element model of O-ring was established, and its transient contact strength characteristics were studied according to different pre-compression rates. The results show that the pre-compression ratio of 15% to 20% can maintain good sealing performance and ensure the working life of seal rings.

INTRODUCTION

With the maturity of pneumatic technology, pneumatic hoisting equipment is more and more widely used in industry (Xiao *et al*., 2016). For the pneumatic balancer, the friction performance of the sealing ring is the basis to ensure the normal operation of the piston. Rubber seals are suitable for a variety of different sealing media, including oil, water, chemical and other mixed media. Effective sealing effect can be achieved by choosing suitable rubber materials and formulation design. The sealing ring is simple in design, compact in structure and convenient in assembly and disassembly. The sealing ring cross-section structure is extremely simple, and has self-sealing effect, sealing performance is reliable. Because the sealing ring itself and the structure of the installation part are extremely simple and standardized, it is very easy to install and replace. At present, grease lubrication is generally used in engineering to reduce the friction between the seal ring and the cylinder. The grease thickness and contact pressure between the seal ring and the cylinder have a key influence on the service life of the seal ring. (Yao *et al*., 2017). At the same time, under the condition of pre-compression, the contact strength of the sealing ring is also the basis to ensure the reliability of the work. Therefore, it is of great significance to quantitatively analyze the contact pressure and grease film thickness on the sealing ring surface.

The numerical solution of motion model

Analysis of motion model

At present, the most common cylinder material of pneumatic balancer in engineering is carbon steel or aluminium alloy, which has high hardness and stiffness (Zhang *et al*., 2015). It is generally regarded as rigid body in contact analysis with sealing rings. The sealing ring in the pneumatic balancer is generally O-ring, and the material is high elastomer, which can achieve good dynamic sealing effect (Ou and Xue, 2016). In order to facilitate analysis and calculation, the motion between the seal ring and the cylinder is simplified, that is to say, the cylinder is assumed to be a moving body and the O-ring is a stationary body. The motion simplification diagram of the whole model is shown in Fig.1. The motion governing equation of grease lubrication is a typical second-order partial differential equation. At present, the main methods for solving the motion governing equation include finite difference method (FDM) and finite element method (FEM). Because the mathematical expression of boundary conditions is complex and the programming of differential calculation is very complicated (Lv and Yang, 2015), the numerical simulation of lubrication characteristics based on PDE module in MATLAB can achieve higher computational efficiency and improve computational accuracy through higher degree of discrete refinement.

Analysis of sealing characteristics along contact direction

The characteristics of contact stress (σ_c), grease film thickness (h) and friction force (F_f) along the contact direction x are obtained through continuous iteration. In terms of contact stress, different pre-compression ratios (5%, 10% and 15%) of the sealing rings are defined, and the influence of pre-compression ratio on contact stress in space is studied. As shown in Fig. 2, the distribution of contact stress between O-ring and cylinder under different compression rates is studied. In Fig.2, it can be seen that the contact stress is parabolic in the contact area, and the maximum contact stress is located at the center of the seal ring, i.e. x=0. The contact length increases with the increase of compression ratio. As shown in Fig. 3, the distribution of grease film thickness between the seal ring and the cylinder at different compression rates is studied. As can be

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seen from the figure, the thickness of grease film is very little affected by the compression rate except for the edge area of the sealing ring due to the relatively small load of the pneumatic components. Therefore, the influence of dynamic load of pneumatic balancer on the friction characteristics of cylinder in main contact zone can be neglected. In the boundary contact area, the oil film thickness at the inlet and outlet is quite different. This is because the seal ring is a high elastic device. In the relative motion with compression effect, the contact length between the seal ring and the cylinder increases with the increase of compression rate. But too large compression ratio will lead to too large oil film thickness in the edge area, which will reduce the effective lubrication effect. Therefore, reasonable pre-compression ratio has an important impact on the improvement of lubrication performance. Fig. 4 shows the distribution of grease film thickness between seal ring and cylinder at different relative sliding velocities with gas pressure of 0.5 MPa and compression rate of 15%. It can be seen that with the increase of relative sliding speed, the thickness of grease film increases, and the length of the approximate parallel area between the three curves decreases. With the increase of relative velocity, the effective oil film thickness increases. This is because the larger relative velocity is helpful to the dynamic storage of grease oil, so the thickness of grease film can be increased by increasing the relative sliding speed. As shown in Fig. 5, the relative sliding speed is 0.3m/s and the compression ratio is 15%. The distribution of grease film thickness between the seal ring and the cylinder under different rheological indices is studied. It can be seen from the figure that the average film thickness of grease increases with the increase of rheological index. Because the rheological index is greatly affected by temperature, the internal relationship between temperature and the thickness of grease film can be inferred indirectly. As shown in Fig. 6, the effect of relative sliding speed and compression ratio on the friction force of grease (gas pressure is 0.5 MPa). As can be seen in the figure, the higher the relative sliding speed is, the greater the friction force of grease is. The increase of compression ratio leads to the increase of viscosity and friction of grease. For pneumatic balancer, the change of compression ratio plays a dominant role in the change of friction force of grease.

Analysis of transient structural characteristics of reciprocating motion

Setting of transient finite element model

During the reciprocating motion between the seal ring and the cylinder, the seal ring will be subjected to a large periodic load, and its transient structural performance has a key impact on the stability of the seal. In this paper, based on the finite element analysis method, the CAE software ANSYS is used to realize the transient structural characteristic analysis (Liao and Huang, 2013; Imai, 2013). The finite element model of two-dimensional O-ring is established. The boundary and load conditions are added and meshes are divided. The maximum contact stress of the sealing ring is calculated under different compression rates. Aiming at the priority level of influencing factors, this paper simulates and studies the movement speed (0.2 m/s) and working pressure (0.3 MPa) of the seal ring as constant conditions, compression ratio (5%-20%), friction coefficient (0.1-0.25) and stroke mode (internal and external travel) as variable conditions.

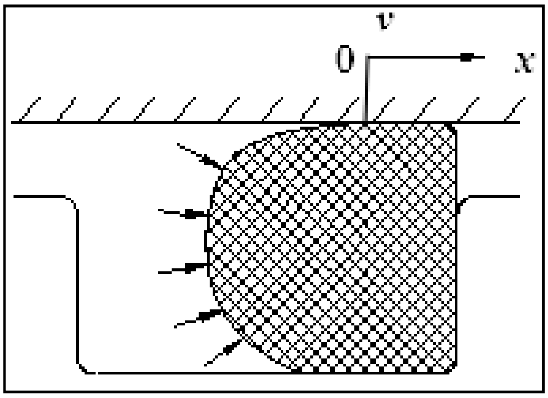


Fig.1. Simplified motion model of seal ring and cylinder

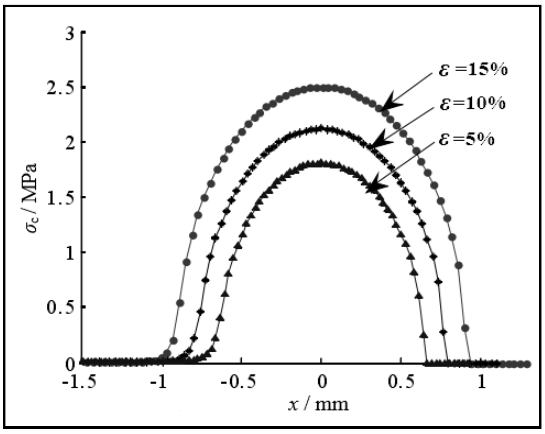


Fig. 2. Contact stress distribution of seal ring under different compression rates

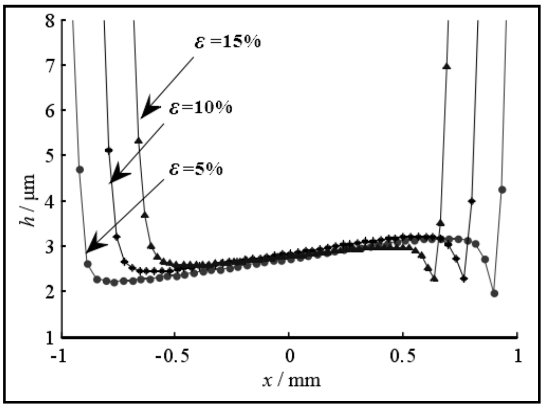


Fig. 3. Distribution of lubricating grease film thickness under different compression rate

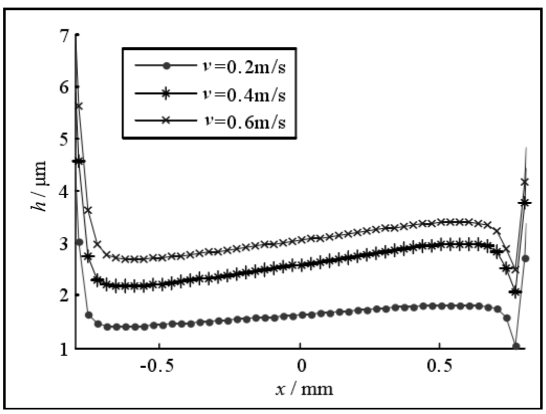


Fig. 4. Distribution of grease film thickness under different relative sliding velocities

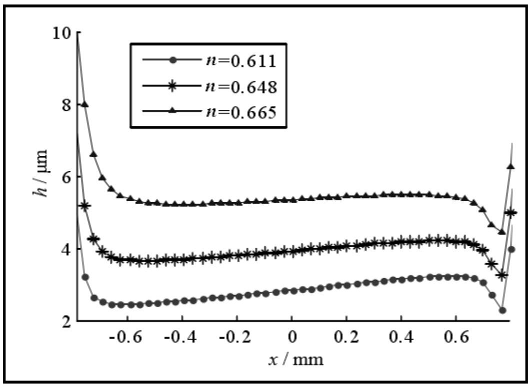


Fig. 5. Distribution of lubricating grease film thickness under different rheological index

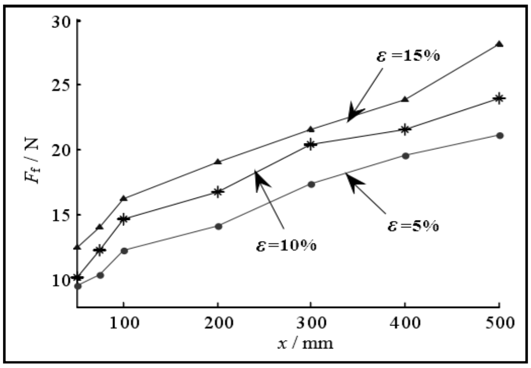
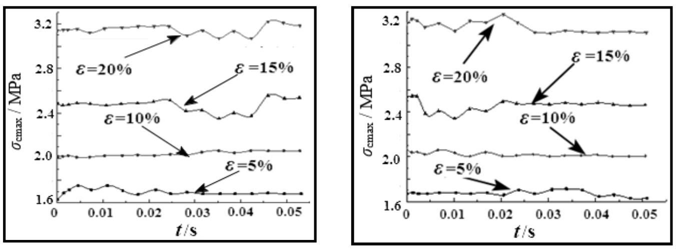


Fig. 6. Effect of relative sliding speed and compression ratio on friction of grease

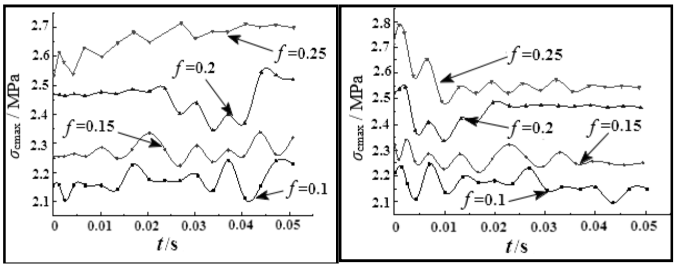
RESULTS

The curves of maximum contact stress under different compression rates are shown in Fig. 7. It can be seen that the maximum contact stress between the seal ring and the cylinder increases with the increase of the compression ratio of the seal ring, and the maximum contact stress value is much higher than the pressure of the gas in the cylinder at work, which indicates that the sealing performance of the seal ring can meet the working requirements. When the compression ratio is 5% and 10%, the variation of the maximum contact stress is relatively stable. When the compression ratio is 15% and 20%, the variation of the maximum contact stress is relatively large. This shows that the compression degree of the seal ring will affect the fluctuation of the maximum contact stress under the same reciprocating velocity and working pneumatic pressure. Fig. 8 is the curve of maximum contact stress under different friction coefficients.



(a) External stroke **(b) Inner stroke**

Fig. 7. Time domain variation of maximum contact stress under different compression rates



(a) External stroke **(b) Inner stroke**

Fig. 8. Time domain variation of maximum contact stress under different friction coefficient

It can be seen that the maximum contact stress between the seal ring and the cylinder increases with the increase of the friction coefficient, and the fluctuation range of the maximum contact stress increases with the increase of the friction coefficient.

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Conclusion

Friction between seal ring and cylinder inner wall needs to be reduced effectively. Therefore, a layer of grease is usually applied to cylinder inner wall. Based on the theory of grease lubrication, the greasy lubrication model of seal ring and cylinder is constructed. Finally, the change rule of film thickness and contact stress in the contact direction between seal ring and cylinder is obtained. In addition, based on ANSYS, the time-domain characteristics of the maximum contact stress under different compression rates, friction coefficients and stroke modes are obtained. The research results are of great significance for improving the performance of pneumatic equipment.

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