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Analysis of the Influence of Structural Parameters of Coupling-Type Casing Threads on Joint Connection Strength

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Abstract

Casing drilling technology originates from mining wire-line coring technology. It uses casing as the drill string to perform drilling and casing running simultaneously without the need for pulling out. This technology can solve downhole accidents in complex formations and is suitable for large-sized boreholes. However, due to the characteristics of the casing, the joint connection strength is weak, the performance is poor, and the thread stress is complex and uneven, making it the weakest link of the pipe string. To fill the gap in the existing research on the influence of thread structure on joint strength, this paper establishes a mechanical analysis model for casing joint threads, explores the influence laws of two factors, namely variable tooth width and shoulder clearance, on the torsional resistance performance of casing threads, and provides a reference for the research on the structural optimization of casing joint threads. The research results show that reducing the tooth width at the small end of the male thread and increasing the tooth width at the small end of the female thread can balance the maximum stress of the male and female threads and improve the load-bearing capacity of the threads. However, a further increase in the tooth width ratio will lead to excessive stress at the small end of the male thread, making it the main failure part. With the increase of shoulder clearance, the stress begins to decrease, and the maximum stress shifts from the female shoulder to the first thread turn. However, an excessively large clearance will reduce the load shared by the shoulder and cause an increase in the overall stress of the thread.

Keywords

Casing Drilling Technology; Special Thread; Torsional Resistance Performance; Stress Distribution; Finite Element Analysis.

1. Introduction

Casing drilling technology is improved from mining wire-line coring technology. Different from conventional drill pipe drilling, it uses casing as the drill string to transmit drilling fluid and weight on bit (WOB). During drilling, the casing is run in synchronously, and there is no need to pull it out after drilling [1-2]. This technology has significant advantages. It can effectively solve downhole accidents such as drilling fluid loss and borehole collapse in complex formations, and is especially suitable for large-size drilling operations in complex geological surface layers. It can quickly run the casing and complete cementing [3-7].

Compared with traditional drill pipes, casing has a larger outer diameter and a thinner wall thickness, resulting in weaker joint connection strength and poorer performance [8]. Casings are mostly connected by threads (with the internal thread of the coupling matching the external thread of the pipe body). During drilling, they need to bear rotational torque as well as longitudinal and transverse vibrations, which makes the stress of the joint threads complex and unevenly distributed [9], thus becoming the weakest part of the pipe string.

Given the crucial connection function of casing threads, the global academic community has carried out a series of systematic investigations focusing on the optimization of joint thread structures, the improvement of stress concentration phenomena, and the enhancement of thread torsional resistance and connection performance. Studies have shown that by specifically adjusting core structural parameters such as tooth height, thread taper, pitch, and thread angle, the stress distribution in the thread engagement area can be effectively optimized, the stress concentration effect can be weakened, and thus the thread connection strength can be substantially enhanced, providing important support for stable application under extreme working conditions [10-14]. However, in the existing research system, as two key structural parameters that have a significant impact on the bearing characteristics of joint threads, tooth width and shoulder clearance have relatively scarce systematic research, and their action mechanisms and optimization laws have not been fully revealed.

To this end, this paper establishes a mechanical analysis model for casing joint threads, explores the influence laws of two factors, namely variable tooth width and shoulder clearance, on the torsional resistance performance of casing threads, and provides a reference for the research on the structural optimization of casing joint threads.

2. Finite Element Analysis Model

For the coupling-type casing thread structure, a three-dimensional solid model is constructed. In the mesh generation process, the C3D8R element type is adopted, and local mesh refinement is applied to the thread tooth area. This ensures calculation accuracy while effectively controlling the calculation cost, achieving a balance between the two. In terms of boundary condition settings, a fixed constraint is imposed on the coupling, and a linear torque load of 15 KN·m is applied to the casing pin.

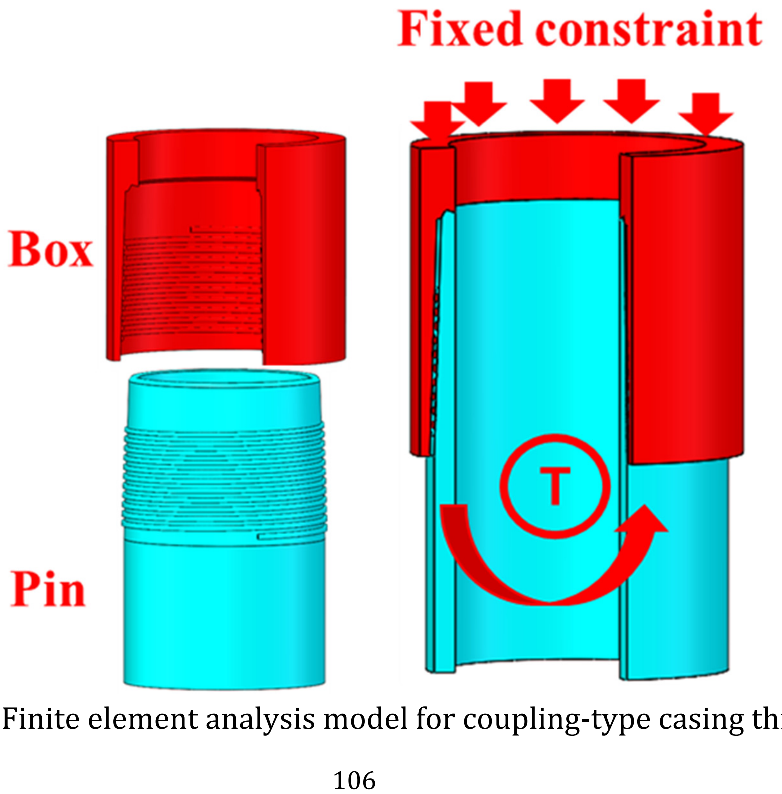

Fig 1. Finite element analysis model for coupling-type casing threads

The 125V grade steel is selected as the material, and its mechanical property parameters are as follows: the yield strength is 862MPa, the Poisson's ratio is 0.29, the elastic modulus is 1.96×10^5MPa, and the density is 7.82×10^3kg/m^3. In this study, the plastic behavior of the material is not considered, and the entire component is regarded as an ideal elastic body for analysis.

3. Analysis of the Influence of Structural Parameters on Joint Connection Strength

3.1. Influence Law of Variable Tooth Width on Joint Connection Strength

To explore the influence law of thread tooth width ratio on bearing capacity, according to the idea that the thread teeth at the small end of the casing joint are small and those at the large end are large, the thread teeth at the small end of the coupling joint are wide and those at the large end are narrow, and the tooth width changes uniformly along the thread helix, finite element calculation models with tooth width ratios of 5:5, 5.5:4.5, 6:4, 6.5:3.5, and 7:3 between the large and small ends of the thread were established respectively. The schematic diagrams of variable tooth width and thread engagement are shown in Figure 2 and Figure 3.

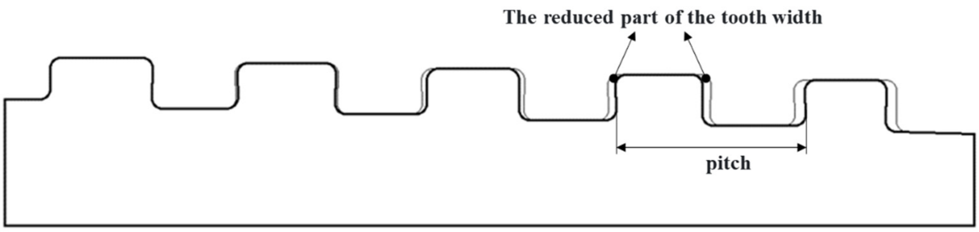

Fig 2. Schematic diagram of variable tooth width

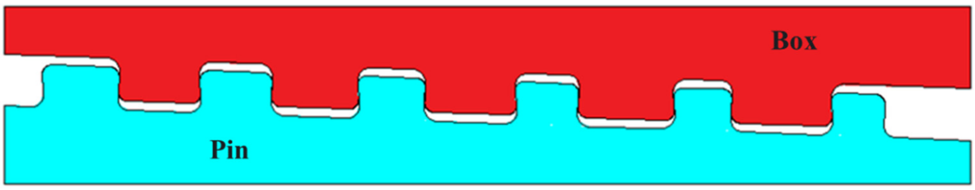

Fig 3. Schematic diagram of thread engagement

The stress distributions under a torque of 15 kN·m with thread tooth width ratios of 5:5, 5.5:4.5, 6:4, 6.5:3.5, and 7:3 between the large and small ends are calculated, as shown in Figure 4.

From the perspective of the stress regulation mechanism, by reducing the tooth width of the small end of the male thread and correspondingly increasing the tooth width ratio of the small end of the female thread, the stress states of both can be effectively adjusted. The essence of this parameter adjustment is to change the force flow transmission path at the contact interface, so that the load ratio borne by the small end of the male thread is increased accordingly, while the load concentration phenomenon at the small end of the female thread is alleviated. However, there is a critical threshold for the adjustment of the tooth width ratio. When the ratio of the tooth width of the small end of the female thread to that of the small end of the male thread is further increased, the stress regulation mechanism will reverse: the excessively reduced tooth width of the small end of the male thread leads to a sharp decrease in its cross-sectional bearing area. Under the same load, the stress level at the small end of the male thread quickly exceeds that at the small end of the female thread, becoming the stress peak area in the entire thread connection structure. At this time, the small end of the male thread will change from the original low-stress area to a weak link prone to structural failure, which is likely to cause plastic deformation or even fracture of the thread root, resulting in a fundamental change in the overall failure mode of the connection system. This indicates that in the optimal design of threads, the

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optimal range of the tooth width ratio needs to be determined to achieve the coordinated optimization of stress balance and structural strength.

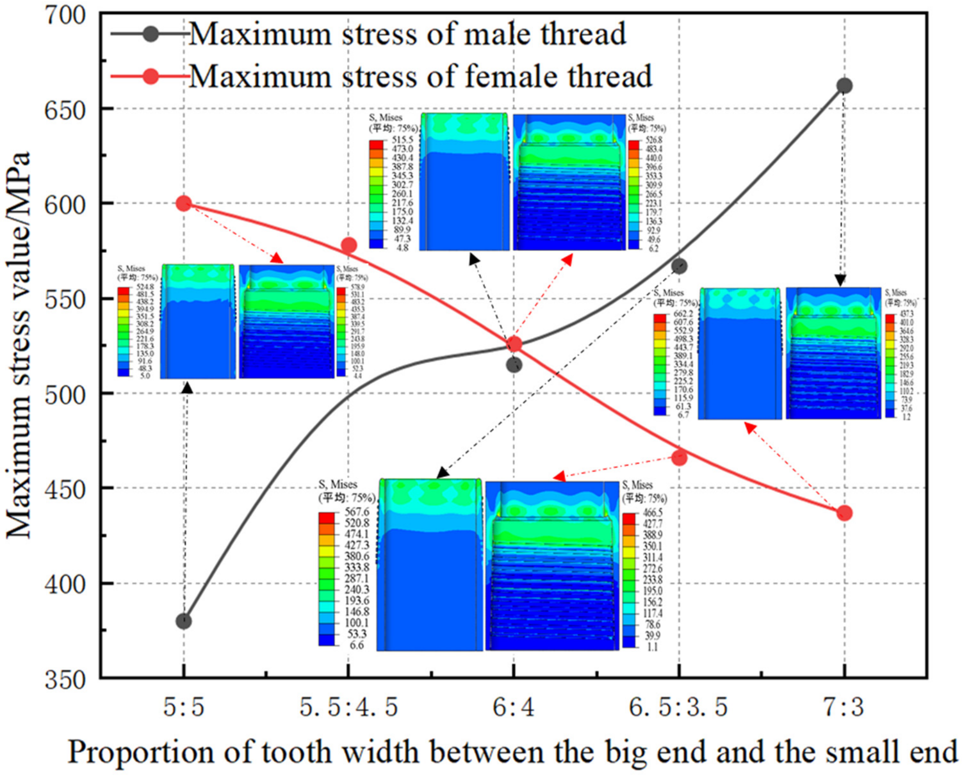

Fig 4. The law of stress variation under different tooth width ratios of the large and small ends of threads

3.2. Influence Law of Shoulder Clearance on Joint Connection Strength

Since the maximum stress always occurs at the shoulder, leaving a certain gap at the female shoulder can balance the stress between the thread teeth and the shoulder. Finite element calculation models with shoulder clearances of 0mm, 0.02mm, 0.04mm, 0.06mm, 0.08mm, and 0.10mm were established respectively. The schematic diagrams of the shoulder and thread engagement are shown in Figure 5.

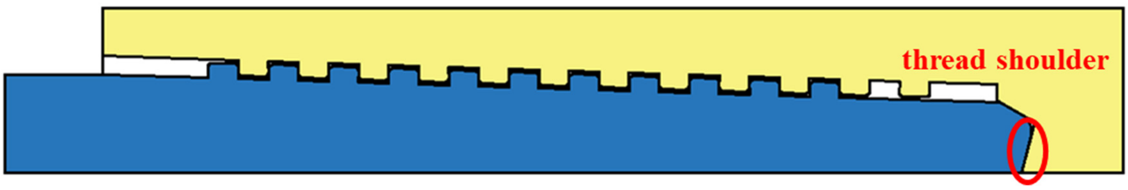

Fig 5. Schematic diagram of the thread shoulder

The stress distributions under a torque of 30 kN·m with shoulder clearances of 0 mm, 0.02 mm, 0.04 mm, 0.06 mm, 0.08 mm, and 0.10 mm are calculated, as shown in Figure 6.

As the shoulder clearance gradually increases, the overall stress level of the connection system will show a downward trend. At the same time, the distribution position of the maximum stress will also undergo an obvious migration, shifting from the initially concentrated female shoulder to the first thread turn. The root cause of this phenomenon of stress distribution change lies in that the change of clearance adjusts the force flow transmission path at the connection interface. The force flow originally mainly borne by the shoulder is partially transferred to the thread structure, thus causing the stress concentration area to change accordingly. However, when the shoulder clearance increases beyond the critical threshold, the situation will develop in an unfavorable direction. At this time, the role of the shoulder as an auxiliary load-bearing part in the connection structure will be greatly weakened, and the proportion of the load it bears will drop sharply. Due to the weakening of the load-bearing capacity of the shoulder, more external loads need to be borne by the thread structure, which leads to a significant increase in the overall stress level of the thread. The excessive increase in thread stress will significantly increase the possibility of plastic deformation of the thread teeth, and also raise the risk of initiation and propagation of fatigue cracks.

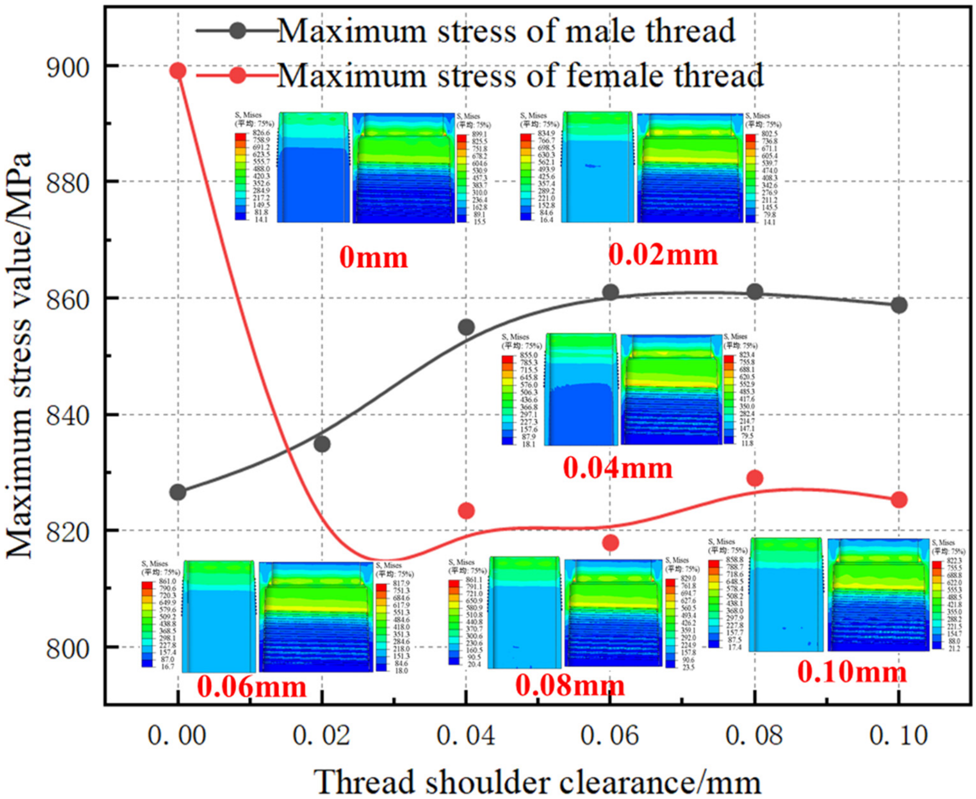

Fig 6. The law of stress variation under different shoulder clearances

4. Conclusion

(1) When under load, the stress at the small end of the male thread of the coupling-type casing thread is lower than that at the small end of the female thread. Reducing the tooth width at the small end of the male thread and increasing the tooth width at the small end of the female thread can balance the maximum stress of the male and female threads and improve the load-bearing capacity of the threads. However, a further increase in the tooth width ratio will lead to excessive stress at the small end of the male thread, making it the main failure part. Therefore, in the optimal design of threads, the optimal range of the tooth width ratio needs to be determined to achieve the coordinated optimization of stress balance and structural strength.

(2) With the increase of shoulder clearance, the maximum stress of the female thread of the coupling-type casing thread begins to decrease, and the maximum stress shifts from the female shoulder to the first thread turn. However, an excessively large shoulder clearance will reduce the load shared by the shoulder, and at this time, the overall stress of the thread increases. Reasonable design of shoulder clearance can balance the load between the shoulder and the thread and improve the load-bearing capacity of the thread.

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