Fluid-solid Coupling Analysis of the Pressure Expansion of Packers

Lanwen Wang¹, Junxu Ge², Xuanyu Sheng¹

¹Department of Mechanical Engineering, Tsinghua University, Beijing 100084, China
²Hangzhou Chenyi Environmental Protection Technology Co., Ltd, Hangzhou, China
wlw13718592388@163.com

Abstract. For the packers, the pressure expansion process and differential pressure loading process have been simulated by the fluid-solid coupling finite element method. The results show that under the internal pressure load of 10MPa at both ends of the hydraulic oil, the structure of the packer can be fully expanded, and the simulated expansion process is consistent with the actual expansion process of the packer in the test. During the internal pressure loading phase of the hydraulic oil, the internal pressure gradually increases, and the pressure near the ends of the hydraulic oil increases faster. During the pressure difference loading phase of the packer, the internal pressure of the hydraulic oil gradually increases, and the growth curves of different nodes are basically the same. The internal pressure speed and viscosity of the hydraulic oil have a great influence on the internal pressure transmission of the hydraulic oil. After the packer is expanded, the stress at the bell mouth where the rubber tube is in contact with the rubber tube joint is large. When actually designing the packer, this location should consider stress concentration or use a stronger material.

1. Introduction

The packer is a downhole tool used in oil and gas well measures to seal wellbore, and is widely used in various production processes of oil exploration and development [1]. At present, in the working process of the high sulfur-resistant and high expansion rate packer, there are accidents such as steel sheet breakage, rubber cylinder damage, and rubber tube joint cracking, which leads to the early scrapping of the domestic packer. When working in the field, the function of the packer is mainly realized by the rubber cylinder assembly. The rubber cylinder assembly is composed of laminated steel strip, an inner rubber tube and an outer rubber tube made of rubber. The working principle is that the internal pressure is applied, the rubber cylinder assembly is expanded after being pressed, the outer rubber cylinder is in contact with the casing of the well wall, and the sealing of the oil and gas well shaft is completed under the action of internal pressure extrusion and upper and lower pressure difference [2].

The finite element method is widely used in the analysis of the force of the packer. It is common to analyze the stress change law of the expansion process of the rubber cylinder, the influence of temperature and size on the contact stress, and the influence of parameters such as the structure of the rubber cylinder, rubber material and friction coefficient on the stress and performance of the rubber cylinder [3]. At present, the method of analyzing the packer expansion by finite element analysis is mechanical analysis, that is, the internal pressure load is set according to the actual working condition of the packer in the well, and the pressure change of the hydraulic oil inside the packer is not actually simulated. Therefore, in order to fully simulate the pressurization expansion process of the packer, the
interaction between the hydraulic oil and the packer cartridge needs to be considered. In this paper, Abaqus is used to analyze the fluid-solid coupling of the packer, and the pressure change of the hydraulic oil and the stress distribution of the components of the rubber tube during the pressure expansion process of the packer are obtained, which provides theoretical support for the sealing and optimization of the packer.

2. Fluid-solid coupling model
The pressure expansion of the packer is a typical fluid-solid coupling problem, and it is necessary to establish a finite element model of the fluid structure and the solid structure separately [4]. The main working parts of the packer solid structure are the inner rubber cylinder, the outer rubber cylinder, the laminated steel sheet, the fixed end rubber joint, the floating end rubber joint and the outer sleeve, so only the three-dimensional model of these structures is established. The simplified three-dimensional model of the packer is shown in Fig.1. The outer diameter of the packer laminated steel sheet is Φ52mm, the outer diameter of the outer rubber tube is Φ60mm, and the inner diameter of the outer casing to be sealed is Φ160mm.

![Fig.1 Solid structure of the packer](a) Front view (Casing is hidden) (b) Left view

In Fig.1, the laminated steel sheet is constructed as a single cylindrical structure and imparts material properties to the orthotropic material, which can greatly reduce the number of contacts and small-sized local units, thereby completely calculating the pressurization expansion process of the packer [5]. The rubber tube joint and casing structure material of the packer is No. 304 steel. The structural material of the inner rubber tube and the outer rubber tube is rubber. The superelastic constitutive model of rubber material needs to be determined by single pull, plane and equal biaxial tensile tests, and the volume change rate experimental data is used to determine the deformation coefficient of the rubber material [6]. Based on the rubber experimental data, a 3rd order Ogden model is selected to fit and assign material parameters.

The fluid domain of the packer is the hydraulic oil inside the inner cylinder. The fluid finite element model is shown in Fig.2. The simulation of the pressure expansion of the cartridge assembly is divided into two stages. In the first stage, 10MPa internal pressure is applied at both ends of the fluid domain to expand the rubber cylinder under the action of hydraulic oil internal pressure. In the second stage, after the rubber cylinder is expanded, the floating end of the outer rubber cylinder is loaded with a pressure difference of 16 MPa. After the calculation is completed, the structural change and internal pressure change after the packer is expanded are obtained.

![Fig.2 Finite element model of fluid domain](a) Front view (Casing is hidden) (b) Left view

3. Results

3.1 Fluid domain
The hydraulic oil expands under the pressure of both ends, and the expansion process of the hydraulic oil is shown in Fig.3.
It can be seen from Fig.3 that under the action of internal pressure of 10MPa at both ends, the two ends of the hydraulic oil that are not restricted by the rubber cylinder joint start to expand first, then the middle of the hydraulic oil begins to expand. After the hydraulic oil is fully expanded, the floating end is contracted by the pressure difference. In order to know the change process of the hydraulic oil end and internal pressure during the whole process, the node A of the end and the nodes B,C,D and E of the four different positions are selected respectively to analyze the change process of the pressure with time, as shown in Fig.4.
It can be seen from Fig.4 that the internal pressure of the hydraulic oil gradually increases in the initial stage of internal pressure loading, and the closer to the end, the faster the pressure increase. When \( t=4s \), the pressure reaches 3.2 MPa, then the pressure difference is loaded. At this time, the internal pressure of hydraulic oil gradually increases, and the growth curves of different nodes are basically the same.

### 3.2 Solid structure

The deformation process of the packer solid structure corresponds to the fluid domain, and the expanded state of the packer is shown in Fig.5. The result in the figure is the displacement distribution of the packer. According to the simulation results, when the internal pressure of the hydraulic oil reaches 3.2 MPa, the structure of the rubber cylinder can be fully expanded, and the rubber cylinder is in contact with the casing, then the entire radial displacement reaches 160mm. This simulated expansion process is consistent with the actual expansion process of the packer during the test.
The results of the stress distribution of the packer after calculation are shown in Fig. 6. According to the calculation results, the maximum stress of the fixed end rubber joint is 594.3 MPa, which position is at the point where the fixed end rubber joint is in contact with the laminated steel sheet. The maximum stress of the floating end rubber joint is 69.84 MPa, which position is at the point where the floating end rubber joint is in contact with the laminated steel sheet. The maximum stress of the outer rubber cylinder is 11.02 MPa, which position is at the edge of the outer rubber cylinder. The maximum stress of the laminated steel sheet is 376.5 MPa, which position is at the point where the end of the laminated steel sheet is in contact with the fixed end rubber joint. The maximum stress of the inner rubber cylinder is 27.57 MPa, which position is at the end of the floating end. As a result, during the working process, the stress at the bell mouth of the rubber cylinder is relatively large. This location should have a good structure or material when the packer is actually designed.
4. **Optimization of the fluid domain**

In the above analysis, it is found that the pressure of the hydraulic oil cannot follow the pressure rise at the end of the hydraulic oil. There are two reasons for this phenomenon. The first is that the internal pressure loading time of the hydraulic oil is too short, and the pressure loading of the hydraulic oil end is too fast, resulting in insufficient fluid flow. The second is that the viscosity of the hydraulic oil is too large, resulting in too much internal friction, which hinders fluid flow. Therefore, in order to achieve rapid transfer of hydraulic oil pressure, the finite element model of the fluid domain is optimized. Firstly, the viscosity of hydraulic oil is reduced. Secondly, the original pressure load at the end of hydraulic oil is set to rise from 0 to 10MPa in 1 second. The amplitude curve is now modified so that the pressure load at the end of hydraulic oil rises from 0 to 10MPa in 10 seconds. By reducing the viscosity, the pressure can be quickly transferred between the hydraulic oil. By slowing down the internal pressure loading speed, the pressure can be well transferred between the hydraulic oil, and the hydraulic oil can be prevented from vibrating during pressure loading. After revising the model, the pressure value of the node at the floating end and four nodes at different position are obtained. The change process of the pressure with time is shown in Fig.7.

![Figure 7](image)

**Figure 7 Results of pressure change**

It can be seen from Figure 7 that after revising the model, the internal pressure change of hydraulic oil lags behind the end pressure at the beginning. After 2.5 seconds, the internal pressure of hydraulic oil and the end pressure increase substantially simultaneously. However, at about 5 seconds, a tip appears on the hydraulic oil pressure change curve, that is, the internal pressure of the hydraulic oil is suddenly greater than the end pressure, and this is the time when the rubber cylinder just expands, and the differential pressure is loaded at this time. In order to analyze the reason of tip, the model is modified below. The differential pressure is removed, and the internal pressure is loaded. After calculating, the pressure change curve is shown in Fig.8.
It can be seen from Fig.8 that after removing the differential pressure, the tip still exists in the pressure change curve. Therefore, the reason for the appearance of tip is not loading the differential pressure, but the rubber cylinder just expands at this time. The expansion state of hydraulic oil at this time is shown in Fig.9.

5. Conclusion
In this paper, the fluid-solid coupling analysis of the pressurization expansion process of the packer is carried out. The results are as follows:

(1) Under the action of internal pressure of 10MPa at both ends of the hydraulic oil, the rubber cylinder of packer can be fully expanded, and the simulated expansion process is consistent with the actual expansion process of the packer in the test, that is, both are expanded an the end first and then expanded in the middle.

(2) In the stage of internal pressure loading, the internal pressure of the hydraulic oil gradually increases, and the pressure closer to the end of the node increases faster. In the stage of differential pressure loading, the internal pressure of the hydraulic oil gradually increases, and the growth curves of different nodes are basically the same.

(3) By analyzing the stress distribution of the components after the packer is expanded, the stress at the bell mouth where the rubber cylinder is in contact with the rubber cylinder joint is large. This location should have a good structure or material when the packer is actually designed.

(4) The internal pressure speed and viscosity of the hydraulic oil have a great influence on the internal pressure transmission of the hydraulic oil. The proper internal pressure speed and viscosity of the hydraulic oil enable simultaneous increase in internal pressure and end pressure of the hydraulic oil.
Acknowledgments
This research was financially supported by the Major National Science and Technology Projects of China (Grant No. 2016ZX05017-002).

References
[1] Jianghan Petroleum Administration Oil Production Technology Research Institute. Packer theory basis and application [M]. First edition, Beijing: Petroleum Industry Press, 1983, 1, 74-83.
[2] Zhang Chengwu. Sealing mechanism of segmented fracturing packer laminated steel sheet expansion cylinder [J]. Petroleum machinery, 2007, 35(3), 5-7.
[3] Wang Peng. Simulation of Working Behavior of HPHT Well Completion Packer [D]. Xi’an Shiyou University, 2018.
[4] Shi Yiping, Zhou Yurong. Detailed explanation of Abaqus finite element analysis examples. Mechanical Industry Press, 2006.
[5] Chen Xing. Study on Mechanical Properties of Typical Heterogeneous Materials Based on Progressive Homogenization [D]. Huazhong University of Science and Technology, 2015.
[6] Lanwen Wang, Xuanyu Sheng, Jiayue Sheng. Analysis of the Pressure Expansion of Bridge Plug Tools and Packers by Equivalent Material Method [J]. Journal of Physics: Conference Series, 2019, 1187(3).