Reliability analysis of packer locking mechanism based on numerical simulation

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Abstract

The locking device of the packer is a key component to ensure the reliability of the packer. Calculating the operational reliability of the locker has important guiding significance for the design of the locker. Based on the nonlinear explicit dynamic finite element analysis method, the finite element calculation model of the locking process of the packer locking device is established. The stress distribution of each component of the locking structure is analyzed, and the ultimate setting pressure and limit conditions are calculated respectively. Stress distribution and displacement distribution of the packer under pressure. After analysis, the locking device calculated in this paper is safe and reliable, which provides a certain basis for the design of the locking device.

Keywords

Packer, locking mechanism, lock ring, finite element analysis.

1. Introduction

The packer is a key device for separating the formation and realizing the processes of staged fracturing, oil well water blocking and layered water injection. The packer is hydraulically compressed by the rubber cylinder and relies on the contact pressure between the rubber cylinder and the sleeve. After the hydraulic compression is completed, the position of the rubber cylinder is fixed by the locking device to provide a supporting force for the sealing performance of the packer, which is one of the key structures of a packer. Once the packer locking device fails, it will cause the packer to fail to set up, affecting a series of subsequent construction operations. Therefore, calculating the locking force of the packer is of great significance for improving the safety of the packer. Based on the finite element method, the finite element model of the locking force calculation of the locking device is established, which verifies the locking reliability of the locking device under the conventional setting pressure and the limit working condition, which is reasonable for the packer locking device. The basis for use is provided.

2. Locking device principle

The locking mechanism adopts an annular body, which is called a lock ring. The inner side of the lock ring has tooth distribution, and the contact end with the upper rubber tube seat is designed as a slope, which can prevent the upper rubber sleeve from retreating, and can also convert a part of the axial force into the radial force of the lock ring, and strengthen the lock ring and the Central tube. Radial locking effect. During assembly, the locking ring is nested in the inner groove of the upper rubber cylinder seat. When the packer is set, the connecting body that is screwed with the upper rubber cylinder seat pushes the locking ring downward, and the upper cone pushes the radial movement of the slip. The final slip and the sleeve are in contact with each other to achieve the setting; after the setting load is removed, the upper cylinder holder pushes the locking ring teeth and the teeth on the Central tube to engage and lock under the elastic force of the upper rubber cylinder. Prevent the rubber sleeve from retreating, thus ensuring the anchoring effect of the packer slip.

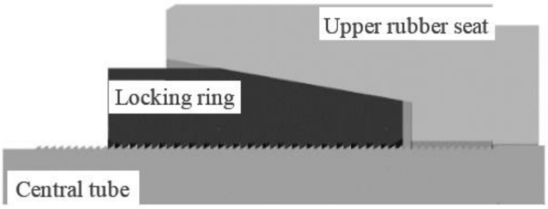


Fig.1 Locking structure working diagram

3. Structural mechanics analysis of locking device

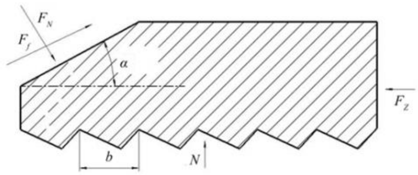


Fig.2 Lock ring compression process

When the packer locking mechanism is working, the wedge surface of the lock ring is in contact with the wedge surface of the upper rubber cylinder seat, and the lock ring is deformed by pressure and meshes with the teeth of the Central tube. Fig.2 shows the compression process of the lock ring. During operation, the rubber cylinder seat is repelled by the rubber cylinder and transmitted to the lock ring. The resilience can be decomposed into a positive pressure FN and a friction force Ff along the wedge surface. Under the action of positive pressure and friction, the lock ring exhibits axial displacement and radial compression. The radial compression load F of the lock ring and the wedge surface of the lock ring are related to the positive pressure FN and the wedge surface inclination angle α, which is :

$$F = F_N \cos\alpha \tag{1}$$

The 6-piece lock ring is compressed under the action of the positive pressure FN of the upper cylinder seat, so that the lock ring produces different internal forces in each section.When the packer locking mechanism is working, the rebound resilience of the rubber cylinder is applied to the upper rubber cylinder seat and then transmitted to the lock ring, and the axial load is converted into positive pressure and friction force through the wedge-shaped surface of the lock ring, and the lock can be obtained by static mechanics. Ring balance equation:

$$N = F_N \cos\alpha - F_f \sin\alpha \tag{2}$$

$$F_Z = F_N \sin\alpha + F_f \cos\alpha \tag{3}$$

among them

$$F_f = F_N \tan\varphi \tag{4}$$

$$F_Z = W_Z (360 - 2\theta_0) / 360 \tag{5}$$

Where: α is the locking ring wedge angle, °; φ is the friction angle of the locking ring wedge surface and the locking ring sleeve, °; N is the radial load of the center tube to the locking ring, N; FZ is the center tube pair lock The axial load of the tight ring, N; WZ is the resilience of the locking ring, N.

The simultaneous (2) to (5) are obtained：

$$N = \frac{W_Z (360 - 2\theta_0)}{360 \tan(\alpha + \varphi)} \tag{6}$$

Therefore, the contact stress σ between the lock ring which is fully locked and the Central tube is:

$$\sigma = \frac{N}{A} = \frac{W_Z}{\pi D_Z bm \tan(\alpha + \varphi)} \tag{7}$$

In the above formula: A is the contact area of the lock ring tooth and the Central tube, mm2; DZ is the outer diameter of the Central tube, mm; b is the tooth width of the lock ring, mm; m is the number of teeth of the lock ring. The shear stress τ of the lock ring is:

$$\tau = \frac{F_Z}{A} = \frac{W_Z}{\pi D_Z bm} \tag{8}$$

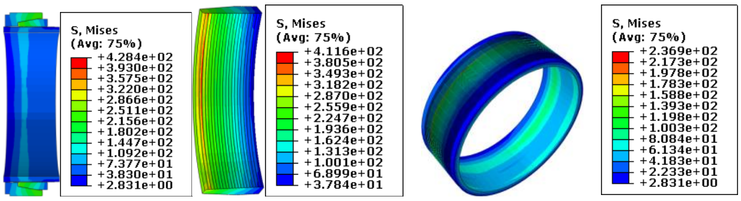
The packer lock ring is compressed by the upper rubber sleeve and locked by the teeth and the Central tube. The equations (7) and (8) show the contact stress and shear stress and the lock ring tooth shape and the lock ring wedge angle. The outer diameter of the packer Central tube is related to the axial pressure experienced by the lock ring.

4. Finite element model establishment

Taking a certain type of packer as the research object, SolidWorks is used to carry out the geometric modeling of the packer locking mechanism. According to the actual construction load of the packer during the setting process and during the actual use, the design sealing pressure is 18MPa. Based on the finite element method, the finite element calculation model of the three-dimensional Central tube-locking ring-upper cylinder seat is established. The Central tube was fixed in the model and an ultimate set pressure of 18 MPa was applied to the right side of the cartridge seat. When the finite element model is established, the material of the lock ring, the Central tube and the rubber sleeve is 42CrMo, the elastic modulus is 212000MPa, the Poisson's ratio is 0.28, and the yield limit is 950MPa.

4.1 Analysis of calculation results

The structure and component stress cloud diagram of the lock ring locking the Central tube and being stabilized is shown in Fig.3:



(a) Locking mechanism (b) Lock ring (c) Central tube

Fig.3 Post-stabilized structural stress cloud

Fig.3(a) shows that the structural stress distribution is relatively uniform and there is no obvious stress concentration. Since the contact area of the upper rubber cylinder seat and the lock block is close to the upper part of the lock block, and the lower part of the lock block is suspended, the stress above the contact area of the lock ring tooth and the lining tooth is generally large, and gradually decreases downward.

The overall stress distribution of the lock ring is relatively uniform, and the stress distribution of each block is basically the same. Therefore, one of the lock blocks is selected for analysis. As shown in Fig.3(b), the stress is mainly concentrated on the upper three teeth of the upper part, that is, near the boss in the upper rubber cylinder seat, and is uniformly decreased downward. The reason is that due to the driving force of the upper rubber cylinder seat, the six locking rings will gather toward their center, resulting in contact pressure between each locking ring, and the contact pressure is in the upper rubber cylinder seat due to the lower hanging of the locking ring. The largest near the boss, the maximum stress of the lock ring is located in this area, and its value is 411.6MPa.

It can be seen from Fig.3(c) that the stress is mainly concentrated in the contact area between the lock ring and the Central tube tooth, and the maximum stress is located at the uppermost portion of the contact area with the lock ring, and its value is 236.9 MPa, and gradually decreases downward.

4.2 Stress distribution analysis of lock ring

By analyzing the stress distribution of the lock ring during the locking process, it can provide a basis for designing a more reasonable lock ring structure. For convenience of description, the number of the locking ring is sequentially numbered from the left side of the lock ring to the right side in the order of the first tooth, the second tooth, the third tooth, ..., the twentieth tooth; each tooth is sequentially from top to bottom. Select nodes, numbered 1, 2, 3, ..., 20, as shown in Fig.4:

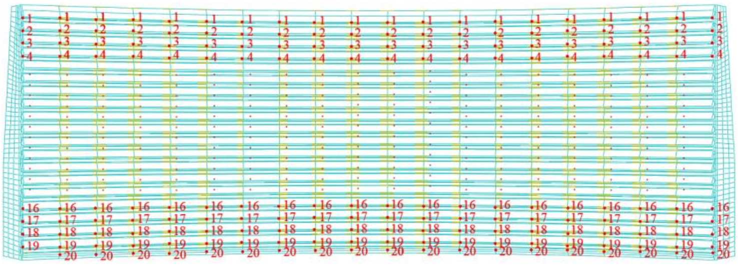
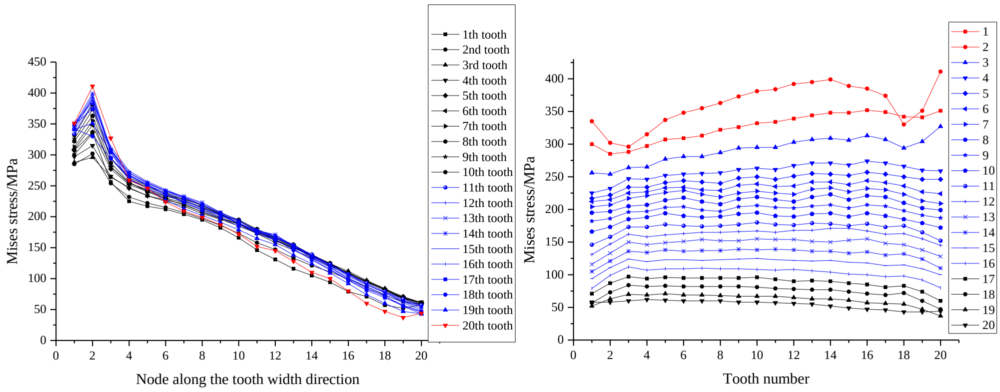


Fig.4 The tooth number and node number of the lock ring

According to the red dot area stress in the above figure, two curves are drawn after the lock ring is locked and stabilized: (1) Fig.5(a) shows the stress distribution of different nodes on each tooth; (2) Fig.5(b) shows the tooth width direction. The stress distribution of each node on different teeth.



(a) Different node stresses on each tooth (b) Different tooth stresses of the same node

Fig.5 Mises stress distribution diagram after lock ring locking and voltage regulation

It can be seen from Fig.5(a) that for the same tooth, the stress increases first and then decreases along the tooth width direction, and the amplitude decreases after the node 3, wherein the maximum stress is concentrated on the second tooth due to the first tooth and The twentieth tooth design height is smaller than the remaining teeth, and the remaining tooth heights are equal, so the first tooth receiving area is smaller than the second tooth; under the driving force of the upper rubber cylinder seat, the six pieces of locking ring will gather toward the center of the circle, resulting in each piece There is contact pressure between the lock rings, and because the lower part of the lock ring is suspended, the stress is largest near the upper part of the lock ring and evenly decreases along the lower part.

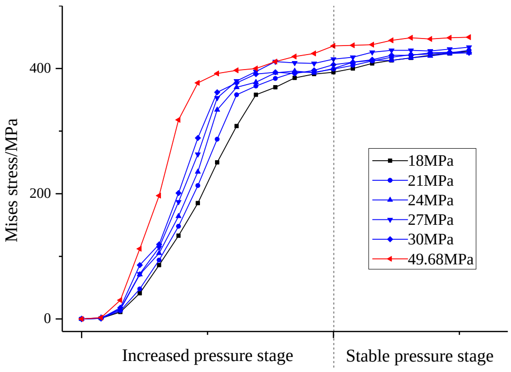
It can be seen from Fig.5(b) that except for nodes 1~3, the other nodes have uniform stress distribution along the tooth number. The stress growth of the same tooth node is stable and there is no stress concentration. Node 2 is the largest stress node on all teeth except the eighteenth tooth, with a maximum of 411.6 MPa.

The stress distribution of the Central tube tooth in contact with the locking ring tooth is similar to that of the locking ring tooth. The stress value of the Central tube tooth in the contact area of the ring tooth of the ring is the same as the maximum stress on the Central tube, which is 236.9.

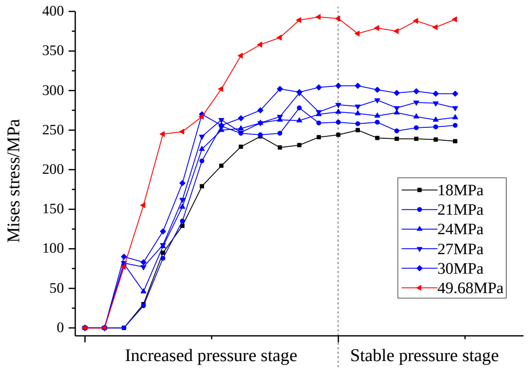
5. Influence of different sealing forces on the locking mechanism

The above process studies the working condition of the lock ring when the hydraulic pressure of the seal is 18MPa. This section will compare the influence of different seal hydraulic pressure on the locking force of the lock ring, and consider the limit of the comprehensive influence of the set pressure and formation pressure. The hydraulic pressures of the set seals were 18 MPa, 21 MPa, 24 MPa, 27 MPa, 30 MPa, and 49.68 MPa (maximum setting pressure and extreme working pressure).

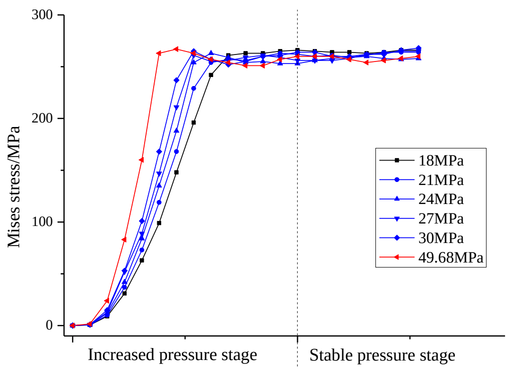
The curves of the maximum stress of the lock ring under different hydraulic seals, the maximum stress of the Central tube, the maximum stress of the rubber sleeve, and the slip of the lock ring with time are shown in Fig.6.



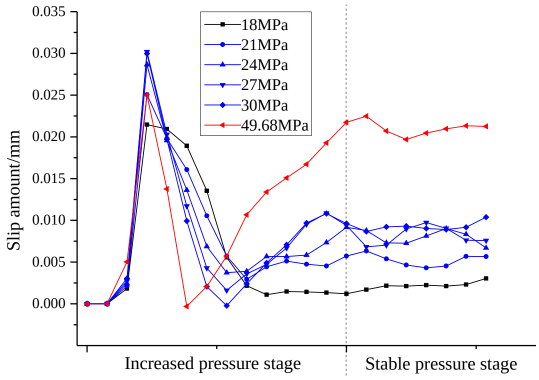
(a) Lock ring stress maximum



(b) Central tube stress maximum



(c) Upper rubber cylinder stress maximum



(d) Lock ring slip

Fig.6 Curve of stress maxima/slip amount with time under different hydraulic pressures

It can be seen from Fig.6(a) that the maximum stress curve of the lock ring under each set hydraulic pressure is similar. In the early stage of the pressurization stage, the maximum stress of the lock ring increases with the increase of the seal hydraulic pressure at the same time, and because of the Central tube There is a small amplitude stress jitter in the contact change of the tooth; in the late stage of the pressurization phase and in the voltage stabilization phase, the maximum stress variation of the lock ring under each seated hydraulic pressure gradually decreases and eventually stabilizes, and the maximum stress value after stabilization does not differ. Big. Moreover, the maximum stress of each hydraulic seal ring is much smaller than its allowable stress, so the strength of the lock ring is safe and reliable.

It can be seen from Fig.6(b) that the maximum stress of the Central tube under different hydraulic pressures will experience a different range of stress jitter due to the contact change with the lock ring at the initial stage of the pressurization stage, after which the stress maximum continues to increase. Until the top of the lock ring is in contact with one end of the boss in the upper rubber cylinder seat, the lock ring cannot continue to gather, and the Central tube stress reaches the maximum; and the change is relatively stable in the late stage of the pressurization phase and the voltage stabilization phase, and the Central tube stress is maximum at the same time. The value increases as the hydraulic pressure of the setting increases. And the maximum stress of each seated hydraulic Central tube is less than its allowable stress, so the Central tube strength is safe and reliable.

It can be seen from Fig.6(c) that the maximum stress curve of the rubberized cylinder seat under each setting hydraulic pressure is similar. In the early stage of the pressurization stage, the maximum stress of the rubberizing cylinder seat increases with the increase of the sealing hydraulic pressure at the same time; During the late stage of the pressurization phase and the voltage regulation phase, the maximum stress variation of the rubber cylinder seat under each set hydraulic pressure gradually decreases and eventually stabilizes. The maximum stress values after stabilization are almost equal. Moreover, the maximum stress of the rubber sleeve under each hydraulic pressure is much smaller than the allowable stress, so the strength of the rubber cylinder is safe.

Fig.6(d) reflects the locking performance of the lock ring under various sealing pressures. It can be seen that in the early stage of the pressurization stage, the lock ring teeth rebound after the upward contact with the Central tube teeth under the driving force of the upper rubber ring seat; In the late stage of the pressurization phase and in the voltage stabilization phase, as the hydraulic pressure of the set seal increases, the lock ring is partially compacted due to the compaction of one end of the rubberized cylinder seat at one end, and the lock ring on the side of the boss in the upper rubber cylinder seat is approached. The teeth mesh with the Central tube teeth to a greater extent than the suspended ends, so the amount of slip of the lock ring increases as the hydraulic pressure of the seal increases. Moreover, the sliding amount of each hydraulic sealing ring can be neglected, so the locking ring locking ability is stable.

6. Conclusion

In this paper, based on the finite element analysis theory, based on the finite element analysis theory, the finite element analysis of the components of the locking structure is carried out, and the stress distribution of each component is obtained. The focus is on the strength check and safety reliability assessment of the lock ring, and the following conclusions are drawn:

(1) Under the design of the sealing pressure, the maximum stress value of the locking device appears on the lock ring, and its maximum stress value is 428 MPa, which can meet the actual construction requirements.

(2) Under the action of the extreme working conditions, the stress distribution law of the locking device is similar to that under the extreme setting pressure, and as the pressure increases, the stress increase decreases, and the maximum stress value is 450 MPa, which can meet the actual construction requirements.

(3) The displacement under the action of the ultimate pressure is about 0.02 mm, and the displacement change is small, which can meet the requirements of self-locking performance.

(4) Under the action of designing the sealing pressure and the extreme working condition pressure, the maximum stress value of each component is less than its allowable stress value, and the locking ring teeth can firmly bite the Central tube teeth without backing or slipping. The strength of the ring structure is checked and the locking performance is reliable and stable.

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