Advances in Applied Sciences
2021; 6(4): 110-115
http://www.sciencepublishinggroup.com/j/aas
doi: 10.11648/j.aas.20210604.16
ISSN: 2575-2065 (Print); ISSN: 2575-1514 (Online)

Analysis of Double Seat Seal of Ultra High Pressure Flat Gate Valve

Wei Junhui[1], Zhang Chuan[2], Jing Hongtao[1], Wang Wei[2], Tu Zhixiong[1], She Xiaomei[2], Zou Yan[2]

[1]Oil and Gas Engineering Research Institute of China Petroleum Tarim Oilfield Company, Korla, China

[2]CNPC BOMCO Drilling & Production Equipment Co., Ltd. Deyang, China

Email address:
wjhui-tlm@petrochina.com.cn (Wei Junhui), 491197292@qq.com (Zhang Chuan), jinghongtao-tlm@petrochina.com.cn (Jing Hongtao), 423407002@qq.com (Wang Wei), tuzx-txn@petrochina.com.cn (Tu Zhixiong), 417530347@qq.com (She Xiaomei), 65903152@qq.com (Zou Yan)

To cite this article:
Wei Junhui, Zhang Chuan, Jing Hongtao, Wang Wei, Tu Zhixiong, She Xiaomei, Zou Yan. Analysis of Double Seat Seal of Ultra High Pressure Flat Gate Valve. *Advances in Applied Sciences*. Vol. 6, No. 4, 2021, pp. 110-115. doi: 10.11648/j.aas.20210604.16

Received: February 12, 2021; **Accepted**: February 23, 2021; **Published**: November 11, 2021

Abstract: As an important part of the Christmas tree, the sealing performance of the flat gate valve is very important, and the O-ring seal is the most commonly used seal in the flat gate valve. Therefore, the research on O-rings is particularly important. For the flat gate valve with a single gate, its structure has gradually developed from a single seat seal to a double seat seal. This article mainly analyzes the sealing principle of the double seat in the ultra-high pressure flat gate valve and the influence of the pre-tightening force of the sealing ring on the sealing effect. Using finite element analysis software, a two-dimensional axisymmetric model of the double valve seat sealing structure was established to study the non-metallic sealing performance of the valve seat. The Mises stress, the maximum contact stress of the sealing surface, and the contact area of the sealing surface of the O-ring seal under different compression ratios are analyzed. The results show that when only the sealing performance and pre-tightening force requirements are considered, an O-ring with a larger wire diameter should be selected as much as possible. When considering the service life of the O-ring seal, the compression rate of the seal ring should not exceed 20%. Therefore, the selected seal ring wire diameter is 3.75mm within the recommended seal ring compression rate range.

Keywords: Flat Gate Valve, Double Seat, O-ring, Sealing Performance

1. Introduction

The gas tree is one of the important equipment at the gas wellhead, and the flat gate valve is the core component of the gas tree. Nowadays, the continuous development of the petroleum industry puts forward higher requirements for the reliability and control of wellhead devices, especially valves. On the one hand, from the perspective of the overall wellhead device, the improvement of the gate valve mainly focuses on the reduction of size and weight, that is, it must be light and flexible; on the other hand, from the structural type, it mainly focuses on the improvement and development of the gate valve., To promote the use of parallel gate valves. For the single gate plate gate valve [1-5], its structure has gradually developed from a single seat seal to a double seat seal. Double valve seat sealing means that when the valve is closed, the front and back of the flat gate valve are sealed at the same time. This structure not only improves the sealing reliability of the flat gate valve, but also is very convenient to use because it is not strictly necessary to distinguish the inlet end and the outlet end during installation. O-rings are the most common seals in flat gate valves. There are a lot of researches on the performance analysis of O-rings. Wang Wei, Zhao Shugao [6, 7] established a non-linear finite element analysis model of the rubber O-ring contact with the groove, and analyzed the contact deformation, contact width and contact stress distribution on the sealing interface of the rubber O-ring during installation and use. Laws provide a theoretical basis for the design and optimization of rubber O-rings. Liu Jian [8] and others used finite element simulation software to simulate the material properties of O-rings and the compression rate during pre-tensioning, and obtained the maximum initial contact of O-rings under different materials at different compression rates, pressure and contact stress distribution law.

In addition to the sealing of the valve seat, it is generally achieved by O-ring seals. Therefore, how to choose a suitable seal ring has become one of the key issues in the manufacture of double-seat flat gate valves. This article mainly analyzes the sealing principle of the double seat in the ultra-high pressure flat gate valve, and the influence of the pre-tightening force of the sealing ring on the sealing effect, to select the most suitable O-ring sealing ring, which lays a foundation for further research on the double seat sealing solid foundation.

2. Sealed Structure

2.1. Metal Sealing Structure

The double-seat flat gate valve has two identical valve seats, which are installed symmetrically on both sides of the gate. Each valve seat is further divided into two parts, an inner valve seat and an outer valve seat, and the inner valve seat is nested in the outer valve seat. Two valve seats and a gate plate together constitute the valve seat metal sealing structure of a double-seat flat gate valve. Its specific structure is shown in Figure 1.

The valve seat of this structure has three sealing surfaces at the inlet and outlet. The sealing surface between the inner valve seat and the gate is completely sealed by metal, while the other two sealing surfaces need to rely on non-metallic sealing.

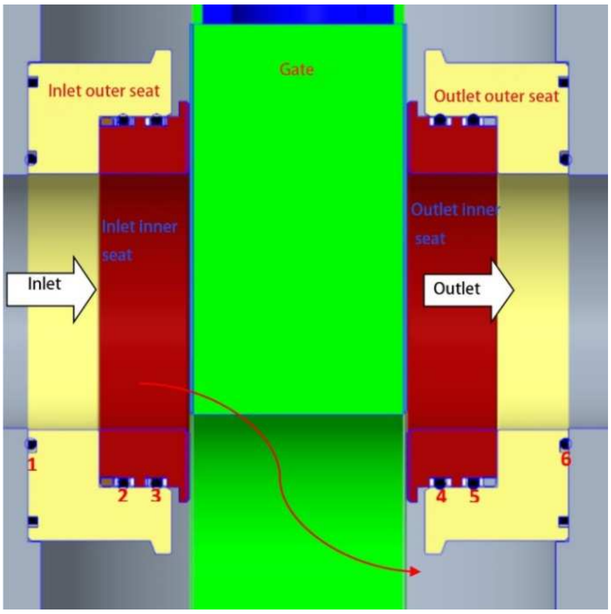


Figure 1. *Schematic diagram of the seat sealing structure of a double seat flat gate valve.*

2.2. Non-metallic Sealing Structure

The non-metallic seat seal of the double-seat flat gate valve is the core of the entire gate valve sealing structure, mainly composed of O-ring seals. The double-seat sealing structure in Figure 1 has a total of 6 O-rings. For the convenience of subsequent description, all O-rings on the seat are numbered, from the inlet end to the outlet end respectively as No. 1-6.

3. Sealing Principle Analysis

When the gate is fully open to fully closed, the high-pressure gas at the inlet enters the valve cavity from the red curve shown in Figure 1 through the through holes of the valve plate symmetrically. At this time, the gas is in a high-pressure state, which is equivalent to the valve cavity has high pressure. Since the pressure before and after No. 1-6 sealing ring is high pressure, all the seals do not play a sealing role at this time. When the gate continues to move downwards, immediately before the gate is fully closed, the internal pressure distribution of the gate valve is shown in Figure 2 (the specific pressure value in the Figure will vary according to the actual situation), and the inlet pressure is the highest (high pressure zone). The valve cavity pressure is the next (second high pressure area), and the outlet pressure is the lowest (low pressure area).

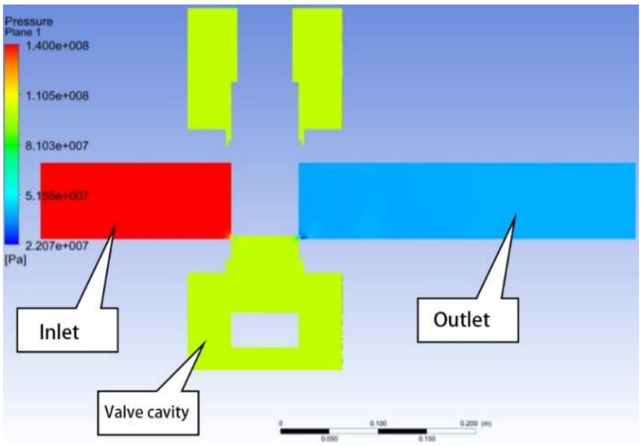


Figure 2. *The internal pressure cloud diagram of the gate valve immediately before fully closing.*

The fully closed state of the gate valve is shown in Figure 3. At this time, the high-pressure gas will flow into the gap between the parts. The small white arrow in the Figure represents the flow direction of the high-pressure gas.

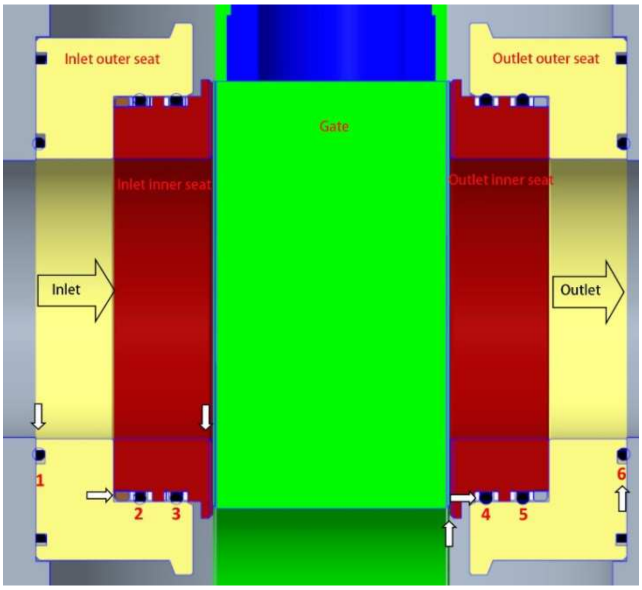


Figure 3. *Schematic diagram of the cross-section of the seat seal fully closed.*

When the gate is fully closed, high-pressure gas remains at the inlet end, and low pressure at the outlet end. At this time, one side of the inner valve seat nested in the outer valve seat is close to the gate, and the other side will not closely fit the outer valve seat under the elastic force of the No. 2 (or No. 5) sealing ring, but A certain size gap is produced, and the size of this gap depends on the elasticity of the sealing ring and the pressing force of the gate plate to the inner valve seat. Figure 4 is a partial enlarged view around the No. 2 sealing ring. The cross-section of the O-ring after being squeezed gradually presents a rectangular profile, and the elastic force of the sealing ring forces a gap between the inner and outer valve seats.

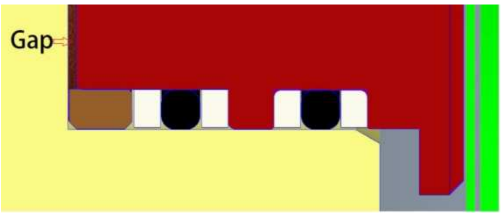


Figure 4. *Partial enlarged view of inner valve seat sealing ring and surrounding.*

When there is a pressure difference, the gate will move closer to the right under the action of the pressure difference and press tightly on the valve seat in the outlet. When the surface is sufficiently smooth, a seal can be achieved between the gate plate and the valve seat in the outlet under the action of the pressure difference, that is, the metal seal between the valve seat in the outlet and the gate plate. Under the pressure provided by the gate, No. 4 and No. 5 sealing rings can seal the air flow path between the valve seat in the outlet and the outer valve seat; the air flow path between the outer valve seat and the valve body is sealed by No. 6 Ring seal.

Since the valve cavity will have sub-high pressure at the moment of closing, there is also a pressure difference between the inlet and the valve cavity. At this time, the No. 1 sealing ring will seal the air flow path between the valve body and the outer valve seat of the inlet, and the No. 2 sealing ring will seal the air flow path between the inner valve seat of the inlet and the outer valve seat of the outlet. At the same time, the high-pressure gas at the inlet will enter the gap between the inner valve seat and the outer valve seat. The high-pressure gas in the gap will push the inner valve seat to move, thereby tightly pressing the inner valve seat in the inlet to the gate, completing the seal between the inner valve seat and the gate in the inlet.

The key to double valve seat sealing is the close fit of O-rings and various gaskets with the inner and outer seat. The pre-tightening [9] force produced by the O-ring seal makes the two inner valve seats close to the gate, and creates a certain gap on the contact surface between the outer valve seat of the inlet and the inner valve seat of the inlet, so that high-pressure gas enters after the gap, the valve seat in the inlet can be tightly pressed on the gate.

In the double valve seat seal, the seal between the inner valve seat and the outer valve seat, especially the seal between the inner valve seat and the outer valve seat at the inlet end, has always been the most problematic place in the entire double valve seat seal.

If the diameter of the sealing ring is slightly smaller, the pre-tightening force of the valve seat after installation will be insufficient. In the case of insufficient pre-tightening force, the inner valve seat and the gate will not fit closely enough, and the difficulty of forming an effective seal will increase. If the diameter of the sealing ring is slightly larger, it will make it difficult for the inner valve seat to be completely installed in the outer valve seat, which will result in insufficient space for the gate between the two inner valve seats, and make the installation of the gate difficult. To some extent, the pre-tightening force between the inner valve seat and the gate can be increased, but it is very likely to scratch the sealing surface of the gate and the inner valve seat during the installation process.

4. Analysis of Sealing Performance of O-ring Seal

4.1. Parameter Setting

The sealing performance of the O-ring seal largely depends on its material [10]. In this paper, polytetrafluoroethylene with many excellent properties is selected as the material of the seal ring. If the material and size of the O-ring seal are determined, they are directly manufactured for pressure testing, the research cycle is too long and the research and development cost is too high. If the finite element simulation analysis is performed on the sealing ring in advance, time can be saved and research and development costs can be reduced.

The choice of O-ring size is directly related to the sealing performance of the O-ring. In this paper, the finite element simulation of O-rings with different wire diameters is carried out. The wire diameters of the seal rings and their corresponding compression ratios [11] are shown in Table 1.

Table 1. *The diameter of the seal ring and its corresponding compression rate.*

Wire diameter (mm)	**3.5mm**	**3.55mm**	**3.6mm**	**3.65mm**	**3.7mm**	**3.75mm**	**3.8mm**	**3.85**
Compression ratio	13.71%	14.93%	16.11%	17.26%	18.38%	19.47%	20.53%	21.56%

According to the O-ring of the outer valve seat, the simulation model shown in Figure 5 is established and meshed. The sealing performance simulation analysis of the O-ring is a large deformation nonlinear analysis. Therefore, when the sealing ring is meshed, the selected element type is a hybrid element suitable for nonlinear analysis, and the rest of the components use reduced integration. The selection of grid type control is mainly quadrilateral.

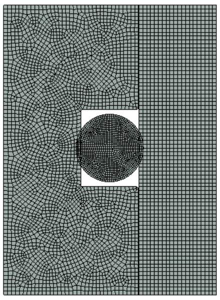


Figure 5. *Finite element analysis model mesh.*

Regarding the O-ring seal as a superelastic approximately incompressible body, its strain energy function is widely described by a constitutive model based on Mooney-Rivlin [12, 13], and the mathematical form is as follows:

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

Among them, C_{10} and C_{01} can be calculated from experimental data. In this paper, C_{10} is 1.87Mpa, and C01 is 0.47Mpa.

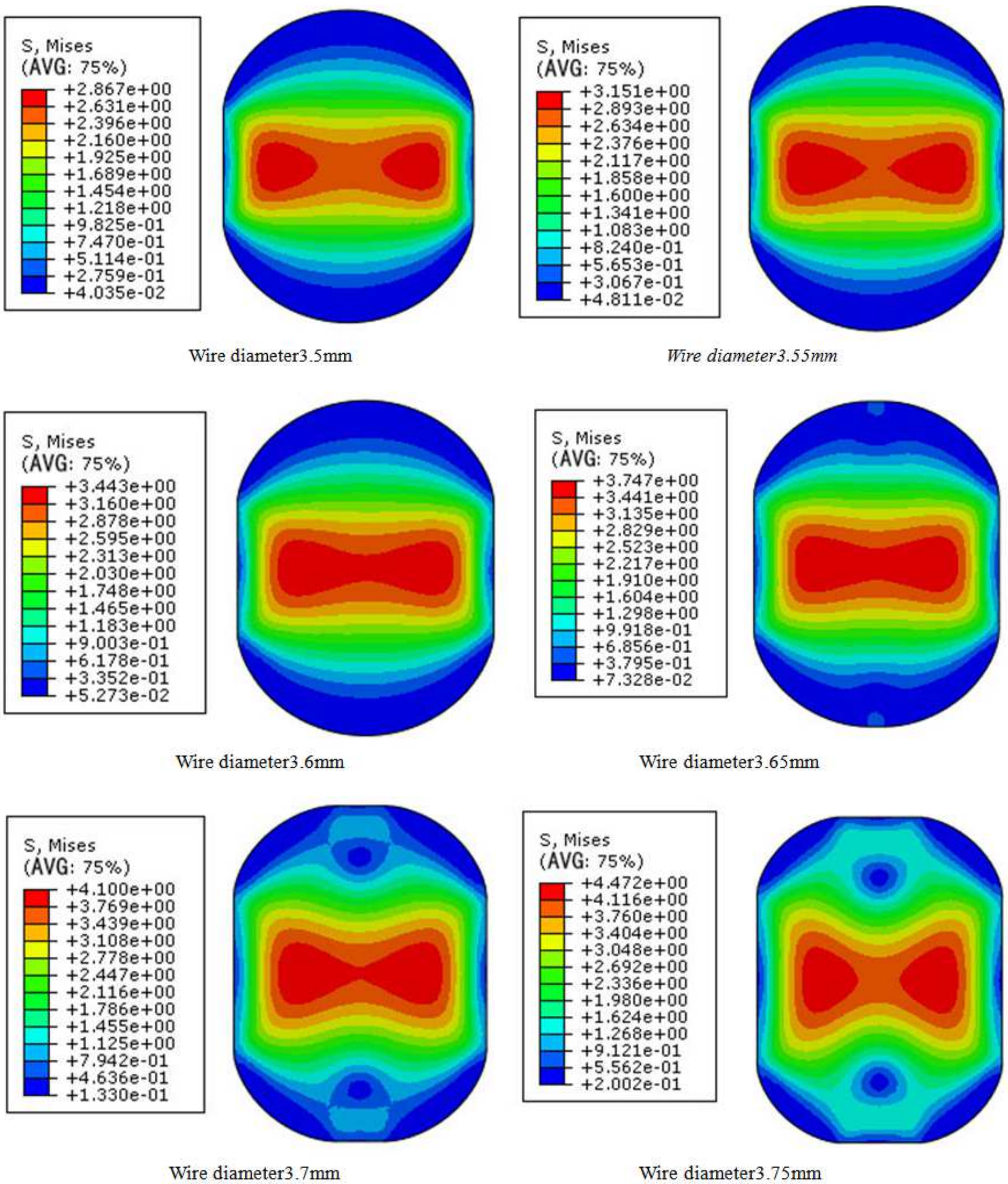
The boundary condition of the O-ring groove is set to be fixed, and the interaction between the O-ring seal and the O-ring groove is set to surface-to-surface contact.

4.2. Simulation Result Analysis

The Mises stress in the ABAQUS software is the von Mises stress, also known as the equivalent stress, which reflects the stress distribution inside the material, and its expression is:

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

The Mises stress of O-rings with different wire diameters is shown in Figure" dumbbell [14]" shape.



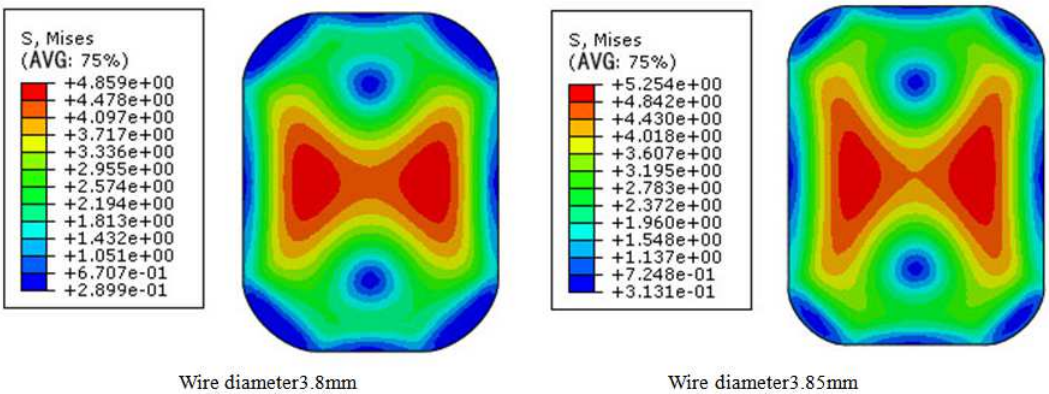


Figure 6. *Mises stress of O-rings with different wire diameters.*

Figure 7 is a graph showing the maximum contact stress [15] of the O-ring seal with the sealing surface after installation and the change in the diameter of the seal ring. The maximum contact stress in the Figure increases as the diameter of the seal ring increases. The maximum contact stress increases relatively slowly before the diameter of the seal ring reaches 3.7mm, and then increases rapidly.

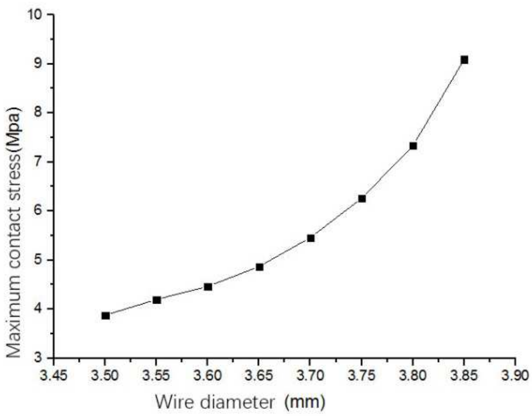


Figure 7. *The maximum contact stress varies with the diameter of the seal ring.*

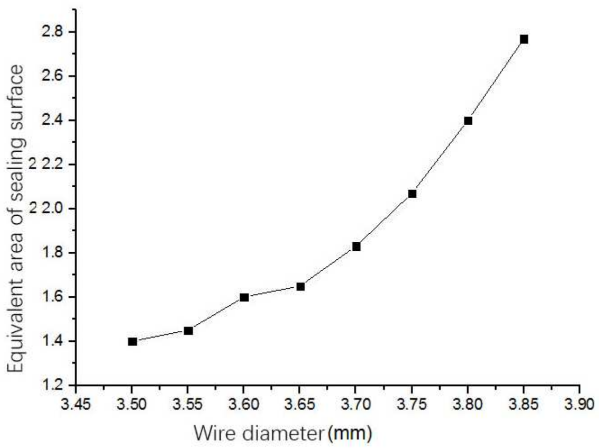


Figure 1. *Curve diagram of equivalent contact area of sealing surface and diameter of sealing ring.*

Figure 8 is a graph showing the equivalent contact area of the sealing surface and the diameter of the sealing ring after the O-ring is installed, where the equivalent contact area [16] is represented by the sealing surface width of the sealing ring. The equivalent contact area of the sealing surface increases as the diameter of the sealing ring increases, and it starts to rise rapidly after the diameter of the sealing ring reaches 3.65mm.

It can be seen from the above results that when only the sealing performance and pre-tightening force requirements are considered, the larger the wire diameter of the O-ring, the better. However, considering the service life of the O-ring seal [17], the compression rate of the seal ring should not exceed 20%. Therefore, the selected seal ring wire diameter is 3.75mm within the recommended seal ring compression ratio.

5. Conclusion

This article analyzes the dual seat sealing principle of the ultra-high pressure flat gate valve, and discusses the influence of the pre-tightening force of the sealing ring on the sealing effect. Through the finite element simulation analysis software, the Mises stress, the maximum contact stress of the sealing surface and the contact area of the sealing surface of the O-ring under different compression ratios are analyzed. It can be seen from the simulation results that when only the sealing performance and pre-tightening force are considered, the larger the diameter of the O-ring seal, the better. When the service life of the O-ring seal is also considered, the compression rate of the seal should be less than 20%. Therefore, after combining various factors, the wire diameter of the double seat O-ring of the ultra-high pressure flat gate valve is 3.75mm.

References

[1] Shen Huiqin. Research on sealing structure technology of flat gate valve in ultra-high pressure gas production wellhead [J]. Petroleum Machinery, 2011, 39 (10): 116-119.

[2] Wang Da. Study on the sealing performance of integral Christmas tree flat gate valve [D]. Southwest Petroleum University.

[3] Zhang Shaohua, Tao Guoqing, Liu Jianfeng, Ye Zhiheng, Yu Hongbing. Talking about the improved design of the structure of the high-pressure flat gate valve seat assembly [J]. China Equipment Engineering, 2019, 07.

[4] Li Xueye. Study on the sealing structure technology of flat gate valve at the head of ultra-high pressure gas production [J], Equipment Management and Maintenance, 2020, 06.

[5] Zhao Zan, Zou Wenjing, Chen Yang. Design and analysis of asymmetric sealing structure of flat gate valve [J]. Valve, 2020, 06.

[6] Wang Wei, Zhao Shugao. Nonlinear finite element analysis of rubber O-rings [J]. Lubrication and Sealing, 2005 (04): 106-107+110.

[7] Liu Peng, Zheng Yuanyuan, Tang Baoshi, Cui Dejun, Yuan Xiaoming. Reliability analysis and software development of O-ring seal based on ANSYS [J]. Hydro-pneumatic and sealing, 2020, 05, 004

[8] Liu Jian, Qiu Xingqi, Bo Wanshun, Xu Junliang. Numerical analysis of the maximum contact pressure of rubber O-rings [J]. Lubrication and Sealing, 2010, 35 (01): 41-44.

[9] Xie Feng, Yang Gao, Huang Zhenhua. Research on the sealing performance of O-ring seal in the triangle area based on finite element [J]. Machine Tool and Hydraulics, 2019, 47 (10): 113-115+140.

[10] Fan Zhimin, Li Long, Wang Qilin. Sealing performance analysis of O-ring seal under deep sea high pressure environment [J]. Mechanical and Electrical Engineering, 2019, 36 (02): 131-135.

[11] Zhang Chengfu. Calculation method of compression rate of O-ring seal and example verification [J]. China Petroleum and Chemical Standards and Quality, 2018, 38 (19): 175-180.

[12] R. Faruk Yükseler. Local and nonlocal buckling of Mooney-Rivlin rods [J]. European Journal of Mechanics-A/Solids, 2019 (78): 103816

[13] Ren Quanbin, Cai Timin, An Chunli, Song Jinsong, Liu Zhongbing. Determination of Mooney-Rivlin Model Constants for Silicone Rubber "O" Seal Rings [J]. Solid Rocket Technology, 2006 (02): 130-134.

[14] Zhang Zhenxing, Zhang Jiangtao, Gong Maotao, Xia Yijie. Finite element nonlinear analysis of O-ring seal of feedwater pump oil seal device [J]. Hydraulics and Pneumatics, 2019 (05): 98-103.

[15] Zhou Zhihong, Zhang Kanglei, Li Jing, Xu Tongle. Finite element analysis of the stress and contact pressure of O-shaped rubber seals [J]. Lubrication and Sealing, 2006 (04): 86-89.

[16] Tan Jing, Yang Weimin, Ding Yumei, Li Jianguo, Yang Weizhang, Lu Xuancai, Tang Bin. Finite element analysis of rectangular rubber sealing ring [J]. Lubrication and Sealing, 2007 (02): 36-39.

[17] D. Battini, G. Donzella, A. Avanzini, A. Zenoni, M. Ferrari, A. Donzella, S. Pandini, F. Bignotti, A. Andrighetto, A. Monetti. Experimental testing and numerical simulations for life prediction of gate valve O-rings exposed to mixed neutron and gamma fields [J]. Materials & Design, 2018 (156): 514-527.