ISSN: 2664-9640

Study on working performance of delayed toe-end sliding sleeve mechanism in horizontal wells

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Abstract

At present, there are more and more unconventional oil and gas wells, such as shale gas and tight sandstone oil and gas, and conventional vertical wells can not meet the requirements of efficient production. Horizontal well fracturing technology is the main technology for efficient development of unconventional oil and gas reservoirs. A new type of delayed toe end sliding sleeve is designed for the first stage fracturing of horizontal wells, and its opening pressure accuracy and opening performance are evaluated through laboratory experiments. The results show that the delayed toe end sliding sleeve has good basic opening performance, shear pressure error of shear pin is within 3%, the delay function meets the design requirements. The three-dimensional finite element model of the delayed toe end sliding sleeve is also established, and the influence of high pressure on its opening performance is analyzed. The results show that the internal pressure of 180Mpa has no influence on the opening performance of the delayed toe end sliding sleeve. This is of great significance to the stimulation and transformation and efficient development of unconventional oil and gas reservoirs in China.

Keywords

Toe sleeve; unconventional oil and gas reservoir; horizontal well; staged fracturing.

1. Introduction

With the deepening of oil exploration and development, unconventional oil and gas wells with low permeability and low porosity such as shale gas and tight sandstone oil and gas are increasing. Conventional vertical wells have been unable to meet the requirements of efficient exploitation. Horizontal wells have gradually become the necessary means to improve oil and gas development. Horizontal well staged fracturing technology is the main technology of unconventional oil and gas reservoir development [1-4]. The bridge plug staged fracturing technology is one of the key technologies of horizontal well staged fracturing. At present, the coiled tubing or crawler is usually used to drag the perforating gun into the first perforation before fracturing construction at home and abroad. After the first layer of fracturing channel is established, the bridge plug is pumped to the predetermined position in the casing for the next fracturing test [5-8].

There are several problems in the first segment of coiled tubing transmission perforation mode : 1) The operation time is long, the first perforation will cost more than 2 days, and the operation efficiency is low ; 2) There are many equipment to be mobilized, such as cranes and pump trucks, which are expensive and prone to risks such as sticking, self-locking and falling objects ; 3) Deep wells, ultra-long horizontal wells, upwarping wells and other coiled tubing tools are difficult to down to the bottom of the well, and can not guarantee the effective horizontal section length. And through the preset toe end sliding sleeve instead of coiled tubing transmission perforation for the first stage fracturing operation, as shown in Figure 1, with the cementing string down into the bottom of the well for normal cementing operation, to be fracturing only through wellhead pressure can be toe end sliding sleeve open, establish inside and outside the casing fracturing channel, without perforation can be the first stage fracturing operation, can greatly improve the operation efficiency, reduce the construction risk, ensure the long horizontal well effective horizontal section, can effectively reduce the development cost of unconventional oil and gas reservoirs such as shale gas, has broad application prospects [9-10].

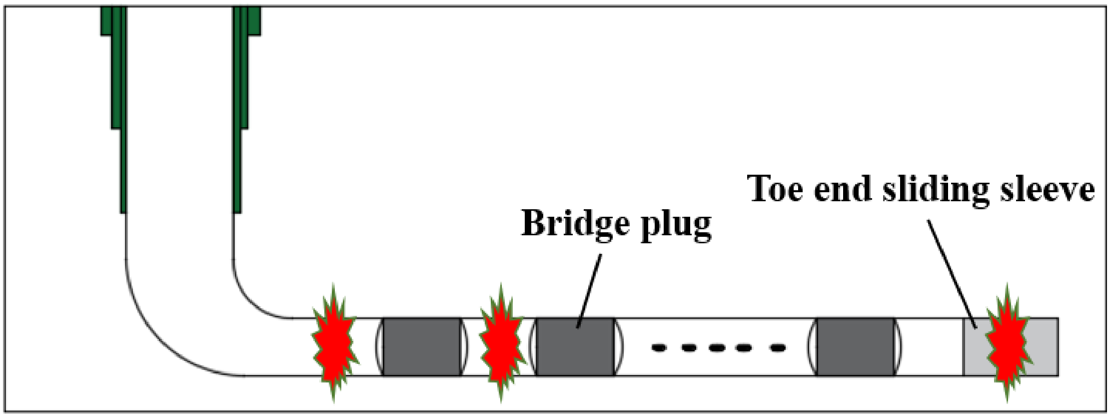


Fig 1 The schematic diagram of bridge plug staged fracturing in horizontal well

At present, relevant foreign companies have made great progress in the research of this technology, and introduced different types of delayed toe-end sliding sleeves, which have been successfully applied in the fracturing construction of unconventional oil and gas reservoirs in foreign countries. However, this tool is still in the stage of development and test in China [11–13]. In view of the above problems, a toe-end sliding sleeve with delay opening function is designed, and the control performance of sliding sleeve opening pressure accuracy and delay starting performance are evaluated through laboratory experiments. The finite element model of sliding sleeve was established by numerical simulation, and the opening performance of toe-end sliding sleeve under high pressure was analyzed. This is of great significance for breaking foreign technological monopoly and possessing China's independent intellectual property rights.

2. Structure Design and Working Principle of Delayed Toe-end Sleeve

In order to solve the problems of low efficiency, high cost and high risk in the first stage fracturing of horizontal wells in unconventional oil and gas reservoirs in China [14], a delayed toe end sliding sleeve for the first stage fracturing of horizontal wells is designed. It is a fracturing sliding sleeve controlled by hydraulic pressure. Its function is to test the pressure integrity of the whole wellbore casing before fracturing and establish the first layer fracturing channel.

The structure of the delay toe end sliding sleeve is shown in Figure 2, which is mainly composed of the upper joint, the lower joint, the outer sleeve, the inner sliding sleeve, the double bus short section, the delay mechanism, the shear ring, the shear pin and the O-ring. The delay opening function of the sleeve is mainly realized by the delay mechanism, which consists of a single valve, a single valve stabilizing device, a current limiting valve and a fixed plug of the current limiting valve. The cavity between the outer sleeve and the inner sleeve is divided into a vacuum cavity and a liquid cavity, as shown in Figure 3. The new pin shear device with special porous shear ring structure has 32 pins, and the total shear pressure can reach 140 MPa, which meets the requirements of high pressure shear. According to the field requirements, the shear pressure can be adjusted by adjusting the number of pins installed. The working principle is that the delay toe end sliding sleeve goes down into the bottom hole with the cementing string at a predetermined position. When the working pressure exceeds the predetermined shear ring shear limit value, the shear ring is cut. Under the action of pressure difference, the inner sliding sleeve moves downward and activates the delay mechanism. At this time, the liquid in the liquid cavity is slowly squeezed into the vacuum cavity. The test time can be changed by adjusting the liquid flow rate. After the test time reaches the predetermined standard time, the inner sliding sleeve moves in place, the sliding sleeve is fully opened and the first fracturing operation is carried out.

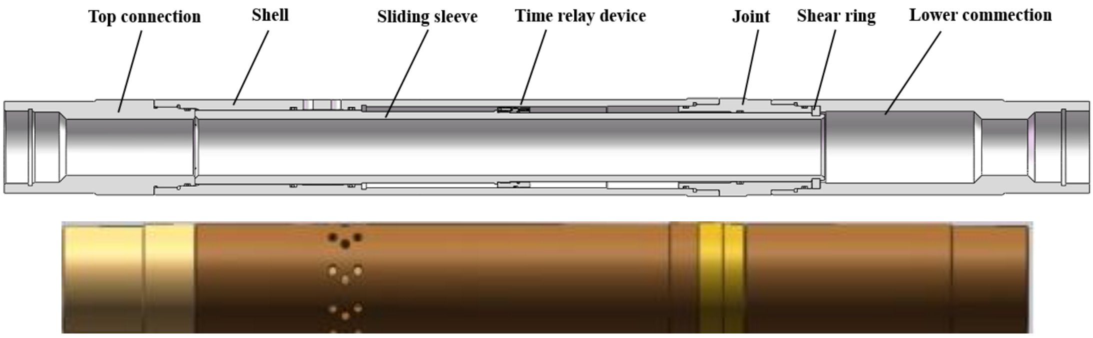


Figure 2 Schematic diagram of toe end sliding sleeve structure

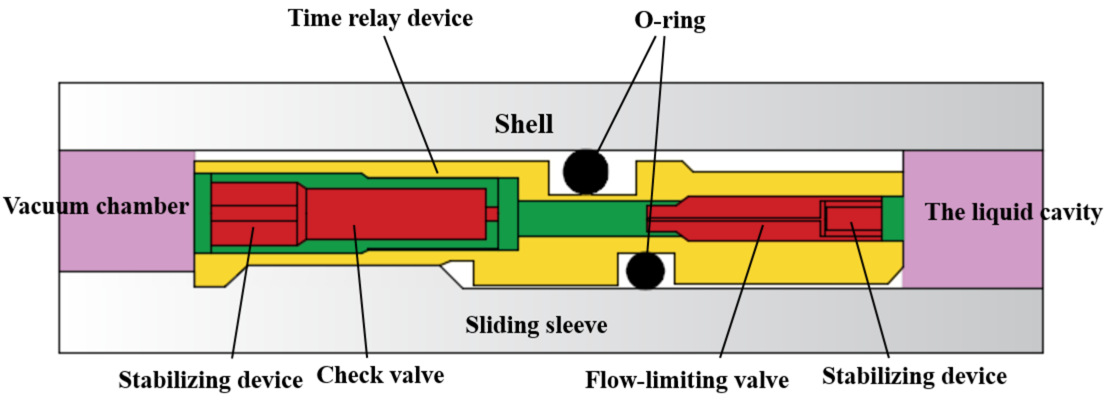


Fig 3 Diagram of delay mechanism

Considering the influence of cement slurry consolidation in the inner wall of the sliding sleeve and entering the sliding sleeve through the sand blasting hole on the opening accuracy and opening performance of the sliding sleeve during downhole operation, special surface treatment was carried out on the inner surface of the sliding sleeve. After treatment, the hardness of the inner surface of the sliding sleeve was greatly increased, and a protective film was formed, so that the cement slurry cannot be consolidated on the inner surface of the sliding sleeve, which greatly improves the opening probability of the sliding sleeve. Surface treatment is also carried out on the sandblasting hole on the outer casing, and the degradable material inclusion layer is covered on the outer side of the main fracturing hole, which can prevent the cementing impurities and cement slurry from entering the sliding sleeve fracture hole. When the sliding sleeve is opened, the internal pressure can break it and communicate effectively with the cement ring and formation, which has no effect on the later layer fracturing construction and oil and gas well production.

3. Laboratory experiments and performance evaluation

In order to verify the basic opening performance, opening pressure precision control performance and delay opening performance of toe-end sliding sleeve, a series of indoor experiments were carried out to evaluate its overall performance.

3.1. Functional opening experiment

At room temperature, the functional opening experiment of toe-end sliding sleeve is carried out to verify its basic opening performance. The experimental process is as follows : only two pins are installed in the shear ring, and the sealing sleeve is used to seal the sand blasting hole of the outer sleeve, and the intelligent hydraulic pressure test system is used to press the sliding sleeve to open. The experimental data are shown in Table 1.

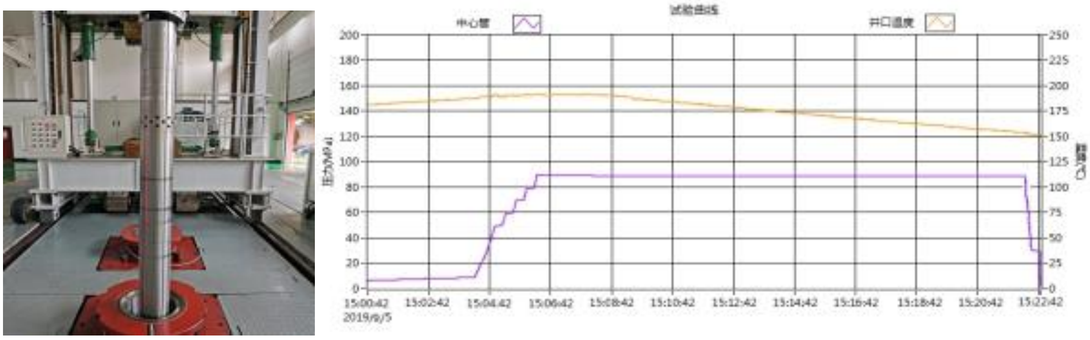
Table 1 Experimental Data on Basic Opening Performance of Sleeve

test types	numbering	design opening pressure /MPa	test pressure /MPa	sleeve travel	open degree /%
Functional opening test	01	12	12.5	110	100
	02	12	12.8	110	100
	03	12	12.2	110	100
	04	12	12.4	110	100

According to the requirements of the experimental process, four experiments were carried out. The experimental results show that the shear pressure value of the pin is high in accuracy and good in stability. The sliding sleeve travels 110 mm and the opening degree is 100 %, indicating that the toe-end sliding sleeve has good basic opening performance.

3.2. High Temperature Overall Performance Experiment

Under the condition of high temperature (150 °C), the experiment was carried out for the overall performance evaluation of the sliding sleeve. The experimental process was as follows : after the sliding sleeve at the toe end was assembled, the lower end was connected with the plug, and the pressure test joint was connected with the high-pressure pipeline of the high-temperature and high-pressure downhole tool experimental system. Firstly, the medium was filled into the tool to exclude air, and the exhaust process was not less than three times. Then, the heating device was started to warm up. When the temperature rose to the experimental temperature, it was kept for 2 – 4 hours. Finally, the pressure device was started, with 10 MPa as the step pressure, and the outer pressure of the sliding sleeve was increased to 70 MPa. At the same time, the inner pressure of the sliding sleeve was increased to 140 MPa, and the pressure was kept and the timing was started until the sliding sleeve was fully opened. The experimental site and experimental curve are shown in Fig. 4.



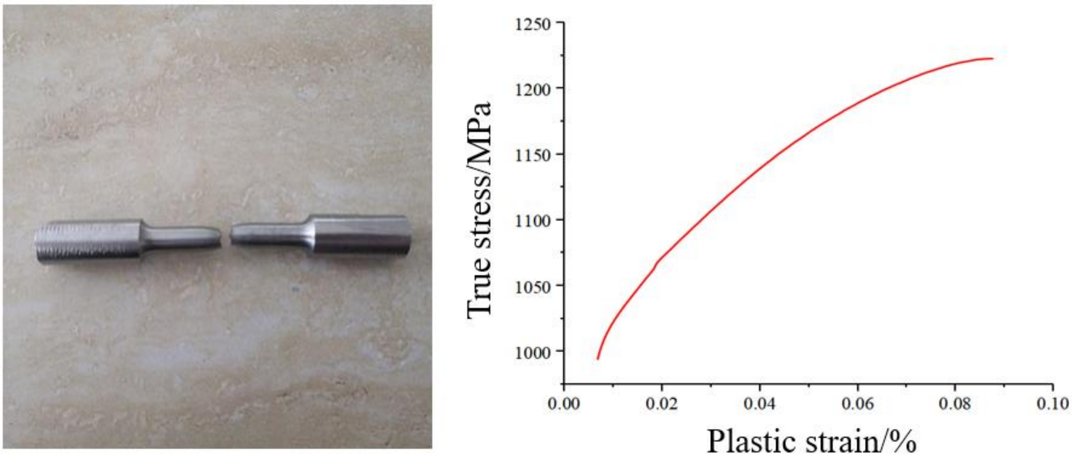
(a) (b)

Figs 4(a)Experimental scene diagram；(b)Experimental diagrams

The experimental results show that the sliding sleeve delay time is 55 min, which fully meets the design requirements. The shear pressure is85.4Mpa, the design pressure is84.5Mpa, the precision error is0.1 %, which meets the requirements of the toe sliding sleeve opening pressure precision control.

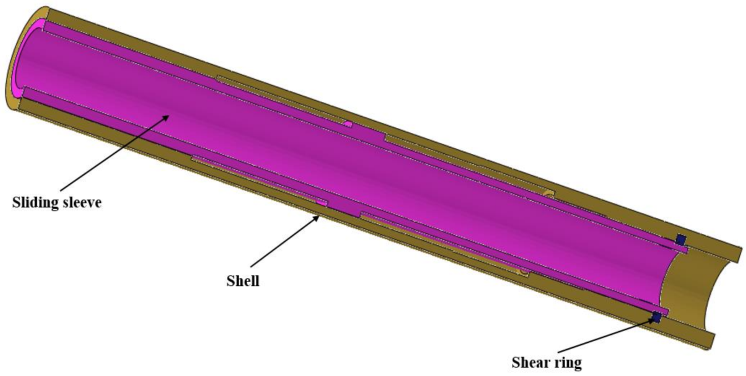
4. Finite Element Simulation

The material of the inner sliding sleeve and outer sleeve of the delayed toe-end sliding sleeve is 35CrMnSiA. The tensile test of the material is carried out. The yield strength of 35CrMnSiA is 987 MPa, and the tensile strength is 1126 MPa. The material object and the stress-strain curve after the tensile test are shown in Fig. 5. The three-dimensional stress model of toe-end sliding sleeve was established by using ABAQUS finite element software, and the opening performance of toe-end sliding sleeve under high pressure was analyzed. The schematic diagram of finite element model is shown in Fig. 6.



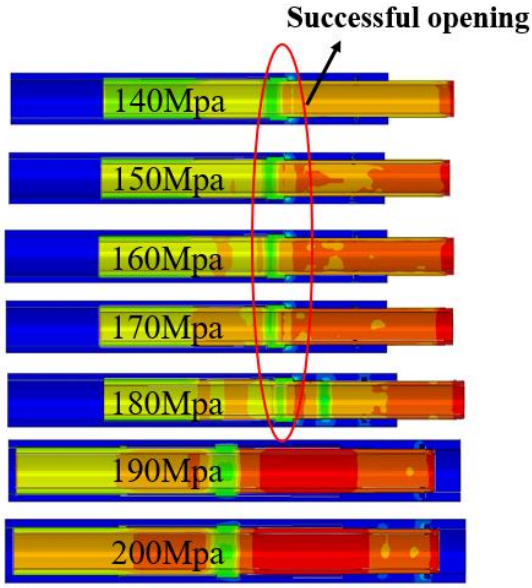
(a) (b)

Figs5 (a)Material drawing after stretching； (b)35CrMnSiA stress - strain curve of material

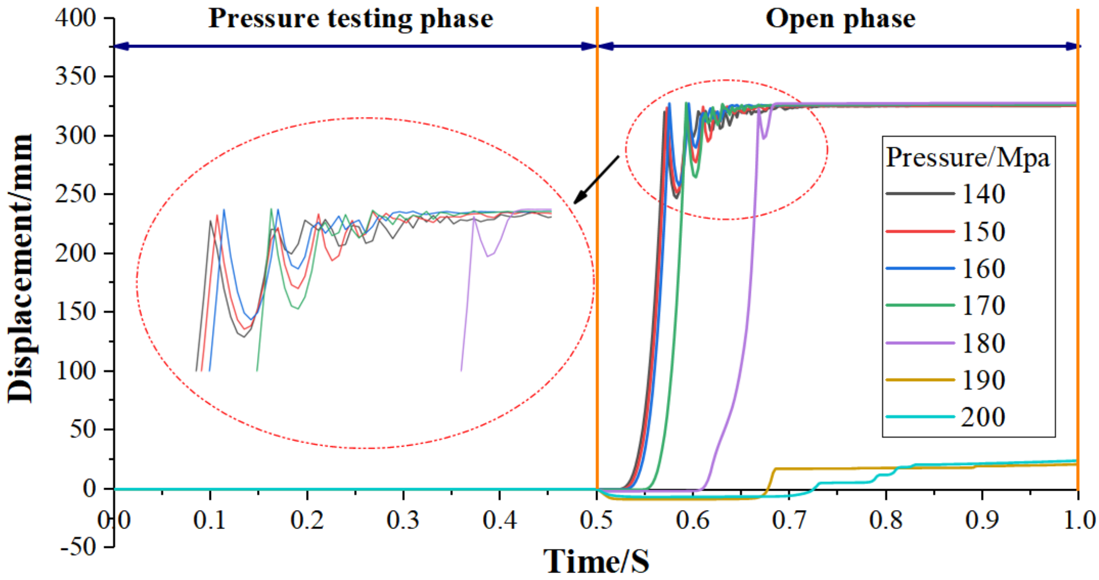


Figs 6 Profile Diagram of Finite Element Model for Toe - end Sleeve

In the finite element analysis, the internal pressure of 140 ~ 200Mpa is applied to the inner surface of the inner sleeve, and then the thrust is applied. The thrust is adjusted according to the magnitude of the internal pressure, and the sleeve can be opened under the thrust. According to the actual situation, complete fixed constraints are applied on both ends of the jacket ; In the internal pressure stage, the axial constraint is applied to the upper end face of the inner sliding sleeve, and the constraint is removed in the thrust stage. Shear ring binding on inner sleeve ; Because the sliding sleeve at the toe end will be fully lubricated before the well, so the friction coefficient of each surface is 0.1. The results of finite element analysis are shown in Figure 7.



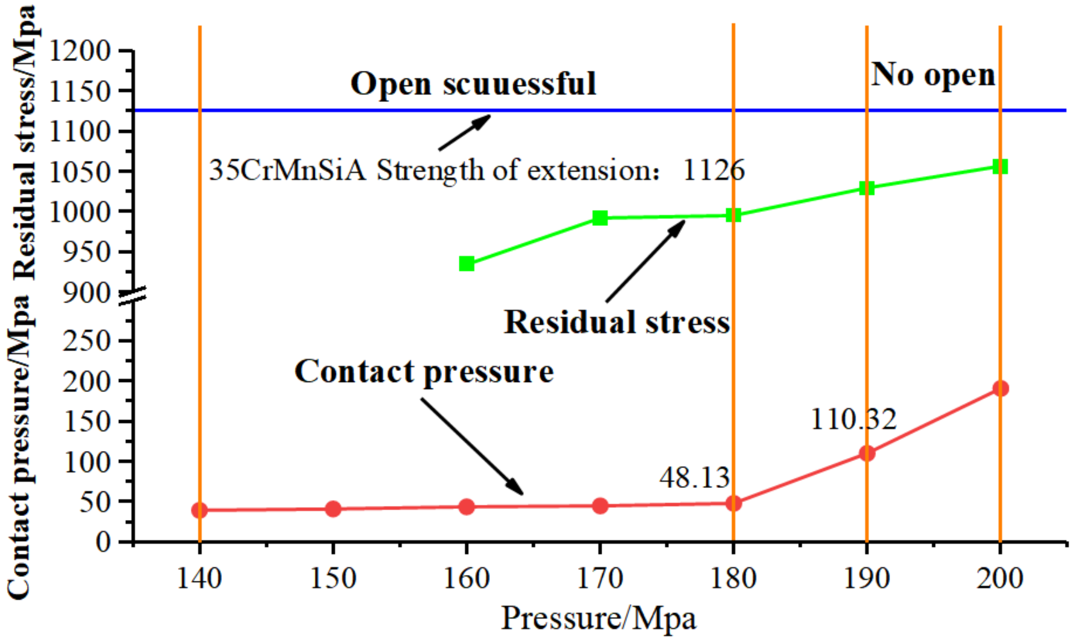
(a)



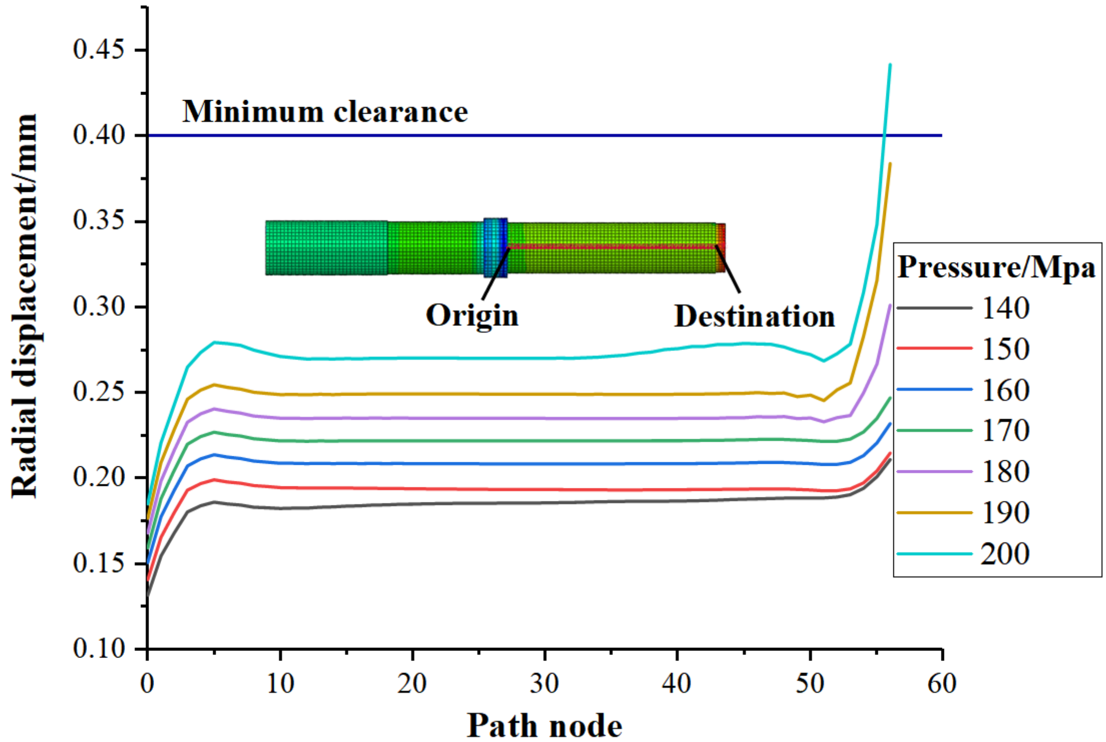
(b)

Figs 7 (a)Cloud chart of finite element analysis results； (b)Displacement diagram of inner sliding sleeve

From Figure 7, it can be seen that under the internal pressure of 140 ~ 180Mpa, the inner sliding sleeve can completely move in place. Under the internal pressure of 190Mpa and 200Mpa, the moving distance of the inner sliding sleeve is very small and cannot be in place. By analyzing the residual stress, contact pressure and radial displacement of the inner sliding sleeve, as shown in Fig. 8, this is because under the internal pressure of 140 – 180 MPa, the residual stress of the inner sliding sleeve is less than the tensile strength of the material, and the radial deformation is small, and the contact pressure is also small. Under the internal pressure of 190Mpa and 200Mpa, the residual stress of the inner sleeve has reached and exceeded the tensile strength of the material. From the diagram, it can also be seen that the contact pressure under 190Mpa is nearly 2.3 times higher than that under 180Mpa, indicating that the radial deformation of the inner sleeve is large, which leads to the increase of the contact pressure and cannot be moved under the thrust.



(a)



(b)

Figs 8 (a)Curves of residual stress and contact pressure of inner sliding sleeve under different test pressure； (b)Radial displacement curve of inner sliding sleeve

Through the finite element analysis, it is concluded that the internal sliding sleeve does not affect its opening performance under the internal pressure below 180 MPa. When the internal pressure exceeds 190Mpa, the radial deformation of the inner sliding sleeve is large, resulting in excessive contact pressure and unable to open normally.

5. Conclusion

Aiming at the first fracturing technology of horizontal wells in unconventional oil and gas reservoirs, a new type of delay toe end sliding sleeve is designed, and the basic opening performance, opening pressure precision control performance and delay opening performance of toe end sliding sleeve are evaluated by laboratory experiments. The results show that the basic opening performance of toe end sliding sleeve is good, the shear pressure error is less than 3 %, and the delay time meets the design requirements. The three-dimensional force model of toe-end sliding sleeve was established by finite element analysis software, and the opening performance of toe-end sliding sleeve under high pressure was analyzed. The results show that the opening performance of toe-end sliding sleeve is not affected under 180 MPa pressure.

As the first fracturing tool of horizontal well instead of traditional perforation fracturing, delayed toe end sliding sleeve can greatly save cost, improve work efficiency and reduce construction risk. However, the research and development of this tool in China is still in the experimental stage, and the cost of using foreign technology is too high. This design is of great significance to the stimulation and efficient development of unconventional oil and gas reservoirs in China.

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ISSN: 2664-9640

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