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Study on Performance Evaluation and Structural analysis of Soluble Bridge Plug Slips

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ABSTRACT: *In the process of volume fracturing of tight oil and gas horizontal wells, the Soluble Bridge Plug has become a key tool for plugging under pressure due to its advantages of rapid solubility, full-bore production and simple construction technology. Slips are the core components to achieve interstage anchoring, and their anchoring quality can determine the success or failure of horizontal fracturing operations. However, the failure of ball seat setting occurs frequently due to structural fracture and uneven anchoring force of slips during volume fracturing. Therefore, in this paper, finite element analysis and structural optimization research are carried out for the anchoring performance of Soluble Bridge Plug slips. slip anchoring performance evaluation system was established with the strength criterion, the maximum contact stress criterion and the contact uniformity criterion as the evaluation indicators. Using finite element simulation technology, the mechanical properties of slips during the anchoring process were studied, and the anchoring performance was evaluated and analyzed. The results show that under the action of 9t setting force, the maximum stress of the slip nail is 1930MPa, and the maximum stress of the slip block is 832MPa, the force is more uniform, and the anchoring performance is better. The research results will guide us to chose and design the soluble bridge plug slips.*

Key Words: *Staged volume fracturing in horizontal wells; Soluble Bridge Plug; Slips; Simulation analysis; Structural optimization*

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I. INTRODUCTION

With the increase of China's dependence on foreign oil and gas resources, there is an urgent need to increase the exploration and development of oil and gas resources and improve oil and gas production, however, conventional oil and gas resources have been unable to meet the demand, and unconventional resources represented by shale gas and tight oil and gas have gradually become the main force of oil and gas production [1]. Unconventional reservoirs have poor physical conditions and strong non-homogeneity caused by natural fracture development, which makes it difficult to achieve economic and effective development by conventional hydraulic fracturing [2-3]. Volumetric fracturing segmentation and modification technology is a key technology for the efficient development of tight oil and gas reservoirs, which has achieved a significant increase in oil and gas production. Soluble bridge plugs have been rapidly popularised in volumetric fracturing construction operations due to their features such as rapid solubility, full-passage production and simple construction process, leading to a revolutionary advancement in horizontal well segmented multi-cluster fracturing technology. However, the harsh environment of volumetric fracturing during the seating of soluble bridge plugs and the high differential pressure of soluble bridge plugs during fracturing may easily cause the failure of the slip anchors, which may lead to downhole accidents and cause economic losses.

For the seating performance of downhole packer tool slip during the working process, the main research methods are indoor test, finite element analysis and theoretical research. In the theoretical aspect, Zhao Yuanzang et al. analysed the force state of the packer slip by using the theory of static mechanics and mathematical knowledge, and obtained the formula for calculating the positive stress on the slip teeth [4]. Liu Zhanguang applied the static equivalent method to carry out a relatively simple calculation of the seating data of the slip packer, and obtained the calculation formulae for the length of the seated pipe column, the length of the loaded pipe column, and the lifting and seating height, etc. [5]. He Xia et al. determined the stress distribution of casing in the section of slip action area by establishing a mathematical model, and obtained the theoretical calculation formula of casing stress in the slip action area [6]. In terms of experimental research, Liu Tianliang et al. established an experimental model of casing damage by packer slip by simplifying the packer structure, and determined the degree of casing damage by slip by distributing displacement sensors around the casing wall and measuring the depth of slip cutting into the casing wall after anchoring [7]. Li Tong et al. analysed the stress distribution law when the slip occluded the casing through the experimental research method, and found that the uneven distribution of the force of each tooth of the slip has an important influence on the failure of the slip [8]. Zhu Xiaohua et al. carried out seating and sealing test for Y440 type packer, and found that there was downward movement of the tool in the process of sealing, and then based on the nonlinear explicit dynamic analysis method, they established a finite element model to analyse the influence of different slip tooth parameters on the anchoring effect [9].

However, the above studies on the anchoring performance of slip are mainly focused on downhole packer tools, and there is a lack of research on soluble bridge plugs for fracturing. The metal slip is the key to securely anchoring the casing wall, and the 'tightness' of the soluble bridge plug determines the success or failure of the fracturing operation in horizontal wells. Therefore, based on a soluble bridge plug with independent intellectual property rights, this paper analyses the anchoring performance of soluble bridge plug slip structure, and conducts finite element simulation study on the anchoring performance of soluble bridge plug slip. The research content of this paper lays a foundation for the further popularisation and application of soluble bridge plugs.

II. Mechanism of action and force analysis of soluble bridge plug slip Analysis of the working process of soluble bridge plug slip

Soluble bridge plug slip as shown in Figure 1, multi-valve slip along the circumference of the uniform distribution, slip base set with hard slip block, the outer set of hoops, so that the movement of the stability of the inner cone in contact with the sliding body. There is a guide groove on the tailstock to limit the movement of the slip along the radial direction. Soluble bridge plug seated sealing, sliding body and tailstock by the role of sealing tool sealing force and the relative movement, the inner side of the slip by the sliding body extrusion, along the radial movement and casing contact, hard slip block bite into the casing wall to achieve the soluble bridge plug anchoring, the sliding body movement to a certain distance when the sliding body on the horse tooth buckle and the tailstock on the horse tooth buckle with the locking of the soluble bridge plug to complete the sealing.

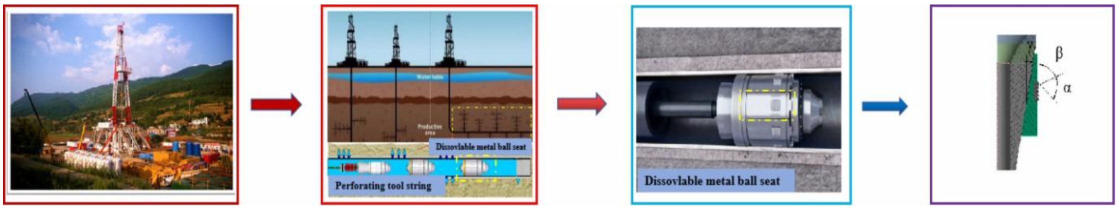


Fig. 1 Tight oil and gas volume fracturing process and soluble bridge plug tool Analysis of forces on soluble bridge plug slip

In the process of seating and fracturing the soluble bridge plug, the slip plays the role of anchoring, fixing the soluble bridge plug on the casing, preventing the soluble bridge plug from moving along the axial direction of the casing, and ensuring the sealing of the soluble bridge plug. During the working process of the soluble bridge plug, the fracture of the slip or serious damage to the casing wall may cause a safety accident, which is a serious threat to the safe production of oil and gas. Therefore, it is necessary to analyse and study the force on soluble bridge plugs. The structure of soluble bridge plug slip consists of multiple flaps of slip, now we take one flap of slip and analyse its force, the structure and force of slip are shown in Fig. 2.

Through the above mechanical analysis, the formula for solving the contact pressure between the slip and casing in the seated sealing condition can be known. It can be seen from the formula (10) and Fig.3that the top angle of the slip tooth α and the inclination angle of the slip tooth β have a greater influence on the contact pressure between the slip and the casing wall, thus affecting the anchoring performance of the slip, and providing theoretical basis for the later structural design focuses.

III. Establishment of evaluation index system of soluble bridge plug slip anchoring performance

As one of the key components of the soluble bridge plug, the anchoring effect has an important influence on the performance of the soluble bridge plug, once the failure of the slip, it will directly affect the oil and gas production and the safety of downhole operation. By analysing the main failure forms of soluble bridge plug slip, the contact pressure criterion, slip strength criterion and casing strength criterion are established to evaluate the anchoring performance of soluble bridge plug slip.

Structural safety evaluation guidelines: strength guidelines

In the segmental fracturing process of horizontal wells, the slip bites into the casing under the seating force, and both the slip teeth and the casing are subjected to large stresses. At the same time, in the case of using inlaid tooth slip, the tooth grooves on the slip base may be subjected to large stresses [10], and the strength of the slip base needs to be calibrated. In order to ensure that the soluble bridge plug slip and casing are not damaged, the maximum equivalent stress is used as an index to evaluate the safety of the soluble bridge plug anchorage structure. The evaluation criterion is: the maximum equivalent force on the teeth of the soluble bridge plugs, the base of the bridge plugs and the casing should not exceed the yield strength of the corresponding materials, and the maximum equivalent force on them should be minimised to ensure the reliable anchoring of the soluble bridge plugs.

Criteria for evaluating the performance of slip anchoring: maximum contact stress criterion

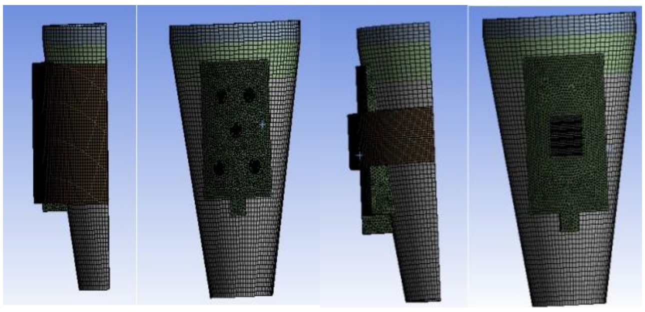
In the process of horizontal well fracturing, in order to ensure the solid anchoring of the soluble bridge plug, it is necessary to maintain a large contact pressure between the slip teeth and the casing wall. In this paper, the maximum contact pressure between the slip and the casing wall is used as one of the indicators to judge the anchoring performance of the slip of the soluble bridge plug, and the maximum contact pressure criterion is established. The evaluation criterion is: under the action of seating force, the larger the maximum contact pressure between slip and casing wall is, the more stable the anchoring is.

Guidelines for evaluating the performance of slip anchoring: contact uniformity criterion

Fracturing conditions in horizontal wells are complicated, and impacts and vibrations may intensify the downward movement of soluble bridge plugs or even cause them to slip or leak, so it is difficult to ensure the stable anchoring of the slip when the contact pressure between the slip and the casing is not uniformly distributed, and the more uniformly the contact pressure is distributed between the slip and the casing, the more reliable the anchoring will be. This paper establishes the evaluation criteria of anchoring performance of slip contact uniformity, taking the average contact pressure and standard deviation of contact pressure (S) between slip and casing as the indicators of contact uniformity between slip and casing, so as to evaluate the anchoring performance of slip. The evaluation criteria are: the contact between slip and casing should be as uniform as possible, the larger the average contact pressure between slip and casing, and the smaller the standard deviation of contact pressure, the better the anchoring effect.

Simulation analysis of soluble bridge plug slip anchorage performance Finite element modelling of soluble bridge cecava

This paper simplifies the structure of soluble bridge plugs according to the working principle of soluble bridge plug seating and anchoring components. In this paper, we mainly study the influence of slip structure on the seating and anchoring performance of soluble bridge plugs, so we omit the sealing ring and other structures, and keep the sliding body, slip and casing structure. Considering that the slip is a symmetric structure in the soluble bridge plug, only a single slip needs to be analysed by finite element analysis to reduce the computational complexity. Meshing intelligent mesh generator is used to delineate the structured mesh. In this paper, the sliding body is meshed by the sweep method, the mesh size of the kawa matrix is set to 2 mm, the mesh size of the kawa block or kawa nail is set to 1 mm, Face Sizing is used on the inner wall surface of the casing, the mesh size is set to 1.2 mm, and the global mesh size is set to 3 mm. the mesh division is shown in Fig. 4.



a Embedded slip nail slip   b Embedded slip block slip

Fig. 4 Mesh division for simulation study of slip anchoring performance

Soluble aluminium alloy is used for the material of the soluble bridge plug sliding body and slip base body, and the material of the slip block is cemented carbide.

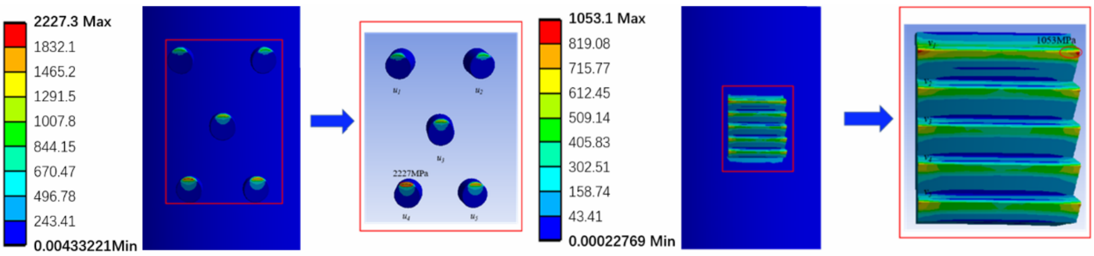
According to the working principle of soluble bridge plug slip, the casing side and outer surface are set as fixed constraints, and the axial displacement of the lower surface of the slip base body is 0mm. the downward displacement is applied to the upper surface of the sliding body, and the normal displacement of the contact surface of the slip base body and the base is 0mm.

After the boundary conditions are applied, the support reaction force on the upper end surface of the sliding body is obtained under different displacements, so as to obtain the stress, strain and contact pressure on the slip block/slip nail and casing wall when the seating force is not greater than 9t, the seating force on a single slip is not greater than 1.5t.

Analysis of calculation results

Based on the above setup, computational analysis of the seating process of soluble bridge plug slip is carried out. In order to compare the performance of slip nail type slip and slip block type slip, finite element analysis of slip nail and slip block type slip is carried out to grasp the slip stress, casing wall stress and contact pressure between slip and casing wall during the seating process of bridge plug.

The results show that, in the case of seating force not more than 1.5t, the distribution of contact pressure between the two structures of slip and casing is shown in Fig. 5. When embedded slip nail slip is used, the contact pressure between slip and casing wall is larger at the top of the slip nail, while the other parts of the slip nail are not in contact with the casing wall, and the maximal contact pressure between the slip nail and the casing wall reaches 2,227MPa. The embedded slip block slip is in contact with the casing wall at the top of the slip block teeth, and the contact pressure is more evenly distributed, with a maximum contact pressure of 1053MPa.



a Embedded slip nail slip   b Embedded slip block slip

Fig.5 Stress distribution of contact stress between two structures of slip and casing wall

The embedded slip nail contact pressure is concentrated in the vicinity of the contact with the casing wall, the maximum pressure of the slip nail is 1930 MPa, the embedded slip contact pressure is more uniformly distributed, the maximum pressure of the slip block is 832 MPa. The yield strength of the slip nail/block material is 981 MPa, and the maximum stress on the slip nail is far more than the yield strength of the material, and the slip nail may undergo a large plastic deformation, which will result in the failure of slip anchoring. Anchoring failure.

The stress distribution of the casing wall during the two structural slip is shown in Fig. 6. The maximum pressure of the casing when embedded in the slip nail slip is 1212MPa, and the maximum pressure of the casing when embedded in the slip block slip is 847MPa, and the yield strength of the casing material is 738MPa, and the contact pressure between the slip nail and the casing wall is too big, which may lead to the damage of casing wall and affect the anchoring effect. Simulation results show that the anchoring effect of embedded slip block slip is better than embedded slip nail slip.

The stress distribution of the slip base is shown in Figures 7 and 8, the maximum pressure of the slip base is 344 MPa when embedded in the slip nail, and 176 MPa when embedded in the slip block. The stress distribution of the five grooves embedded in the slip nail is not uniform, and the lower part of the grooves is significantly higher than the upper part of the grooves. The overall stress in the tooth groove of the embedded slip block is uniform. The yield strength of the slip base material is about 350MPa, and the maximum pressure of the slip base is close to the yield limit when the slip nail is embedded, which may cause plastic deformation of the slip base, and the slip anchoring may fail during operation.

Finite element simulation analyses of the two existing slip structures were carried out to obtain the equivalent stresses of the two structural slip structures. Simulation results show that the use of embedded slip nail slip, slip and casing are subjected to greater stress, slip can not be firmly anchored; the use of embedded slip block slip, slip force is more uniform, can achieve better anchoring effect, but for the slip block there is also a structural parameter on the slip anchoring performance is not clear, need to be further investigated to optimise the best combination of parameters.

IV. CONCLUSION

The structure and working principle of soluble bridge plug and the process of horizontal well segmental fracturing with soluble bridge plug are analysed. The index system for evaluating the anchoring performance of soluble bridge plugs is established, and the equivalent force between the slip and casing, the maximum contact pressure between the slip and casing, the average contact pressure and the standard deviation of the contact pressure are used as the indexes for evaluating the anchoring performance of the slip, which provides a reference basis for the subsequent evaluation and analysis of the performance of soluble bridge plugs.

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