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Research on Depth of Casing Anchored by Hydraulic Anchor Barrel Slip

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Abstract

Hydraulic anchors are often used in acidized fracturing tubing strings in deep and high temperature wells in oilfields. Their main role is to anchor tubing strings and anchor packers, effectively preventing string deformation or packer failure. During the anchoring process of the hydraulic anchor, the single hydraulic anchor mandrel has the characteristics of small force area, large stress and easy damage, and there will also be large damage to the casing; the overall force area of the mandrel is also relatively small, and the anchor poor effect. In this paper, a barrel slip is designed, which has a large force area of the claws and good anchoring effect, which can effectively reduce the damage to the casing. A combination of mechanical analysis, finite element analysis, and experiment was used to conduct the research. The results showed that the depth of the barrel slip stuck into the casing increased with the increase of pressure load; under the same load, the depth is related to the parameters such as the claw tooth apex angle and the slip angle. Due to the uneven force of the claws, the depth of the slip stuck into the casing is also different. Generally speaking, due to the unidirectional load of the slip, the depth of the slip stuck into the casing is greater. The barrel slip and the casing have a large bearing area. The slip can effectively ensure the working performance of the hydraulic anchor while reducing the damage to the casing.

Keywords

Hydraulic anchor; Barrel Slip; Casing; Depth.

1. Introduction

Hydraulic anchors are often used in acidified fracturing tubing strings in deep and high temperature wells in oilfields. Their main role is to anchor the tubing string [1] and the anchor packer, effectively preventing the deformation of the tubing string or the failure of the packer. During the process of obtaining oil gas flow or effluent by acid fracturing in oil fields, the hydraulic anchor is activated under the pressure difference between the tubing and the casing, and the anchor claws are stuck into the casing under the effect of the piston force. This increases the reliability of anchoring. During the process of anchoring the casing or after anchoring the casing, the single hydraulic anchor mandrel has the characteristics of small force area, large stress and easy damage, and there will also be large damage to the casing; the overall force area of the claws is also relatively small, and the anchoring effect is poor.In recent years, many scholars have performed elastoplastic contact analysis on the mandrel anchoring sleeves.Literature[2] established a mechanical model of claws anchoring casing based on the law of conservation of energy, and compared and analyzed the maximum depth of the conventional hydraulic anchor claws stuck in P110 and TP140. Literature [3] developed a new type of anchor slip, designed a slotted structure perpendicular to the slip direction, and analyzed and calculated the depth of the slip stuck in casing at different tooth angles, and studied its stress

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distribution law. The slip can solve the problem that the slip is extended in advance and the run-in is blocked.Literature [4] applied Matlab to study the regularity of the depth of the conventional packer slips stuck in the casing. Literature [5] established a cone-slip-casing contact model, and used ANSYS software to analyze the depth and maximum stress of the slip into the casing.

In summary, there is not much research on the problem of claws stuck in casing. The depth of claws stuck in casing under the same setting pressure is relatively large. It mainly provides design and research ideas in terms of tooth angle and setting parameters.To this end, the author has designed a barrel-shaped slip, which has a large force area of the claws and good anchoring effect. The surface nitriding treatment not only ensures the hardness of the minions (HRC50-60), but also preserves the overall toughness.,which,effectively reduce damage.

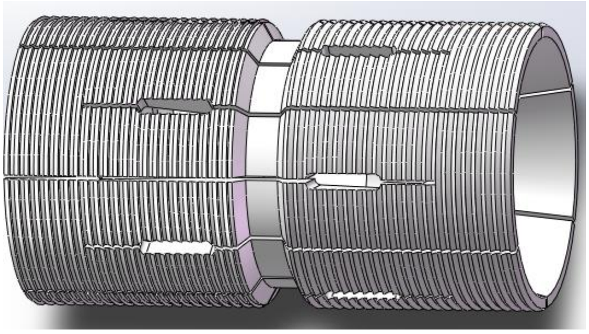

Figure 1 Schematic diagram of barrel slip

2. Mechanical model

Under the action of the setting pressure difference, the claws of the slips will gradually get stuck in the casing. In this process, the contact stress will increase and the casing will deform elastically and plastically. Since the force of each claw of the slip is uneven, one claw of the slip is usually studied.As shown in Figure 2, the claw width is b, the apex angles are η_1 and η_2, and the depth of claw stuck in casing is h.

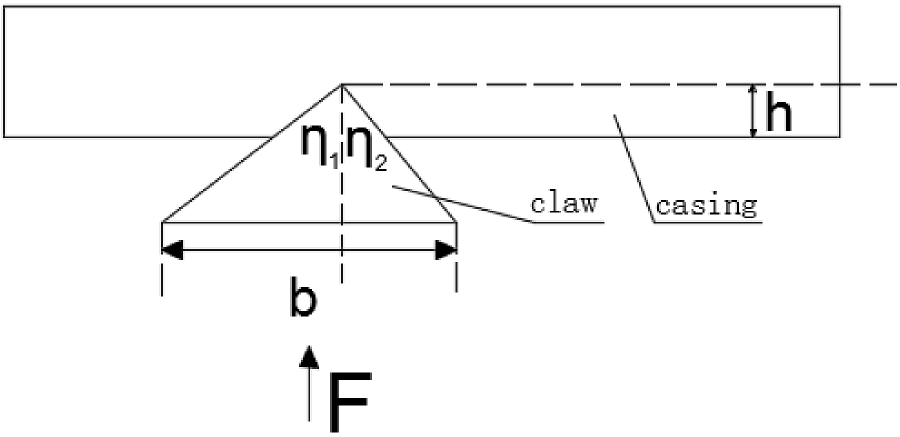

Figure 2 Schematic diagram of contact between slip and casing

Under the action of the force F in the vertical direction, the slip claw is in contact with the casing upward, and the pressing force P can be expressed as follows:

$$P = \psi A_{ca} \sigma_{jy} \tag{1}$$

Among them, ψ is the coefficient of the shape of the slip claw, take $\psi = 0.73$; $A_{ca} = ktb_x$, k is the contact coefficient, t is the wall thickness of the casing, b_x is the width of the claw stuck into the casing; σ_{jy} is the ultimate compression strength of the casing.

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When the depth of the claw stuck into the casing is h, the width of the claw stuck into the casing is $b_x = h(\tan\eta_1 + \tan\eta_2)$, and the pressing force p_x can be expressed as follows:

$$P_x = \psi k t \sigma_{jy} h(\tan\eta_1 + \tan\eta_2) \tag{2}$$

The claw has kinetic energy under the action of vertical forces.The E_k can be expressed as follows:

$$E_k = F(L+h) \tag{3}$$

Where L is the radial distance between the slip claw and the casing.

During the process of the slip stuck into the casing, the work by the resistance between the claw and the casing is E_P.The E_P can be expressed as follows:

$$E_P = \int_0^h P_x d_x \tag{4}$$

From the law of conservation of energy,The relationship of E_k and E_p can be expressed as follows:

$$E_k = E_P \tag{5}$$

The joint solutions (2)-(5) can be obtained:

$$h = \frac{F + \sqrt{F^2 + 2FL\psi k t \sigma_{jy}(\tan\eta_1 + \tan\eta_2)}}{\psi k t \sigma_{jy}(\tan\eta_1 + \tan\eta_2)} \tag{6}$$

It can be seen from the above formula that the depth of the claws stuck into the casing increases non-linearly with the increase of the force. Generally, the greater the force, the greater the depth, and the greater the damage to the casing. Therefore, when designing, the reasonable technical parameters of the claws should be selected according to the maximum working pressure of the tool.

3. Finite element method simulation analysis

Oil casings are thin-walled parts. When the tool is setted, the slip claws are forced into the inner wall of the casing by the piston force. The damage of the slip to the casing increases with the increase of the depth . Therefore, the depth of the claws stuck in casing should be reduced as much as possible without the failure of the anchoring of the slip. The force and the depth of each of the claws are different. Solving the depth is cumbersome and the accuracy cannot be guaranteed. The finite element method is used to study this problem.

Because the slip structure is asymmetric structure, the number of claws is large, and there are complex contact nonlinear problems in the simulation process. Therefore, the LS-DYNA module of ANSYS was selected to analyze the problem of slip stuck in the casing.

3.1 Finite element model and material parameters

As shown in Figure 3, the finite element model consists of an upper cone, a inferior cone, slips and casing. Among them, the slip claw tooth apex angle η is 85 °, and the slip tilt angle α is 15 °. The cone and the slip are in frictional contact, the slipper teeth are in frictional contact with the inner wall surface of the casing, and the outer surface of the casing is fixed. The inferior cone pushes the slip anchor anchoring casing under the setting pressure, and the upper cone is fixed.

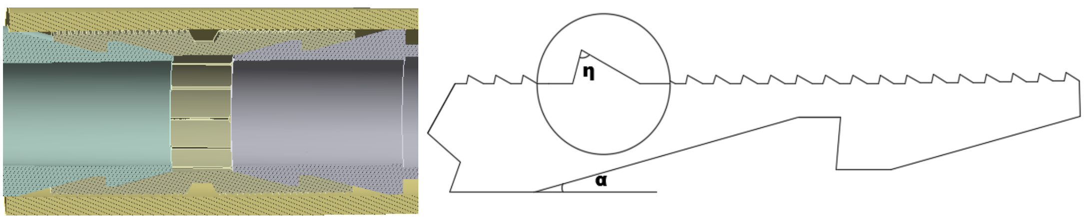

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Figure 3 Finite element model

The material of the slips and cones is 40CrNiMo. The surface of the slips' teeth is nitrided to ensure the hardness of the surface of the teeth (HRC50-60), which improves the toughness and wear resistance. The casing is a P110 petroleum casing, which belongs to a high anti-extrusion casing [6]. The specific material parameters of slips, cones and casing are shown in Table 1.

Table 1 Table of material parameters

	Elastic modulus E（MPa）	Poisson'sratio μ	Yield strength （MPa）
slips, cones	2.15e5	0.25	1903
casing	2.0e5	0.26	758

3.2 Finite element analysis

As the geometrical features of the tip of the slip claws are relatively sharp, there will be more serious penetration problems during contact with the inner wall of the casing. Therefore, the accuracy of the results of contact calculation directly defined using the contact wizard that comes with ANSYS software cannot be guaranteed. Now we use LS-DYNA's Keyword Snippet to define contact. The main operation purpose of the instruction is to increase the contact stiffness [7] of the contact pair and the node detection frequency to reduce the penetration value reasonably. The smaller the contact pair penetration value, the more accurate the calculation result, but the convergence difficulty will increase accordingly. Insert the named set to name the contact object. The inner wall surface of the casing is named set 1. The outer surface of the claw manipulator is named set 2. The two cones are named set 3 and named set 4. The slip is named set 5. The contact commands of the inner wall surface of the casing and the outer surface of the claws are shown in Figure 4; the contact commands of the cones and slips are shown in Figures 5 and 6.

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Commands
$   Keyword Snippet
$   Do not leave any unintentional empty lines in this editor
*CONTACT_NODES_TO_SURFACE
$     1SSID     2MSID     3SSTYP     4MSTYP    5SBOXID    6MBOXID       7SPR       8MPR
          2         1          4          0                                1          1
$       1FS       2FD        3DC        4VC       5VDC    6PENCHK        7BT        8DT
        0.1       0.1          0          0         10
$      1SFS       2SFM       3SST       4MST      5SFST      6SFMT       7FSF       8VSF
         10          1
$     1SOFT   2SOFSCL    3LCIDAB    4MAXPAR     5SBOPT     6DEPTH     7BSORT    8FRCFRQ
          2                                          3          5         15
```

Figure 4 The contact commands of the inner wall surface of the casing and the outer surface of the claws

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Commands
$   Keyword Snippet
$   Do not leave any unintentional empty lines in this editor
*CONTACT_ONE_WAY_SURFACE_TO_SURFACE
$     1SSID     2MSID     3SSTYP     4MSTYP    5SBOXID    6MBOXID       7SPR       8MPR
          5         3          2          2                                1          1
$       1FS       2FD        3DC        4VC       5VDC    6PENCHK        7BT        8DT
        0.1       0.1          0          0         10
$      1SFS       2SFM       3SST       4MST      5SFST      6SFMT       7FSF       8VSF
         10          1
$     1SOFT   2SOFSCL    3LCIDAB    4MAXPAR     5SBOPT     6DEPTH     7BSORT    8FRCFRQ
          2                                          3          5
```

Figure 5 The contact commands of upper cone and slip

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Commands
$   Keyword Snippet
$   Do not leave any unintentional empty lines in this editor
*CONTACT_ONE_WAY_SURFACE_TO_SURFACE
$     1SSID     2MSID    3SSTYP    4MSTYP   5SBOXID   6MBOXID      7SPR      8MPR
          5         4         2         2                             1         1
$       1FS       2FD       3DC       4VC      5VDC   6PENCHK       7BT       8DT
        0.1       0.1         0         0        10
$      1SFS      2SFM      3SST      4MST     5SFST     6SFMT      7FSF      8VSF
         10         1
$     1SOFT   2SOFSCL   3LCIDAB   4MAXPAR    5SBOPT    6DEPTH    7BSORT   8FRCFRQ
          2                                       3         5
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Figure 6 The contact commands of inferior cone and slip

3.2.1 Analysis results

Figure 7 is a Von-Mises stress cloud diagram of slips and casing under a load of 70 MPa. It can be seen from the figure that the slip is gradually anchored by the push of the inferior cone, and the stress of the slip is mainly concentrated at the sharp corner of the slip. Its maximum stress is 2182.7 MPa, which exceeds the material's yield limit of 1903 MPa. Plastic deformation will cause sharp corners to be rounded, and the slip joints will not be ideal sharp corners after actual processing, but will have a certain angle. The rounded corners of the curvature will not affect the overall expansion and recovery of the slip.

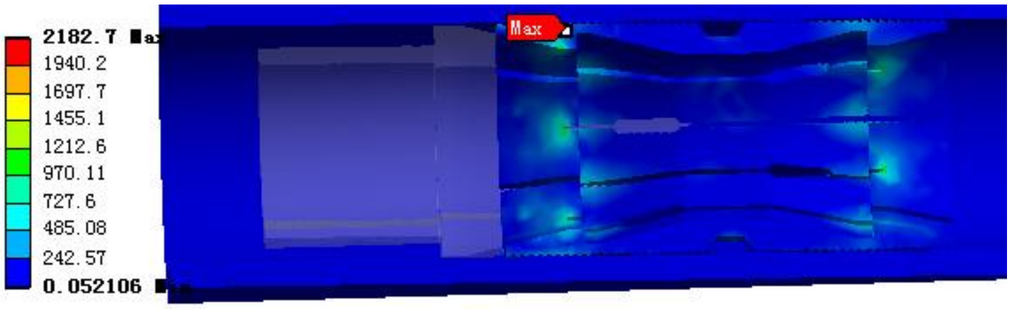

Figure 7 Von-Mises stress cloud diagram

Figure 8 is a displacement cloud diagram of the slip claws stuck into the casing under a load of 70 MPa. It can be seen from the figure that: due to the slip being loaded in one direction, that is, the inferior cone pushes the slip and the upper cone is fixed, the depth of the stuck side of the casing is obviously greater than the non-loaded side. The maximum insertion depth is 0.24mm. Compared with similar literature, the depth of the slip stuck in the casing is significantly reduced, which can effectively protect the casing.

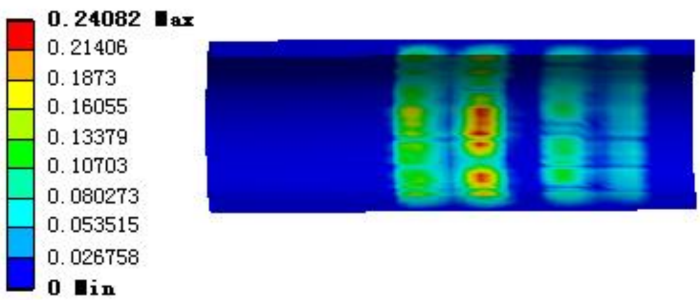

Fig. 8 Cloud displacement of slip stuck in casing

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3.2.2 Effect of the apex angle of the slip teeth on the depth

The apex angles of the claw teeth η are 75 °, 80 °, 85 °, 90 °, and 95 °, and a pressure load of 20-70 MPa is applied for research. The displacement cloud diagram of the casing is shown in Figure 9.

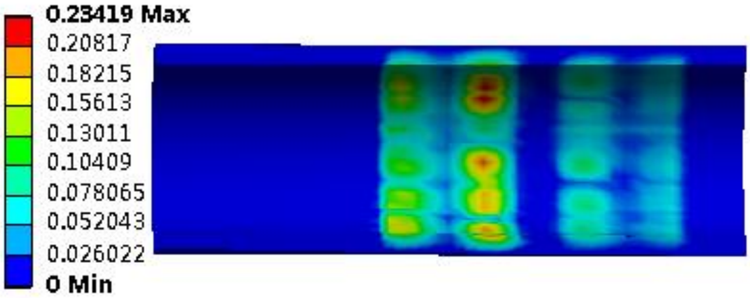

Figure 9 Displacement cloud diagram of the casing at 70MPa and apex angle of 80 °

Figure 10 is a curve of the depth of the slip stuck into the casing under different apex angles. The greater the pressure load, the greater the depth . Theoretically, the smaller the apex angle of the claw teeth, the easier it is for the slip to be inserted into the casing, and the depth will be greater. It is because the tip angle of the teeth is too small, which results in excessive local stress on the claws.The plastic deformation of the top of the claws is not conducive to be stuck into the casing.

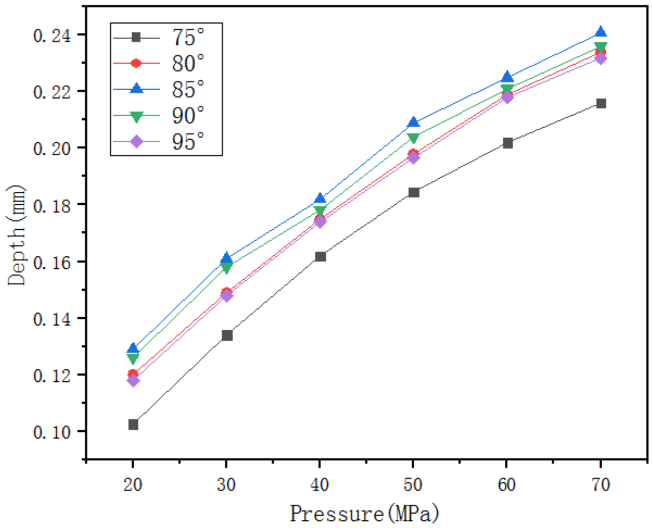

Figure 10 Depth curve of slip stuck into the casing under different apex angles and loads

3.2.3 Effect of the slip tilt angle on the depth

Now select the tilt angle α of the claws 5 °, 10 °, 15 °, 20 °, and apply a pressure load of 20-70MPa for research. The results are shown in Figure 11. As can be seen from the figure, the depth increases with the increase in pressure load; the depth increases with the increase of the tilt angle, but considering that the hydraulic anchor needs to bear the axial load.So the slip tile angle should not be too large.

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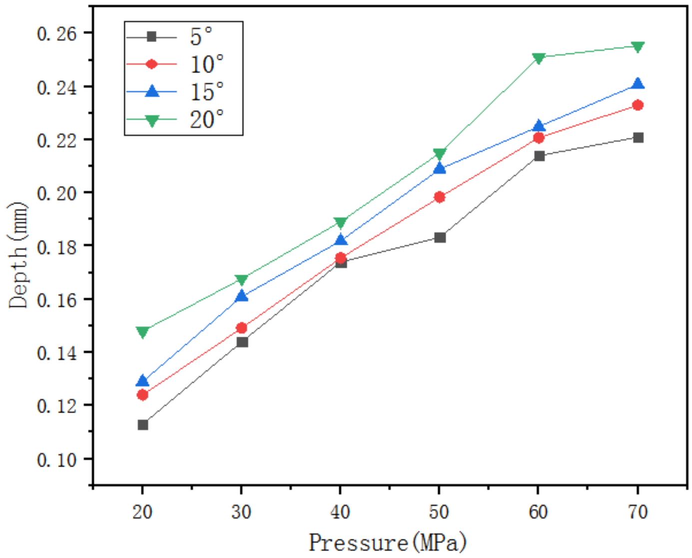

Fig. 11 Depth curve of slip stuck into the casing under different tilt angle and load

4. Performance test

In the foregoing, the establishment of the cone-slip-casing mechanical model and the finite element simulation analysis have been completed. From the results of the finite element analysis, it can be concluded that the depth of the barrel slip stuck into the casing is small, which can effectively protect the casing, but the depth affects the anchoring effect of the slip. If the depth is too small, it is not good for the hydraulic anchor to anchor positioning. For the confirmation of the accuracy of the simulation results, performance tests are used to verify the design of the test scheme to conduct experimental research on the working performance of the hydraulic anchor, which provides a basis for the practicality and reliability of the barrel slip.

4.1 Parts assembly

(1) Before assembly, clean all parts and blow dry with air compressor;

(2) All threads are assembled in place, and each sealing surface should be free of jamming and scratching;

(3) During assembly, all parts are lubricated with butter;

(4) After the test is completed, wipe the water stains on the inside and outside of the tool, check that all seals and sealing surfaces are not damaged.

Figure 12 Test parts

4.2 Test procedure

(1) Put the tool into the test casing. The tool and casing are connected to the tensile machine.

(2) Suppress 20MPa, cut off the inferior cone shear pin, and keep the pressure 20MPa, so that the hydraulic anchor slip can fully anchor the test casing.

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(3) Relieve the pressure in the tool cavity to 0MPa, and gradually increase the tensile force to 47t (calculate the corresponding tensile stress of 6000m-3 1/2 "tubing with the temperature effect and bulging effect to be 40t ±), and observe the anchoring state of the hydraulic anchor.

(4) Record the change of the water pressure value applied by the pressure pump during the test, and check the displacement of the hydraulic anchor after the end.

4.3 Analysis of test results

As shown in Figure 14, after the hydraulic anchor is unsealed, the casing is less damaged and the slip is in good condition. The test results show that the hydraulic anchor can be effectively anchored and de-anchored. It has an anchoring force of more than 470KN at a setting pressure difference of 20MPa and the axial displacement of the hydraulic anchor meets the design requirements. In summary, the large area of the barrel slip of the hydraulic anchor and the casing is large. The slip can ensure the anchoring of the hydraulic anchor while reducing the damage to the casing.

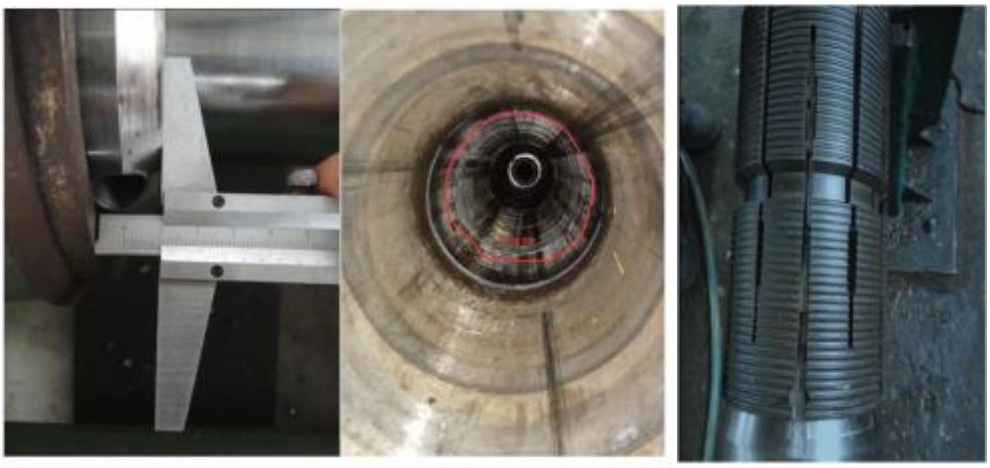

Figure 13 Test results

5. Conclusions

In this paper, the idea of combining mechanical analysis, finite element analysis method and performance test is used to calculate and verify the process of the hydraulic anchor barrel slip stuck into the casing. The following conclusions can be drawn:

(1) The depth of the slip stuck into the casing increases with increasing pressure load; under the same load, the depth is related to the parameters of the slip claw tooth apex angle and the slip tilt angle. Due to the uneven force of the slip, the depths of the slip stuck into casing are also different. Generally speaking, due to the unidirectional load of the slip, the depth of the loaded side is greater.

(2) Combining mechanical calculations, finite element simulation analysis and performance test, it can be seen that the barrel slip and the casing have a large bearing area. The slip can effectively guarantee the working performance of the hydraulic anchor while reducing damage to the casing.

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