Finite element analysis of conical teeth for hydraulic pipe tongs

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Abstract. During well operation, corrosive gas such as H₂S in the well will cause serious corrosion damage to the column. In order to minimize the impact of corrosion, the oilfield gradually replaced the standard steel casing by a corrosion-resistant alloy (CRA) casing. Conventional tongs was widely used in casing for mark-up and break-out operation. But Zhou et al [1] thought that the tong teeth destroys the galvanized layer of CRA on the casing surface, where the corrosion easily happens. Therefore, a design scheme of the conical teeth for hydraulic pipe tongs was proposed, and the mechanical properties of the conical teeth were simulated by finite element software to analyze the degree of damage to the casing.

1. Research background
Hydraulic pipe tongs is used to mark and break casing, its two main structures are the die and the tooth plate. The die is the base of the tooth plate, used for mounting the tooth plate. The tooth plate is used to hold drill pipe and drilling tool. When marking and breaking different diameters of the casing, we need to use the appropriate specifications of the tooth plate and the die to ensure that there will be no skidding, tripping and so on.

In January 2013, Wu et al [2] developed a kind of low stress tong teeth with spot mark and sand surface. The tong teeth is made of alloy steel and it is flat or arc-shaped, its surface is bonded with the cemented carbide layer by brazing. The tong teeth has good anti-corrosive effect on the corrosion-resistant alloy (CRA) casing and long service life.

In July 2014, Li et al [3] developed a tooth plate. It uses the surface blasting process, through a series of cleaning, sandblasting, testing and other processes to achieve the tooth plate covered with a layer of particles on the surface, which will increase the surface roughness of the tooth plate, but also to avoid slipping.

In October 2008, Xu et al [4] developed a non-bite-friction tong teeth. The friction layer is fixed on the dovetail pin of the tong teeth by the rivets, the drainage groove is left on the friction layer, and the tong teeth is wedged. This tong teeth can reduce bite marks to extend the service life.

From the above survey, we can conclude that in the late stages of oil exploration, the conditions in the well bore are complicated and harsh. The coarse and sharp teeth marks will form irreversible corrosion damage under the well. Therefore, it is necessary to analyze the teeth for hydraulic pipe tongs from the working mechanism of the tong teeth, and to study the influence of the size of the teeth on the casing. Finally, a kind of teeth mark with better comprehensive performance is designed, which is of great significance in protecting the corrosion-resistant casing.
2. Methodology of the conical teeth

Hydraulic pipe tongs will achieve torque transmission when the tong teeth bites the casing, so the surface of the casing will appear marks when the tong teeth scratches the casing. The depth of the teeth left on the casing surface is called the amount of casing deformation. Within the maximum allowable range of the load on the casing surface, we simulate the amount of strain on the casing surface when the conical teeth of the hydraulic pipe tongs are simultaneously subjected to both tangential and radial forces.

Based on the research of Liu Jun et al [5-9], the conical teeth designed by the author has a friction coefficient of 0.2 and 0.4, and the angle of the tong teeth is 30° and 60° respectively, as shown in Figure 1 and figure 2. When analyzing the behavior of the tong teeth when they come in contact with the casing, we set the contact type of the casing and teeth to be the surface contact, and take the contact position of the teeth on the casing surface to refine the mesh. The two ends of the casing adopt the fixed constraint, the tong teeth will not be displaced in the axial direction due to the limitation of the jaw of the hydraulic pipe tongs.

![Figure 1. Structure of 30° conical teeth.](image1)

![Figure 2. Structure of 60° conical teeth.](image2)

2.1. Introduction of finite element software

ANSYS software is a large-scale universal finite element software, which is widely used. The software can run in most computers and operating systems, and the ANSYS file is compatible with all its product lines and working platforms. ANSYS includes three main modules, pre-processing module, analysis and calculation module, post-processing module. Pre-processing module mainly provides entity modeling and meshing tools. Users can construct finite element model or import entity model. ANSYS Workbench is based on the analysis software --ANSYS Design Space(DS), and the software is easy to use and has a good interface with CAD. After years of development, the ANSYS Workbench Environment awe is formed by the pre-and post-processing function of the classical ANSYS software and the interface style of DS.

ANSYS Workbench has the following characteristics:

1. System simulation project management.
2. Bi-directional parameter transmission function.
3. Advanced transfer parts processing tools.
4. Advanced mesh processing, which can handle complex geometric models and mesh division.
5. Support for ANSYS finite element analysis.
6. The embedded material library is convenient for editing and application.

2.2. Finite element simulation of the conical teeth

The casing used was a 5-inch half-casing, its outside diameter is 127 mm. The outside diameter of the conical teeth is 147 mm, the inside diameter is 127 mm and the height of the conical teeth is 5 mm. The axial length of the study was 200 mm. T8 carbon steel and 20Cr are selected for the conical teeth, and the mechanical properties of T8 carbon steel and 20Cr are shown in table 1 below. In order to improve the design accuracy, the dividing grid used for tong teeth is hex dominant. In addition, the mesh of the contact area between the casing and the tong teeth and the surrounding mesh are more detailed, the rest of the other parts are relatively loose. The simulated assembly diagram of two conical teeth and the casing is shown in figure 3, and that of four conical teeth with the casing is shown in figure 4.
Table 1. Mechanical properties of materials.

| Material name   | Yield Strength | Elastic Modulus | Poisson's ratio | Hardness HRC |
|-----------------|----------------|-----------------|-----------------|--------------|
| T8 carbon steel | 930 MPa        | 223 GPa         | 0.277           | >62          |
| 20Cr            | 540 MPa        | 200 GPa         | 0.211           | 56           |

According to four sets of factors, such as the arrangement of the teeth marks, the angle of the tooth plate, the material of the tong teeth and the friction coefficient of the contact surface, the tightening effect of the teeth mark on the casing are simulated by finite element software. Due to space limitations, most of the simulated images are no longer displayed, only the final simulation results are displayed. The stress, strain and deformation of the conical teeth for hydraulic pipe tongs are shown as follows.

Figure 3. The simulated assembly diagram of two conical teeth with 30° tooth plates and the casing.

Figure 4. The simulated assembly diagram of four conical teeth with 60° tooth plates and the casing.

Figure 5. The stress diagram of two conical teeth and the casing.

Figure 6. The strain diagram of two conical teeth and the casing.
Figure 7. The deformation diagram of two conical teeth and the casing.

Figure 8. The stress diagram of four conical teeth and the casing.

Figure 9. The strain diagram of four conical teeth and the casing.
Figure 10. The deformation diagram of four conical teeth and the casing.

Table 2. The simulation data of the conical teeth.

| The angle of the tooth plate, the number of teeth | A tooth plate with 30° | A tooth plate with 60° |
|-------------------------------------------------|------------------------|------------------------|
| **Installation layout**                        | Two conical teeth mounted symmetrically on the casing surface | Four conical teeth mounted symmetrically on the casing surface | Two conical teeth mounted symmetrically on the casing surface | Four conical teeth mounted symmetrically on the casing surface |
| **T8 carbon steel**                            | 504.62MPa               | 259.15MPa              | 368.86MPa               | 186.94MPa               |
| The overall structural stress after analysis    | 0.002364                | 0.001236               | 0.001901                | 0.000958                |
| Overall structural strain after analysis        | 0.021571mm              | 0.014555mm             | 0.027737mm              | 0.014349mm              |
| The overall structural deformation after analysis | 488.25MPa               | 250.89MPa              | 366.03MPa               | 183.58MPa               |
| Overall structural strain after analysis        | 0.0024478               | 0.001288               | 0.001962                | 0.000989                |
| Overall structural deformation after analysis   | 0.022411mm              | 0.011907mm             | 0.028189mm              | 0.014572mm              |

| The angle of the tooth plate, the number of teeth | A tooth plate with 30° | A tooth plate with 60° |
|-------------------------------------------------|------------------------|------------------------|
| **Installation layout**                        | Two conical teeth mounted symmetrically on the casing surface | Four conical teeth mounted symmetrically on the casing surface | Two conical teeth mounted symmetrically on the casing surface | Four conical teeth mounted symmetrically on the casing surface |
| **T8 carbon steel**                            | 508.93MPa               | 260.59MPa              | 375.58MPa               | 188.02MPa               |
| The overall structural stress after analysis    | 0.002393                | 0.001249               | 0.001932                | 0.000963                |
| The overall structural strain after analysis    | 0.021939mm              | 0.011589mm             | 0.028340mm              | 0.014614mm              |
| Overall structural deformation after analysis   | 492.32MPa               | 252.3MPa               | 368.78MPa               | 184.73MPa               |
| Overall structural strain after analysis        | 0.002492                | 0.001302               | 0.001999                | 0.000995                |
| Overall structural deformation after analysis   | 0.022789mm              | 0.012051mm             | 0.028796mm              | 0.014844mm              |

| **20Cr**                                       |                        |                        |                        |                        |
| **Installation layout**                        | Two conical teeth mounted symmetrically on the casing surface | Four conical teeth mounted symmetrically on the casing surface | Two conical teeth mounted symmetrically on the casing surface | Four conical teeth mounted symmetrically on the casing surface |
| The overall structural stress after analysis    | 508.93MPa               | 260.59MPa              | 375.58MPa               | 188.02MPa               |
| The overall structural strain after analysis    | 0.002393                | 0.001249               | 0.001932                | 0.000963                |
| Overall structural deformation after analysis   | 492.32MPa               | 252.3MPa               | 368.78MPa               | 184.73MPa               |

(1) We select T8 carbon steel, two tooth plates on the device, the friction coefficient is 0.2, the degree of the tooth plate is 30°. The stress is shown in figure 5, the strain is shown in figure 6 and the deformation is shown in figure 7.
2. We select T8 material, four tooth plates on the device, the friction coefficient is 0.2, the degree of the tooth plate is 60°. The stress is shown in figure 8, the strain is shown in figure 9 and the deformation is shown in figure 10.

After simulation analysis by finite element software, the simulation data of the conical teeth is summarized in table 2.

2.3. Analysis of the results
Considering the actual situation of the simulation, there may be some error between the result of the finite element simulation and the experimental result of the conical teeth. Therefore, the simulation conclusion of the tong teeth can only be generalized to analyze the force situation of the different teeth under different conditions. Analysis of the above images and data, you can draw the following results:

(1) In terms of the arrangement of the teeth marks: ①If the angle of the tooth plates is same, the load applied by the hydraulic pipe tongs will be equally divided by the tooth plates when the number of the tooth plates increases, which will result in the stress and strain reduce. Therefore, changing the clamping method of the hydraulic pipe tongs to increase the number of tooth plates can reduce the force of the tong teeth. ②If the angle of the tooth plates is same, the deformation of the casing will be significantly reduced when increasing the number of tooth plates.

(2) In terms of the angle of the dental plates: ①In the same arrangement, the value of stress and strain decreased obviously with the increase of the angle of the tooth plates. In addition, because the size of conical teeth is small, the tong teeth is not sharp when increasing the angle of the tooth plates, the force on the casing surface will tend to be more uniform and the stress and strain will reduce. ②In the same arrangement, increasing the angle of the tooth plates, the contact area between the casing and the tong teeth will increases, and the amount of deformation increases.

(3) In terms of the materials used: In the small conical teeth structure, the deformation of T8 carbon steel teeth is smaller than that of Cr20 teeth. The use of softer Cr20 alloy steel will significantly increase the deformation, but the increase is limited. So the conical teeth should try hard to choose a material with higher hardness than Cr20.

(4) In terms of friction coefficient: If the arrangement, the angle of the tooth plates and the selected materials is same, the stress, strain and deformation will increase with the increase of the friction coefficient, but the change is particularly small, so the result will not be greatly affected.

3. Conclusions
In this paper, finite element software was used to simulate and analyze the effect of teeth marks on the casing. According to four factors that affect the teeth marks, such as the arrangement of the tong teeth, the angle of the tooth plates, the material of the tooth plates and the friction coefficient of the contact surface, different types of the conical teeth were respectively simulated and analyzed. For these four groups of factors, we completed 16 sets of simulation experiments of the conical teeth for hydraulic pipe tongs.

After comparing the simulation results, we can see that in order to reduce the damage to the casing surface, we should try to use the small conical teeth with more rigid materials, the larger number of the tooth plates and the larger angle of the tooth plates. Finally, through data analysis, it is recommended to use a small conical teeth with more hard materials, four tooth plates mounted symmetrically on the casing surface and 600 tooth plates, which will improve the working efficiency of the hydraulic pipe tongs and the service life of the casing.

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