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ANALYSIS OF SEALING ELEMENT OF THE CAGE TYPE THROTTLE VALVE

Liu PengZhi Li YueQin Xiao Fei

（Southwest petroleum university institute of electrical and mechanical engineering，chengdu sichuan 610500）

Abstract

Use the software of finite element analysis. Use Abaqus to analyze the influence on con-tact stress and Mises stress in different parameter of Polytetrafluoroethylene spring energized seal ring under ultrahigh pressure .The analysis shows :the Maximum Mises stress appear on the bottom of groove all the time; the size of posterior lip angle has direct influence on seal lip and the area of its contact surface, the proportion of the sealing lip and its contact surface decrease with the in-creasing of the angle. Cause the increasing of contact stress under same working pressure. In mo-tive seal, maximum contact stress fluctuating with time. The higher the speed, the greater the fluctuation is. Meanwhile stress concentration appears at lip when axle moves down. Friction coefficient has an effect on maximum contact stress Mises stress of the lip when axle moves down.

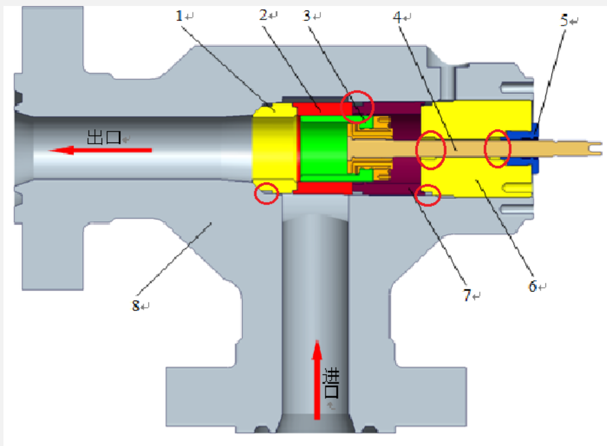
Key Words: spring energized seal ring ; contact stress; Polytetrafluoroethylene

1. Introduction

Throttle valves are necessary equipments for high pressure、high yield gas field. Its sealing property depends on quality of product. It also guarantees safe operation of throttle valve. According to the gas field feedback，seal invalidation is main invalidation form of throttle valves in a cage. Its sealing element, spring energized seal ring, is a sealing element which forced by machinery spring. For the advantage of its simple structure、thermostability、high sealing pressure、seal contact pressure stability, it is used as sealing element of spring energized seal ring in natural gas industry. U shape or V shape sealing ring are replaced to acpuire excellent sealing property. At home and abroad, research on lip-type seal ring mainly concentrates on Y shape and V shape seal ring. But rarely study on spring energized seal ring. Wang Guorong[2] studies on the working sealing property of reciprocate sealing shaft with Y shape seal ring during static seal or motive seal. Chun-Ying Lee[3] uses Ansys software to analyze contact property of lip-type seal ring in different interference fit. F.Riddar [4] studies on effects of different lubricating strap on lip-type seal ring. This article mainly study on spring energized seal ring which is the sealing element of cage type throttle valve. Base on nonlinear dynamics and statics simulation. Study on the effect of structure parameter on sealing property systematically. To provide theoretical basis for the spring energized seal ring of the construction optimization.

2. The seal mechanism of spring energized seal ring and force analysis

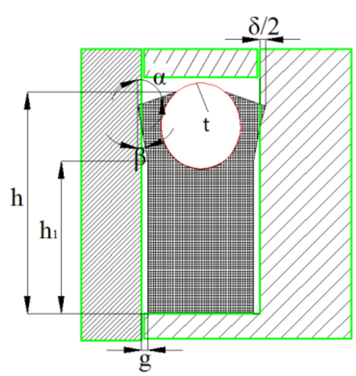
Structure of cage type throttle valve is shown in figure 1.The red circle means sealing surface. Figure 2 shows structure sketch map of spring energized seal ring. Its sealing mechanism is similar to Y shape seal ring. But its initial sealing force not only provided by the lip， but also the combined action of inside annular spring. A small lip magnitude of interference can provide enough initial sealing force. When fluid pressure effect on, every spot that seal ring contact with sealing medium have normal pressure which equal to medium pressure， So the root of seal ring、Inside lip and outside lip will receive axial compression, sealing contact surface become wide， contact stress increase.



1-pedestal; 2-Corbula; 3-plunger; 4-piston rod ;

5-pressing cap; 6-outside gland; 7-spacer bush;   8-valve body;

Figure 1. Structure of cage type throttle valve



α-former lip angle ；   β-posterior lip angle ；

h1- size of root； h-height of seal ring；

δ/2- half of decrement；t-spring。

g- gap between seal and axle or between seal and groove

Figure 2. Structure sketch map of spring energized seal ring

During working, spring energized seal ring mainly receives medium pressure stress、contact stress、sliding friction force、extrusion force caused by lateral oscillation of valve rod and braced force of valve body. All forces above act on the seal ring together. Among them, the first four forces are principal factors that influence sealing property and stress of seal ring. Under ideal working condition, the pressure on seal ring is shown in figure 3.In figure 3：PL means medium pressure；Fc means contact pressure；Ff means sliding friction force; FN1 and FN2 mean the constraining force of valve body.

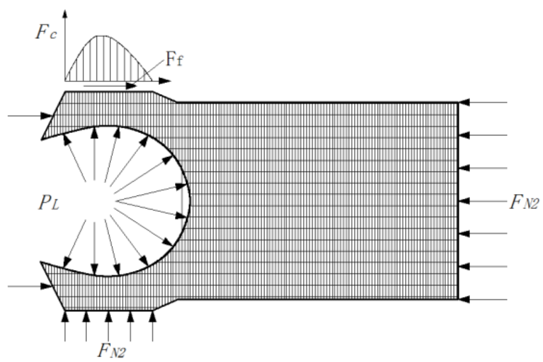


Figure 3. Stress sketch map of spring energized seal ring.

Contact stress of spring energized seal ring is constitute of initial contact stress σ0 which is generated by precompression and contact stress Δσp which is generated by working stress. It can be expressed as:

$$\sigma_p = \sigma_0 + \Delta\sigma_p = \sigma_0 + kp \quad (1)$$

In the formula: $k = \frac{v}{1-v}$.v means poisson ratio of material；P means work stress.

In accordance with seal theory and equilibrium of forces, the necessary and sufficient conditions to insure the sealing structure work well is that contact stress should bigger than inside pressure of medium. So，to insure the sealing property of seal ring. Its maximum contact stress should meet requirement as follow:

$$\sigma \geq p \qquad (2)$$

That means contact stress should bigger or equal to pressure inside medium, or it would be leak and lead to failure.

3. Modeling of finite element

3.1 Material of seal ring

Material of spring energized seal ring is improved polytetrafluoroethylene. Its elasticity modulus E is 980MPa.Poisson ratio μ is 0.4[5].Material type of reciprocating axle and seal groove, which used in cage type throttle valve, is 316. Elasticity modulus E is 200GPa.Poisson ratio μ is 0.3. Spring is made of stainless steel material. Seal ring is installed in the groove. Pressed spring generate outward tension, urge sealing lip cling to sealing groove and working surface. Immobilized effect of spring can conquer the slight decentration of metal working face and abrasion of sealing lip. To retain sealing property which is expected. Two methods can simulate ring spring. One is making it as a kind of cylinder with proper material. The other is a finite element model without spring. Add a corresponding spot force or surface force [6]. In this article, all models are ideal shape. Decentration and disturbances are inexistent. So the spring in spring energized seal ring is ignored during simulation process for simplifying seal model. Add an equivalent pressure instead of it.

3.2 Finite element model of spring energized seal ring.

Establish two-dimension axial symmetry finite element model of seal ring、beam barrel and groove in finite element software. Author of this article Considers about the complexity of polytetrafluoroethylene. For the convenience of research, fundamental assumptions of numerical modeling are as follow：

（1）Regard seal structure as ideal axial symmetry model；

（2）Material of spring energized seal ring has certain elasticity modulus E and poisson ratio μ ；

（3）Longitudinal compression that spring energized seal ring receive is caused by boundary conditions constraint；

（4）Ignore the effect of temperature on sealing material；

（5）Ignore the effect of creepage on sealing material.

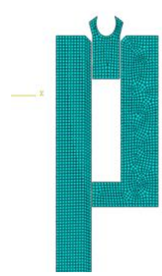


Figure 4. Finite element model of spring energized seal ring

Figure 4 is the finite element model which shows structure of spring energized seal ring. Gridding pattern choose Standard quadrilateral reduced integral grid. There are three contact pairs in model. All contacted models choose “Surface-to-surface contact”. According to simulation process of finite element model, two steps constitute the static seal characteristic analysis of spring energized seal ring. First step: for reciprocating axle and seal groove add complete constraint. Add a downward displacement to spring energized seal ring. To realize assembling of spring energized seal ring and add precompression to it. It needs to establish different interaction contact pairs.

Second step : relieve displacement load of spring energized seal ring， add pressure at the lip.

In the simulation of dynamic seal performance, the axial fixed constraint of the lifting shaft i s changed into the axial velocity constraint.

4. Simulation and interpretation of result

4.1 Numerical analysis of static seal

Valve rod remains static in steady state and it need not consider about contact friction. When axle moving up and down, the stress on seal ring is influenced by contact stress、kinematic velocity of valve rod、medium pressure、Contact friction factor、radial direction stress of valve rod and many other factors. Mises stress means the breakdown stress of material in Abaqus software. Mainly reflect the inside stress distribution situation of material. It is the main parameter of elastomer. Its stress expression is：

$$\sigma_m = \left\{ \left[\left(\sigma_1 - \sigma_2\right)^2 + \left(\sigma_2 - \sigma_3\right)^2 + \left(\sigma_3 - \sigma_1\right)^2 \right] / 2 \right\}^{1/2} \qquad (3)$$

In general， slackness of rubber material will speed up as the increasing of Mises stress. Cause stiffness degradation and lead to crack [7]。

Initial compression rate is the ratio of magnitude of interference and breadth of section. The well-behaved of spring energized seal ring in seal ability depends on fit dimension of spring energized seal ring and groove to a great extent to form a reasonable compression stretch. Working pressure is 70Mpa.When the lip magnitude of interference reach 12% .Distribution of Mises stress and contact stress are shown in the figure 5 and figure 6.

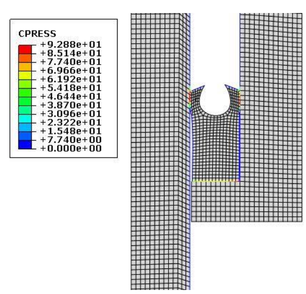


Figure 5. Contact stress distribution

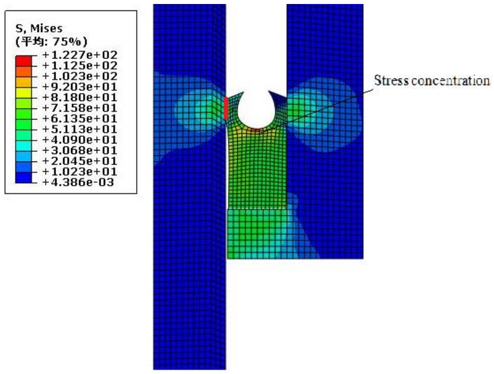


Figure 6. Mises stress distribution

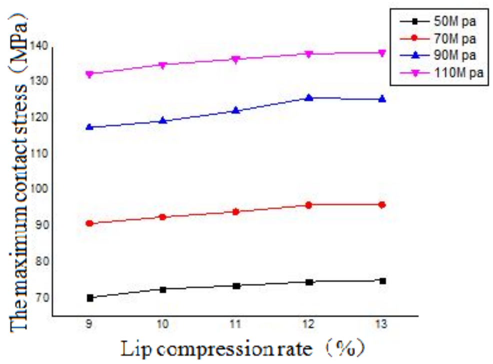


Figure 7. Relationship between lip compression ratio and maximum contact stress

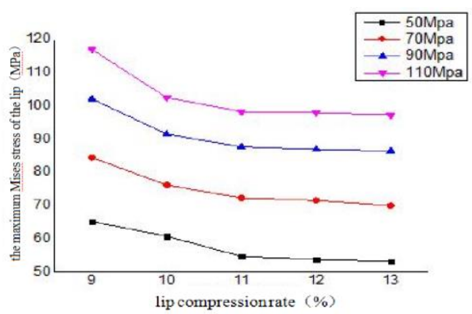


Figure 8. Relationship between lip compression ratio and Mises stress

As shown in figure 6, stress concentration appears at the bottom of seal groove. Mises stress reach maximum. Figure 7 shows the relationship between maximum contact stress of seal ring contact surface and compression ratio. It can be seen from figure that when valve rod remain static, medium pressure is the main factor that influence sealing property. Under different working pressure, the maximum contact stress increases with lip magnitude of interference. When it exceeds 12%, it verges to stabilization. Firure 8 shows maximum Mises stress of seal ring lip decreases with the increasing of initial compression ratio. When it exceeds 11%, it verges to stabilization. It usually choose magnitude of interference between 11%—12% in engineering. Because an overlarge magnitude of interference will cause the increasing of friction between seal lip and contact surface. Lip of the seal ring may abrasion. Life of seal ring will decrease.

β=12°，g=0.16mm，make a numerical simulation analysis to former lip angle α. The working pressure is 50MPa、70MPa、90MPa and 110MPa. Perform finite element analysis for each situation. Data range of former lip angle is defined between（55°，85°），each increment is defined 5°.

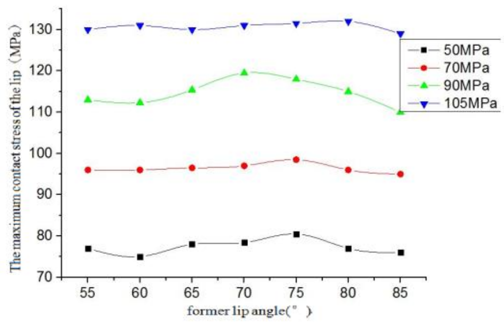


Figure 9. Changing curve that maximum contact stress change with former lip angle

It can be seen from figure 9，it is still medium pressure that influences the maximum contact stress. Former lip angle has little influence to maximum contact stress under same pressure.

Range of working pressure is chose between 50～110MPa.The working pressure is 50MPa、70MPa、90MP and 110MPa. Perform finite element analysis for each situation. The other parameters remain unchanged. Data range of posterior lip angle is defined between（8°，14°），each increment is defined 1°.

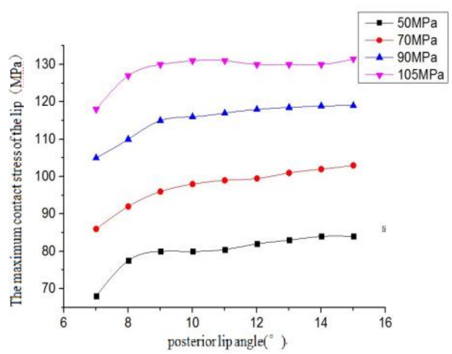


Figure 10. The changing curve that maximum contact stress change with posterior lip angle

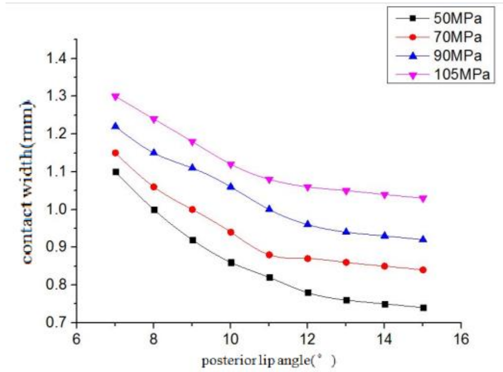


Figure 11. changing curve that contact width change with posterior lip angle

It can be seen from figure 10, maximum contact stress rising with the increasing of posterior lip angle. Combine with figure 11, it can infer that the size of posterior lip angle affect seal lip and proportion of contact surface directly. The area between the sealing lip and the corresponding contact surface decrease with the increasing of the angle. Cause the increasing of contact stress under same working pressure.

4.2 Dynamic seal numerical analysis

Numerical modeling of motive seal is based on static seal. After spring energized seal ring install and add working pressure. The friction coefficient f is 0.05. Axle does a reciprocating motion.

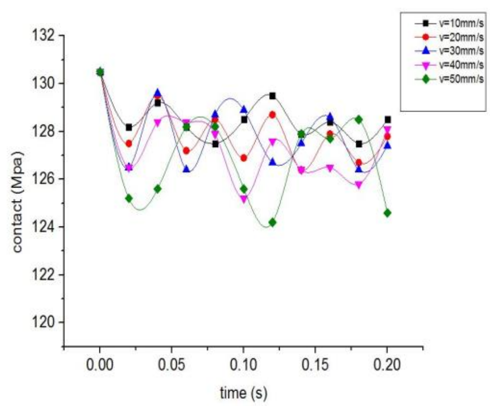


Figure 12. Contact pressure changing with time when axle going up

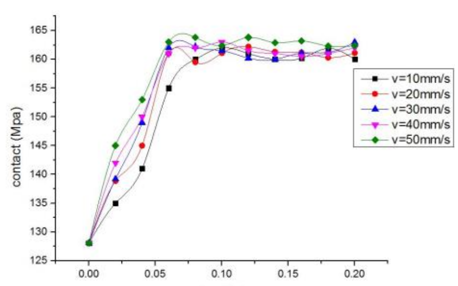
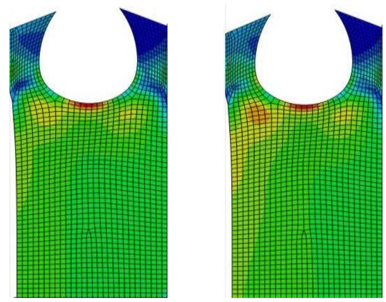


Figure 13. Contact pressure change with time when axle going down



（a） axle going up （b） axle going down

Figure 14. Mises stress nephogram in motive seal

Figure 12 and figure 13 show that， when axle going up. Contact pressure fluctuating with time. The higher the speed, the greater the fluctuation is. When axle going down. Maximum contact stress has great change. Stress concentration appears on the top of the lip. No matter axle going up or going down. Maximum contact stress is always greater than working pressure under different speed. It shows that spring energized seal ring still has excellent motive seal property under different speed. With the increasing of the speed， it may lead to the failure of seal. Figure 14 shows that，compared with axle going up，deformation of lip increases when axle going down. Mises stress at the root of the lip increases。

The movement of valve rod is slippage contact. It may generate slide contact friction. Direction of it is opposite to the movement of valve rod, it is also the source of axial direction shear stress. Polytetrafluoroethylene does well in high temperature resistance and decay resistance. Well-designed polytetrafluoroethylene has a long lifetime. It is frictional wear that cause the final failure [7]. It is known in the solid material which has the smallest friction coefficient of engineering materials up to now[8].But the manufacturing precision, immersion of working medium and friction wear problems may cause friction between the sealing ring and the groove wall changes [9].When medium pressure reaches 105 MPa, analyze different coefficient of friction f. There is a red track in picture 14(a), analyzing the friction coefficient of the maximum contact stress distribution with the effect of friction coefficient according to the track. Shown as the picture below

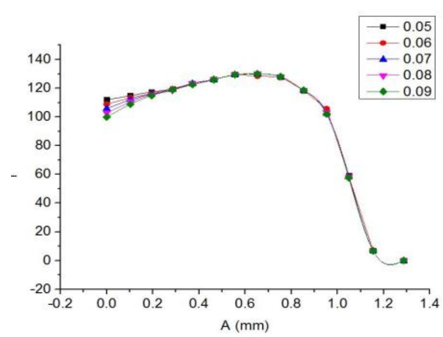


Figure 15. contact pressure change with contact width when axle going up

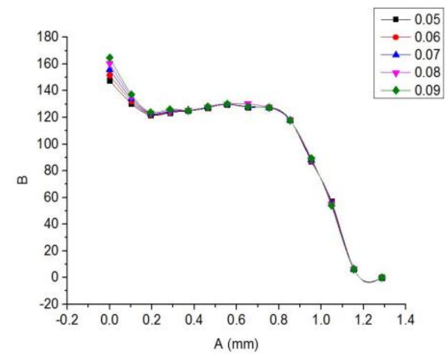


Figure 16. contact pressure change with contact width when axle going down

Figure 15 and 16 show that under different coefficient of friction, axial distribution of maximum contact stress is identical. Changing of coefficient of friction has great influence on seal ring contact stress when axle going down.

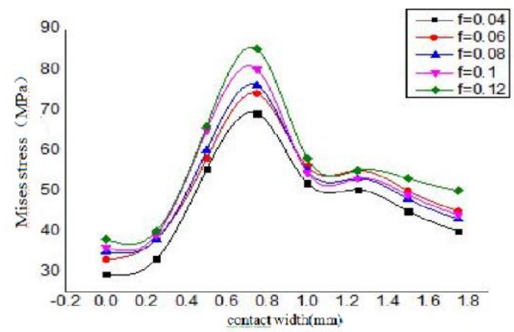


Figure 17 . Changes of Mises stress friction coefficient of spring energized seal ring

Figure 17 shows that the maximum value of stress appears at the place where the contact stress is maximum. And the friction coefficient is positively correlated. It shows that excessive contact stress will make spring energized seal ring a better sealing property in motive seal. Meanwhile it will produce a bigger Mises stress and Mises stress are different when axle going up and down. Fatigue rupture will appear at the lip.

5. Conclusion

This article studies on several factors of spring energized seal ring which mainly influence sealing property. The following conclusions are obtained：

（1） The stress distribution of the seal ring under different working conditions is obtained by finite element analysis. It can effectively estimate the area that may cause the failure of the fracture. Just the palce where Mises stress get maximum.

（2）When valve rod stays static, medium pressure is the main factor that affects the performance of the seal. Maximum Mises stress appears at bottom of groove and bigger than medium pressure. Former lip angle has little influence on sealing property. The size of posterior lip angle has influence on sealing surface area. Under the same medium pressure，posterior lip angle increasing with the contact stress。

（3）When axle going up，maximum contact pressure fluctuats with time. The greater the speed, the bigger fluctuation. When valve rod moves back，friction coefficient has a great influence on maximum contact stress and stress concentration appears at the top of the lip. Lip receives alternating stress during motive seal process，and lead to fatigue failure easily。

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Mailing address：Southwest Petroleum University Xindu District of Chengdu city in Sichuan Province. Postcode：610500

Contact phone：18067047358