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Research Article

Design of an ultra-high torque double shoulder drill-pipe tool joint for extended reach wells

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Abstract

Drill-pipe tool joints in extended reach wells often suffer a shear failure. In view of this, an ultra-high torque double-shoulder pipe joint was designed according to the deformation compatibility relation of the drill-pipe tool joint under torque. It is structurally characterized by long primary and secondary shoulders, small thread taper and large fillet radius of bottom tooth. First, a 3D numerical simulation model was established for this type of joint, named the XSJ joint here, based on the principle of virtual work, the Von Mises yield criterion and the nonlinear contact theory. Second, orthogonal optimization was performed on its key structural parameters by means of the orthogonal optimization method. The optimal combination of key structural parameters of the XSJ joint is taper 1:16, thread pitch 6.55 mm, guiding surface angle 29°, bearing surface angle 28°, and tooth height 3.755 mm. Finally, the bearing performance and fatigue performance of this tool joint and the API tool joint were calculated and compared using the Simulia Abaqus fe-safe software. Compared with the API tool joint, the XSJ joint is better, and its tensile strength, torsion strength, bending strength and compression strength increase by 10.65%, 62.5%, 2.75% and 52%, respectively. Its tension compression fatigue life, bending fatigue life, torsion fatigue life and composite fatigue life increase by 1.19 times, 1.74 times, 550 times and 28.79%, respectively. It is concluded that the designed XSJ joint is significantly improved in term of torsion capacity while its tension strength, bending strength and compression strength are not decreased, so it can better meet the drilling conditions of extended reach wells.

Keywords: Extended reach well; Tool joint; Shear failure; Torsion capacity; Bending capacity; Orthogonal optimization; Bearing property; Fatigue life

1. Introduction

In recent years, with the extensive application of extended reach well drilling technology in drilling engineering, the problem of shear failure of the drill-pipe tool joints caused by large downhole drag and torque has become increasingly prominent, which leads to increased drilling cycle and cost and becomes one of the main factors that limit the drilling engineering benefits. Statistics show [1,2] that, at the most conservative estimate, at least 500 drill pipe failure accidents occurred each year in domestic oil and gas fields, most of which are closely related to the drill-pipe tool joints, resulting indirect economic losses of up to CNY40 million. At present, more than 25% of the drill-pipe tool joints in China are imported directly from abroad. The import price is over 2 times than the domestic price. Moreover, for 60% of the drill-pipe tool joints, their structures are just imported from other countries, but the products are manufactured in China, with a large amount of patent royalties payable. These results in high investment, high risks and low profits for domestic drill-pipe tool joint manufacturers [3].

In order to reduce the failures of the drill-pipe tool joints during downhole operation, people have done a lot of research on the drill-pipe tool joints in recent years. Reasonable mechanical models and numerical calculation methods have been established based on theories and experiments, which produce

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more accurate mechanical properties prediction of the drill-pipe tool joints. Van Wittenberghe et al. used the optical dynamic 3D displacement analysis technique to evaluate the fatigue crack propagation behavior of threaded pipe connection [4]. Shahani et al. conducted numerical calculation of the contact stress and tensile stress concentration coefficient of drill-pipe tool joints [5]. Korin et al. proposed the introduction of controlled residual compressive stress at the maximum stress of a joint to alleviate the generation of fatigue cracks [6]. Akyildiz et al. studied the influence of machining parameters on the strength of joints [7]. Santus et al. carried out in-depth study on torsional strength comparison between two assembling techniques for aluminum drill pipes [8]. Ren Hui et al. designed a new double shoulder drill-pipe tool joint and analyzed its torsional performance [9]. Gao Lianxin et al. proposed a new directional HLBT-8ADE drill-pipe tool joint structure, and analyzed the torque sharing between the primary shoulder and the secondary shoulder and the thread under yield torque [10]. Zhu Xianghua et al. established the three-dimensional mechanical model of a drill-pipe tool joint, and conducted in-depth study on the failure of drill pipe thread gluing at the exit side of horizontal directional drilling and corresponding solution, and proposed an anti-bending drill-pipe tool joint [11]. Zhuang Yong et al. analyzed the stress of a drill-pipe tool joint under different fastening turns through the drill-pipe tool joint 2D axis symmetric model [12]. Helian Changlin designed a high torsional joint thread with a negative angle thread tooth bearing surface using the orthogonal optimization method [13]. These researches mainly focused on the mechanical properties analysis and failure prevention of drill-pipe tool joints, but few researches deal with an ultra-high torque double shoulder drill-pipe tool joint under large torque loads in extended reach wells.

Under this background, a high torque double shoulder pipe joint was developed according to the deformation compatibility relation of a drill-pipe tool joint. Based on the principle of virtual work, Von Mises yield criterion and contact nonlinear theory, a three-dimensional numerical simulation model of high torque double-shoulder drill-pipe tool joint was established. Orthogonal optimization method [14] was used to optimize the critical structure parameters. Thus, an ultra-high torque double shoulder pipe joint with a better performance was attained and named the XSJ joint here. The comparison of bearing and fatigue performance between the XSJ joint and the API drill-pipe tool joint highlights the advantages of the former in extended reach well applications.

2. A mechanical model of high torque drill-pipe tool joints

2.1. Mechanical characteristics of drill-pipe tool joints under a torque load

By applying torque to the end face of the pin or the box of the drill-pipe tool joints, the thread tooth and the shoulder surface will be compressed in engagement due to the influence of the lead angle. The roughness of the interacted surface may induce a friction under torque loads, so that a friction torque between the contact surfaces can be formed. When the drill-pipe tool joint is subjected to an external torque load, the sum of the friction torques on the thread tooth and the shoulder is equal to the applied external torque according to the static equilibrium, and the resultant force on the thread tooth is equal to the force on the shoulder. Fig. 1 shows the mechanical characteristic of the drill-pipe tool joints under a torque load.

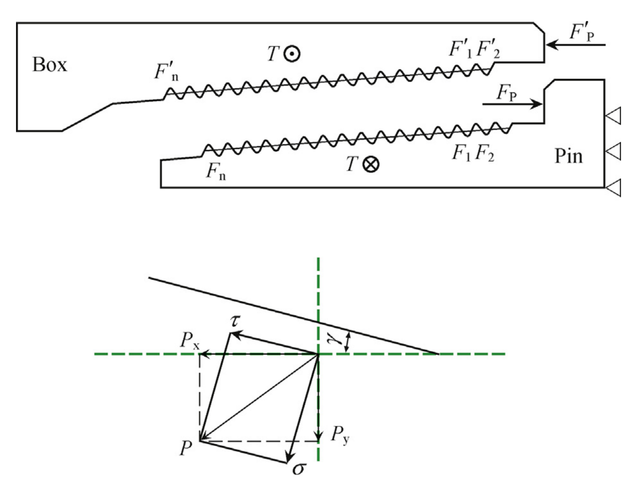
If the drill-pipe tool joint has no shoulders, the applied external torque will be borne entirely by the thread tooth; otherwise, the torque borne by the thread tooth is equal to the external torque minus the friction torque on the shoulder. Thus, the shoulder can protect the thread tooth to a certain extent. Assuming that the external torque of the drill-pipe tool joint is T, the torque on the shoulder is T_P, and the torque on the whole thread is T_T. According to the deformation compatibility relation of the drill-pipe tool joint, $T = T_P + T_T$. The relative value of T_P and T_T is related to the torsional rigidity of the shoulder and the root of the external thread large end, so the following could be attained [15]:

$$\frac{T_T}{T_P} = \frac{GI_T}{GI_P} = \frac{I_T}{I_P} \tag{1}$$

where, G is the shear modulus; I_T is the moment of inertia of the cross section of the external thread root; I_P is the moment of inertia of the shoulder surface cross section.

Under the torque load, the shoulder shares part of the torque load for the thread tooth, reducing the torque load on it. In order to further reduce the torque load on the thread tooth, an auxiliary shoulder is proposed to share the load on the thread tooth and reduce the peak stress at the thread tooth to improve the torsion resistance. So, the condition of high torque performance is proposed:

$$T = T_T + T_P + x \tag{2}$$



Note: ⊗ is the inward force that is perpendicular to the paper;
⊙ is the outward force that is perpendicular to the paper;
△ is the fixed boundary

Fig. 1. Mechanical characteristics of the drill-pipe tool joints under a torque load.