Finite Element Analysis of Double-shoulder Drill Joint

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Abstract

With the extensive application of advanced drilling technologies such as ultra-deep well, directional well and large displacement well, the down hole working conditions become worse and worse, and higher requirements are put forward for the performance of oil drilling tools. In the whole section of oil drill string, the joint thread is its weak part. Under normal circumstances, the load that the thread can bear is only equivalent to 60\%~80\% of the strength of the pipe body. The failure of the drill joint caused by the screw thread accounts for 40\% of the failure accidents every year. Based on this background, this paper proposes a new double-shoulder joint structure, and studies its stress-strain characteristics under the conditions of upper buckle torque, upper buckle torque + axial load and larger load by means of finite element analysis technology. The results show that the new structure can effectively solve the problem of excessive stress concentration in the thread section of the traditional API thread under high load, which provides a reference for the subsequent research and development of the new structure of the drill thread joint.

Keywords

Drilling tool thread; Double shoulder structure; Finite element analysis.

1. Introduction

With the development of oil and gas drilling technology, the reliability requirement of drill pipe is higher and higher\cite{1}. In recent years, as scholars at home and abroad have made more and more in-depth studies on deep Wells and ultra-deep Wells, the number of combined drilling tools, such as screw drill and rotary guide, has also been increasing, and more stringent requirements have been put forward for screw thread in complex process Wells\cite{2}. The thread connection strength of the drill string has become a limiting factor for the overall drilling level. When the drill pipe undertakes the drilling task, the threaded joint section is the weakest part of the drill pipe joint, and the threaded end bears the combined load of axial load, bending load and torque load, which leads to the failure of the drill pipe. Under such harsh working conditions, it is of great significance to carry out stress checking analysis on the joint thread of drill pipe.

2. Theoretical basis of thread joint analysis of drilling tools

2.1. Thick-walled cylinder theory

Drill tool thread is the most vulnerable and important part of the drill pipe, according to sealing mechanism of the drilling tool thread, thread sealing is to rely on for interference fit between the teeth, the tool joint thread connection part of the stress of screw thread and sealing performance of the image is larger, the stress on the size and the axial load, torque, inside and outside the mud pressure, etc. Are more closely linked. When the drill pipe is subjected to the above load, it can be regarded as a thick-walled cylinder under internal and external pressure, and the thick-walled cylinder theory in mechanics can be used for theoretical analysis \cite{3}.
Mechanically a thick-walled cylinder is defined as a cylinder subject to both internal and external pressures and thick-walled and radius are of the same order of magnitude. Oil well pipe string is usually considered as a thick-walled cylinder. The stress and strain at each point on the cylinder are symmetric with respect to the axis, and its structural diagram is shown in Fig.1.

![Fig.1 Schematic diagram of thick-walled cylinder theory](image)

According to the geometric shape and load-bearing characteristics of the thick-walled cylinder, and considering the static equilibrium and physical relationship, the following formula can be obtained in the column coordinate system:

\[
\begin{align*}
\sigma_r &= \frac{R_i^2 P_i - R_e^2 P_e}{R_e^2 - R_i^2} - \frac{(P_i - P_e) R_i^2 R_e^2}{R_e^2 - R_i^2} \cdot \frac{1}{R^2} \\
\sigma_\theta &= \frac{R_i^2 P_i - R_e^2 P_e}{R_e^2 - R_i^2} + \frac{(P_i - P_e) R_i^2 R_e^2}{R_e^2 - R_i^2} \cdot \frac{1}{R^2} \\
\end{align*}
\]

When the thick-walled cylinder only bears the internal pressure load, the radial stress and circumferential stress of the cylinder as well as the radial displacement of the inner surface are:

\[
\begin{align*}
\sigma_r &= \frac{R_i^2 P_i}{R_e^2 - R_i^2} \left(1 - \frac{R_e^2}{R^2}\right) \\
\sigma_\theta &= \frac{R_i^2 P_i}{R_e^2 - R_i^2} \left(1 + \frac{R_e^2}{R^2}\right) \\
u_{ri} &= \frac{P_i R_i}{E} \left(\frac{R_e^2 + R_i^2}{R_e^2 - R_i^2} + \mu\right) \\
\end{align*}
\]

When the thick-walled cylinder only bears the external pressure load, the radial stress and circumferential stress of the cylinder as well as the radial displacement of the inner surface are:

\[
\begin{align*}
\sigma_r &= \frac{R_e^2 P_e}{R_e^2 - R_i^2} \left(1 - \frac{R_i^2}{R^2}\right) \\
\sigma_\theta &= \frac{R_e^2 P_e}{R_e^2 - R_i^2} \left(1 + \frac{R_i^2}{R^2}\right) \\
u_{ri} &= \frac{P_e R_e}{E} \left(\frac{R_e^2 + R_i^2}{R_e^2 - R_i^2} - \mu\right) \\
\end{align*}
\]
2.2. Finite element analysis method for drill thread

The methods for thread analysis of drilling tools usually include analytical method, test method and finite element analysis method. The analytical method has been mentioned in the previous chapter, but the error of the analytical method is too large, so it can only be used as a reference, not as an accurate result. The test method is simple and clear, and the results are accurate, but the test time is often too long, and the cost is too high. Finite element law is based on modern computer technology, which regards the model as a whole connected by many small units at the nodes, and uses mathematical approximation method to simulate and load the real physical system. It has the characteristics of low cost and high efficiency. In this paper, the finite element analysis method is used to analyze the drill thread. The following is a brief explanation of the finite element analysis technique.

In the process of finite element analysis, the most critical part lies in the finite element model and finite element simulation [4]. The finite element model is an idealized mathematical abstraction of the real system, which consists of some simple shaped elements connected by nodes and bearing certain loads. Finite element simulation is a real system in which geometric and loading conditions are simulated by mathematical approximation and simple and interactive element elements are used to approximate the infinite unknowns with a finite number of unknowns.

3. Finite element simulation of drill thread

This paper focuses on the strength of the drilling tool thread in drill pipe connection state of stress and strain analysis, select the ABAQUS software is Marcel Dassault company, is a powerful finite element software of ABAQUS, the strong analysis ability and ABAQUS simulation the reliability of complex systems, it’s industrial countries in the world and has been widely used in research, in a large number of high-tech product development plays an enormous role. The complex solid mechanics structural mechanics system is especially capable of handling very large and complex problems and simulating highly nonlinear problems.

The Standard module in CAE, namely statics simulation module, is used for simulation. In this paper, based on the NC50 thread type double shoulder drill string joint model in API standard, a simulation was carried out to simulate the loading condition under harsh down hole working conditions, as shown in Figure 3-1. The drill string joint is composed of a male joint and a female joint, of which the male joint includes four parts: the main shoulder, the thread section, the secondary shoulder and the pipe body, and the female joint corresponds to the male thread. Compared with the traditional API joint, the double shoulder joint has higher connection strength and more reliable sealing performance. The secondary shoulder joint can take on an additional part of sealing function after the traditional sealing, effectively improving the service life of the drill thread in various types of complex Wells.

In order to build the finite element model of high precision and high computational efficiency, on the shoulder and the thread part mesh division of fine grid, the grid size is set to 1 mm, will
be divided equally arranged for mesh of hexahedron, to reduce or eliminate the large deformation of the grid, cannot be computed in the distal force, the use of the relatively sparse grid, in order to reduce the overall amount of calculation, improve computing speed, maximum grid size is set to 2 mm.

![Fig.3 The joint stress distribution under the upper buckle torque — Plan 1](image)

It is not difficult to see from the figure that under the applied state of the upper buckle torque, there is an interaction force on the shoulder surface to achieve the sealing function. This state is the load of the drill pipe thread under the normal working state, and then we will add the axial load. FIG. 3 shows the stress analysis cloud diagram when the drill pipe thread is subjected to both the upper buckle torque and axial load at the same time.

![Fig.4 upper buckle torque + 100KN Axial load — Plan 2](image)

![Fig.5 upper buckle torque + 300KN Axial load — Plan 3](image)

In this figure, we can clearly see the advantage of double shoulder threads, that is, both ends share the load, to reduce the load on the thread section, the structure can significantly improve the service life of the drill pipe thread, we can lower the height.

### Table 1 Comparison of three schemes of double shoulder joint

<table>
<thead>
<tr>
<th></th>
<th>Shoulder section Max mises</th>
<th>Thread section Max mises</th>
<th>The end section Max mises</th>
</tr>
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<tbody>
<tr>
<td>Plan 1</td>
<td>83</td>
<td>51</td>
<td>0</td>
</tr>
<tr>
<td>Plan 2</td>
<td>112</td>
<td>97</td>
<td>86</td>
</tr>
<tr>
<td>Plan 3</td>
<td>146</td>
<td>118</td>
<td>159</td>
</tr>
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With the increase of the load, it is obvious that the double end will bear more load, thus reducing the load on the threaded end effectively to achieve the purpose of structural optimization.

4. Summary

In this paper, using ABAQUS software on the stress-strain characteristics of double shoulder in drilling tool thread are studied, through the analysis of double shoulder screw under various load state in shoulder, thread section, maximum stress value of the face are simulated model calculation, the results show that the new structure can effectively alleviate thread focus problems of change over portion, effectively improve the service life of the drill pipe thread under high load condition.

References