Analysis and Optimization of Bowl Skeleton

Yang Zhang, Chao Song and Zheng Xu

ABSTRACT

In the process of oil development operations, the sealing bowl is adopted to seal the drilling fluid in the well. It relies on the interference between the bowl and the casing to achieve the sealing function. And the skeleton can significantly improve the bearing capacity of the sealing bowl. However, sealing bowls with different kinds of steel skeletons have huge differences in the sealing function. In this paper, by using ANSYS Workbench to establish the bowl model and optimizing the skeleton structure parameters, we can get the optimal skeleton form that meets the requirement of sealing pressure 35MPa.

INTRODUCTION

Sealing bowl is a self-sealing tool which relies on the interference between outer diameter of bowl and inner diameter of casing to achieve its function. Its function is to ensure the high pressure injection of drilling fluid[1]. Rubber is adopted as the sealing component. There are three features of sealing bowl. Its structure is simple. It is easy to operate. And its sealing is reliable[2]. Four factors that affect the performance of sealing bowl are as followed: the parting surface of sealing piece forming mold, the hardness of rubber, the skeleton form, and the finish size of sealing bowl[3]. Steel skeleton can significantly improve the bearing capacity of sealing bowl. In this paper, structure of the skeleton is the chief consideration. Using ANSYS Workbench, we build the rubber bowl model, and simulate its working conditions, and finally get the optimal skeleton which can meet the design requirement of sealing pressure 35MPa.

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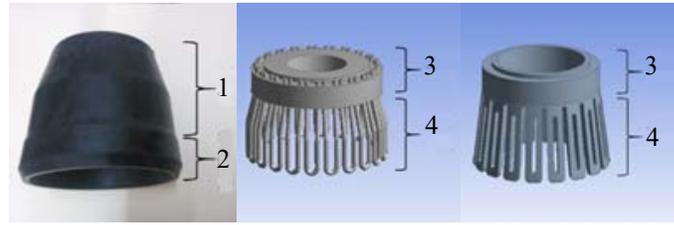
(a) sealing bowl (b) traditional skeleton (c) innovative skeleton
1-main body; 2-sealing lip; 3-based frame; 4-pressure frame
Figure 1. The structure of sealing bowl.

STRUCTURE OF SEALING BOWL

As shown in Figure 1-a, the bowl is divided into main body and sealing lip. Rubber hardness is 73 to 78 degree in Shore A[3]. The structure of skeleton is shown in Figure 1-b and 1-c. Based frame is used for positioning. Pressure frame is used for bearing the working pressure. Traditional skeleton is shown in Figure 1-b. Its manufacturing is simple, but it has only a few variable parameters. Innovative skeleton shown in Figure 1-c has more variable parameters. Working process is shown in Figure 2. Sealing lip is pressed on the casing. Under pressure difference on both sides, the bowl opens further, which enhances the sealing performance[4].

FINITE ELEMENT ANALYSIS OF SEALING BOWL

Model Building and Material Setting

Establish models including traditional skeleton and innovative skeleton. Initial state is shown in Figure 2-a. The outer diameter of casing is 139.7mm. The inner diameter is 124.3mm. Mooney-Rivlin is adopted while defining the rubber material.
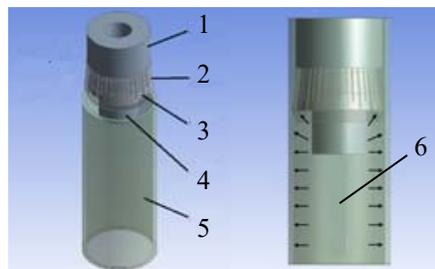
(a) initial state   (b) bowl into the casing
1-ring; 2-rubber; 3-skeleton; 4-mandril; 5-casing; 6-working pressure
Figure 2. The working process of sealing bowl.

The hardness of 76 (IRHD) is equal to elastic modulus 9.14MPa, andc01 and c01 are 1.01555 and 0.50778 respectively [5,6]. Based frame, pressure frame and ring are built as one part. Its material is 60Si2Mn, whose elastic modulus is 206GPa, and Poisson ratio is 0.29, and yield strength is 1200MPa.

Mesh, Constraints and Loads

The contact relationship is frictional. Friction coefficient is 0.3[5]. Use sweep method on main body while meshing. Shape checking is set to "aggressive". Open the large deflection. Fix the casing. In the first step, set the bowl to the downward displacement 144.5mm, so that it can enter the casing pipe. In the second step, apply fluid pressure 35MPa[7,8] to the inner side of bowl.

Solve

Sealing criterions are that contact pressure between bowl and casing should be larger than seal pressure, and the bowl does not occur stress failure[9]. As can be seen from Figure 3 and Figure 4, there are significant areas over sealing pressure 35MPa both in the traditional bowl and innovative bowl. The rubber stress of traditional bowl is almost equal to innovative bowl. Both skeletons have significant areas over yield limit 1200MPa. Comparative analysis shows that the performance of innovative bowl is better than traditional bowl.
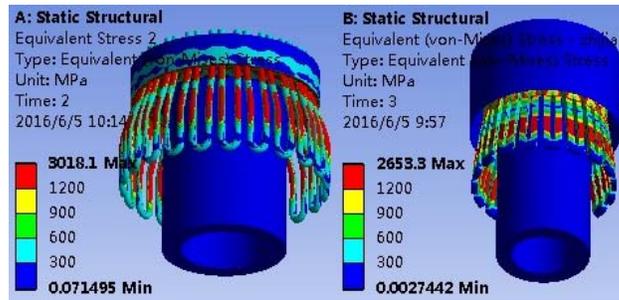
OPTIMIZATION OF THE BOWL SKELETON

Innovative bowl and its dimensions are shown in Figure 5.Optimizations mainly include branch interval "a", root thickness "t" which is equal to "(100-2b)/2", skeleton length "c", and ring length "d". The effect of skeleton optimizations on the contact pressure and rubber stress is very small, so skeleton stress is only considered in the following simulation.
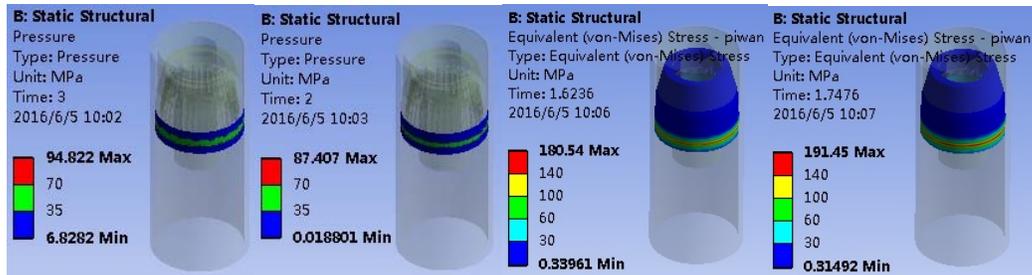
(a) traditional bowl   (b) innovative bowl   (c) traditional bowl   (d) innovative bowl
Figure 3. Contact pressure and rubber stress.

(a) traditional skeleton   (b) innovative skeleton
Figure 4. Skeleton stress.

Optimization of Branch Interval

Establish model as shown in Figure 2. Change branch interval "a" to 2, 2.4, 2.8,···, 4.8mm. Remaining parameters and settings are the same. The results are shown in Figure 6-a. When "a" is less than 3.2mm, single branch becomes wider with the decrease of "a". Stress becomes higher because of the worse stiffness. When "a" is larger than 3.2mm, single branch becomes narrower with the increase of "a". Higher stress is generated because of the insufficient structure considering strength and stiffness, the optimal value of branch interval is 3.2mm.

Optimization of Root Thickness

Establish model as shown in Figure 2, in which "a" is 3.2mm. As the limit of the structure, the maximum "t" is 12.35mm, calculated by "(100-75.5)/2". Change "t" to 8, 10,12.35mm. Remaining parameters and settings are the same. The results are shown in Figure 6-b. With the decrease of "t", the stress is greatly increased. The reason is that skeleton root plays a supporting role, and its strength requirement is more important than flexibility. The thicker the skeleton root is, the stronger it will be. The optimal value of the root thickness is 12.35mm.
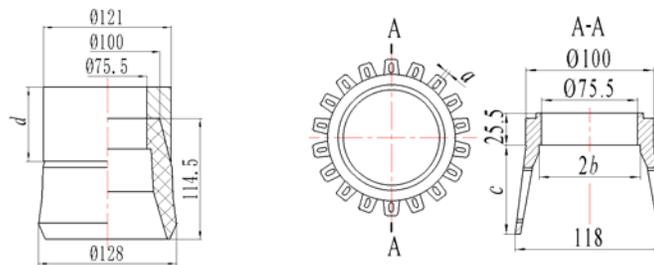
(a) bowl   (b) skeleton
Figure 5. Innovative bowl.

Optimization of Skeleton Length

Establish model as shown in Figure 2, in which "*a*" is 3.2mm, "*t*" is 12.35mm. Change "*c*" to 63, 66, 70mm. Remaining parameters and settings are the same. The results are shown in Figure 6-c. With the increase of the "*c*", the stress is reduced. The reason is that the longer the skeleton is, the better elastic deformation it will be. The optimal value of skeleton length is 70mm.
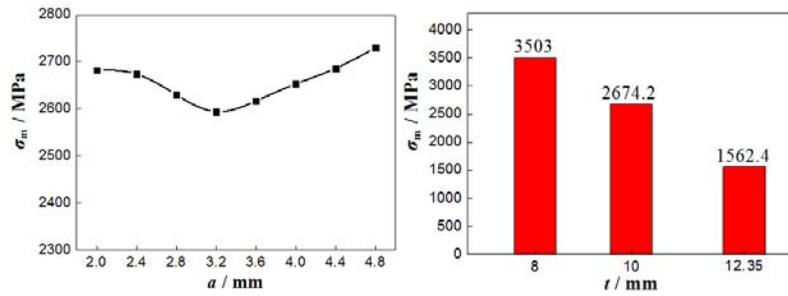
Optimization of Ring Length

Establish model as shown in Figure 2, in which "a" is 3.2mm, "t" is 12.35mm, "c" is 70mm. Change "d" to 40, 35,···, 15mm. Remaining settings are the same. The results are shown in Figure 6-d. When "d" is less than 30mm, the skeleton stress is almost in the same level. The ring length is too short to achieve its function. Considering the cost of processing, we take the optimal ring length as 35mm.

**Simulation and Verification of The Optimal Skeleton Form**

The optimal skeleton is a=3.2mm,t=12.35mm, c=70mm, d=35mm.Simulation results are shown in Figure 7. The inner side of skeleton has a small area over allowable stress, but most areas are less than 1200MPa. In conclusion, the optimal skeleton can meet the design sealing requirement of 35MPa.

CONCLUSIONS

Taking into account the strength and stiffness, skeleton branch intervals should not be too large or too small. The root thickness of the skeleton has great influence on the sealing performance. The greater the value is, the higher intensity the sealing bowl will be. The longer the pressure frame is, the better sealing performance the bowl will be. In order to ensure the auxiliary effect of ring, its length should not be too small. For the sealing bowl in this paper, its optimal parameters are as followed: branch interval "a" is equal to 3.2mm, root thickness "t" is equal to 12.35mm, skeleton length "c" is equal to 70mm, and ring length "d" is equal to 35mm.
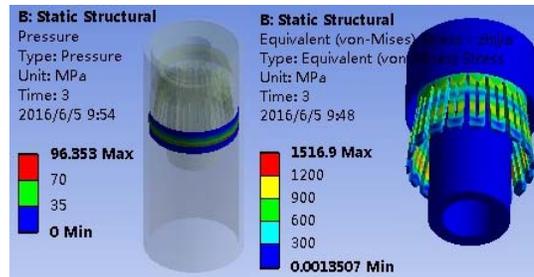
(a)   different branch intervals (b) different root thickness
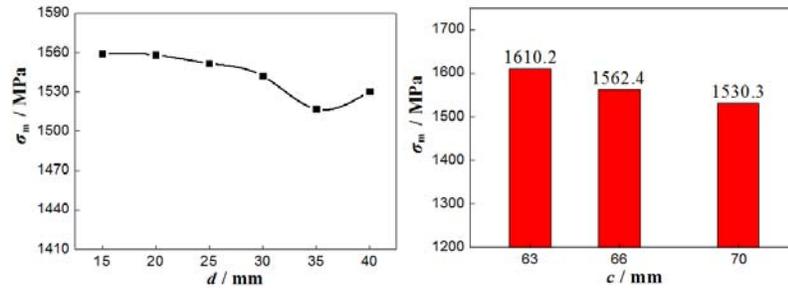
(c) different skeleton lengths   (d) different ring lengths
Figure 6. Maximum stress of skeleton.

(a) contact pressure   (b) skeleton stress
Figure 7. Simulation of the optimal sealing bowl.

REFERENCE

1. Meijiang Yan. 2014. "Research on the key system of φ139.7mm clamp sleeve cycling head,". Beijing University of Chemical Technology.(in Chinese)
2. Xinsheng Yuan. 1998."Application of rubber cup packer in horizontal well," Xinjiang Petroleum Science & Technology, 8(2): 42-44. (in Chinese)
3. Zhi Zheng. 2004."Research on improving the qualified rate of the size of sealing rubber cup," Rubber Technology Market, (12): 13-15. (in Chinese)
4. Ming Zhao, Xinguo Peng, Zhanguan Wu, et al. 2010."The new technology of anti-knock on shock of cup packer," Science & Technology Information, (14): 4. (in Chinese)

5. Xiaojun Zhou, Zhiming Duan, Jian Wang, et al. 2013. "Finite element analysis of packer's rubber sealing performance by ANSYS Workbench," Industrial Control Computer, 26(11): 111-113. (in Chinese)
6. Wei Wang, Tao Deng, Shugao Zhao. 2004. "Determination for material constants of rubber Mooney-Rivlin model," Special Purpose Rubber Products, 25(4): 8-10. (in Chinese)
7. Xuehong Wang, Jing Dan, Kangmin Yang, et al. 1999."Research and application of cup packer HNX344-114," China Petroleum Machinery, 27(11): 39-40. (in Chinese)
8. Lixin Zhang, Zejun Shen, Yiliang Li, et al. 2007. "Development and application of packer technology in China," China Petroleum Machinery, 35(8): 58-60+74+80. (in Chinese)
9. Yuhuan Bu, Mingxin Ma, Jianhua Li, et al. 2011."Study on sealing property criterion and structure design method of packer," Lubrication Engineering, 36(11): 75-78. (in Chinese)