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Research on the calculation model of the free point depth of composite pipe string in shale gas horizontal well

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Abstract

Blockage is a relatively frequent accident in the workover process of shale gas horizontal wells. After the blockage occurred, the workover time was prolonged and the loss increased greatly. Efficient, rapid and accurate determination of the free point position is an important basis for solving stuck drill accidents. Based on Hooke's Law of Tension and Compression/Shear, this paper preliminarily establishes a calculation model for the free point of the composite pipe string under the condition of pulling. The research work in this paper is of great significance for accurately calculating the position of free points in engineering.

Keywords

Composite string; Shale gas horizontal wells; Free point; Calculation model.

1. Introduction

Blockage is an accident that occurs frequently during workover in shale gas horizontal wells, and after the occurrence, it leads to prolonged consumption time and increased losses. The blockage accident caused the downhole tools to not work normally during the workover. Therefore, in the process of handling blockage accidents, the location of the free point is particularly critical. Efficient, rapid and accurate determination of the free point position is an important basis for solving the stuck-in accident.

In recent years, a large number of scholars have conducted relevant research on the calculation of free point position, among which the representative ones are: Kuang et al. [1] used numerical simulation to calculate the workover string in highly deviated wells and compared them with theoretical models. The results show that the numerical simulation method can efficiently and accurately calculate the position of the free point. At the same time, the influence of the buckling instability and friction of the pipe string was also considered, and it was found that the upward force and the deformation were in a nonlinear relationship, and the relationship between the force and the position of the free point was calculated. Xu et al. [2] established an analytical solution based on Hooke's law and the principle of calculus, considering the influence of circular arc well deviation and dynamic friction. This model can more accurately describe the relationship between the depth of the free point and the elongation of the pipe string. Song [3] based on Hooke's law and applied calculus theory, considering factors such as pipe coupling, pipe string thickening, etc., the lifting method is used to analyze the force of the single pipe string and the composite pipe string respectively, the corresponding free point calculation method is obtained, and the pipe string correction coefficient is determined. Li et al. [4] based on the calculation principle of free point depth and Hooke's law, the frictional resistance of the pipe string in the borehole under the same hook load condition during the lifting and lowering process is equal and opposite, and it is deduced that the pipe string in the casing can be eliminated. The calculation formula of the free point depth affected by friction resistance. At the same time, the operation method and implementation steps of the calculation formula are proposed. Ran et al. [5] through theoretical derivation, the calculation formula of the free point measured by the stretching method is obtained, and the processing methods of these influencing factors are studied in two aspects: vertical well and inclined well according to various influencing factors of free point measurement. Finally, the correction formula for the free point measurement of the vertical well stretching method and the effective method for dealing with the friction factor in the inclined well are obtained. Han [6] analyzed the principle of the traditional free point depth calculation method, and pointed out the specific problems of the method described in the existing domestic and foreign documents. Through analysis, the calculation method and calculation formula of free point that can basically eliminate the influence of friction resistance are given.

In summary, many scholars have used numerical methods and finite element methods to conduct detailed studies on the location of the free points. The models have been simplified to a certain extent, and the effects of friction load, buoyancy, drill pipe joints and thickened parts have not been fully considered. Based on Hooke's Law of Tension and Compression/Shear, this paper preliminarily establishes a calculation model for the free point of the composite pipe string under the condition of pulling. The research work of this paper provides a new method for accurately finding the position of the free point in engineering practice, which has an important practical role in engineering.

2. Calculation model establishment

2.1. Traditional calculation method of free point depth

At present, the theoretical calculation methods of the free point mainly include the pulling method and the torsion method. The pulling method and the torsion method both are based on the mechanics of materials. The pulling force (torque) of a metal material when it undergoes elastic deformation under the action of pulling force (torque) and its elongation (torsion angle) has a linear relationship. Materials that satisfy Hooke's law are called linear elastic or Hooke-type materials. The characteristics of drill string materials can be regarded as Hooke type materials. Based on this principle, the relationship between tension and elongation, torque and torsion can be expressed as (1) and (2):

$$\begin{cases} \lambda_i = \dfrac{L_i(F_i + F_{i-1})}{2E_i A_i} \\ \varphi_i = \dfrac{L_i(T_i + T_{i-1})}{2G_i J_i} \end{cases} \tag{1}$$

$$\begin{cases} G = \dfrac{E}{2(1+\nu)} \\ J = \dfrac{\pi}{32}(D_i^4 - d_i^4) \end{cases} \tag{2}$$

When considering the influence of the thickened part of the drill pipe joint, the correction coefficients K_λ and K_φ of the lifting method and the torsion method can be obtained according to equations (1) and (2). The relationship between the tensile force and the elongation, the torque and the torsion of the unit body L_i can be expressed as (3):

$$\begin{cases} \lambda_i = \dfrac{L_i(F_i + F_{i-1})}{2K_{\lambda i}E_i A_i} \\ \varphi_i = \dfrac{L_i(T_i + T_{i-1})}{2K_{\varphi i}G_i J_i} \end{cases} \tag{3}$$

In formulas (1), (2), (3), λ_i is the elongation of the pipe string (mm); L_i is the length of the pipe string (m); E_i is the elastic modulus of the pipe string (N/m^2); F_i is the tensile force acting on the pipe string (N) ; A_i is the cross-sectional area of the pipe string (m^2); φ_i is the torsion increment of the pipe string (°); G_i is the shear modulus of the pipe string (m^4); T_i is the torque acting on the pipe string (N·m); J_i is the moment of inertia of the column (m^4); v is the Poisson's ratio of the string material, dimensionless; D_i is the outer diameter of the drill tool (m); d_i is the inner diameter of the drill tool (m).

2.2. A new calculation method

According to Hooke's law, a new method for calculating the free point position of the drill string under the condition of pulling is established. In this method, the pipe string is separated from top to bottom into N segments of unit bodies, and the length of each unit body is L_1, L_2,..., L_i,..., L_n respectively, the inclination angle corresponding to the upper end of each unit body is a_1, a_2,..., a_i,..., a_n, azimuth angle of each unit body is φ_1, φ_2,..., φ_i,..., φ_n. Based on this, the property parameters such as the length of the pipe string, the inner and outer diameters, the floating weight, the inclination angle, the azimuth angle, and the elastic modulus corresponding to each section of the unit body can be determined in sequence. Using the derived analytical model for calculation of friction and torque, the axial load and torque load at the upper and lower ends of each section of the unit body can be obtained respectively.

The on-site lifting operation method is shown in Fig. 1. Assume that F_a is the hook load when the drill string is in a free state in the drilling fluid, and L_a is the elongation of the drill string in a free state. First, the drill string is slowly and continuously raised from the axial force F_a to F_b, and the drill string elongation increment ΔL_{ba} from F_a to F_b is recorded, and the axial tension difference is ΔF_{ba}. Then the drill string is slowly and continuously raised from the axial force F_b to F_c, and the drill string elongation increment ΔL_{cb} from the axial force F_b to F_c is recorded, and the axial tension difference is ΔF_{cb}. Finally, the axial force F_c is slowly and continuously increased to F_d, and the drill string elongation increment ΔL_{dc} from the axial force F_c to F_d is recorded. The elongation of the drill string for three times of pulling is as shown in equations (4), (5) and (6):

$$L_b = L_a + \Delta L_{ba} \tag{4}$$

$$L_c = L_a + \Delta L_{cb} + \Delta L_{ba} \tag{5}$$

$$L_d = L_a + \Delta L_{dc} + \Delta L_{cb} + \Delta L_{ba} \tag{6}$$

The increments of axial tension of the drill string for three times of pulling are ΔF_{ba}, ΔF_{ca}, ΔF_{da}, respectively, and the increments of elongation are ΔL_{ba}, ΔL_{ca}, ΔL_{da}, respectively. The average values of the three times of lifting increment and elongation increment are shown in equations (7) and (8) respectively:

$$\overline{\Delta F} = \frac{\Delta F_{ba} + \Delta F_{ca} + \Delta F_{da}}{3} \tag{7}$$

$$\overline{\Delta L} = \frac{\Delta L_{ba} + \Delta L_{ca} + \Delta L_{da}}{3} \tag{8}$$

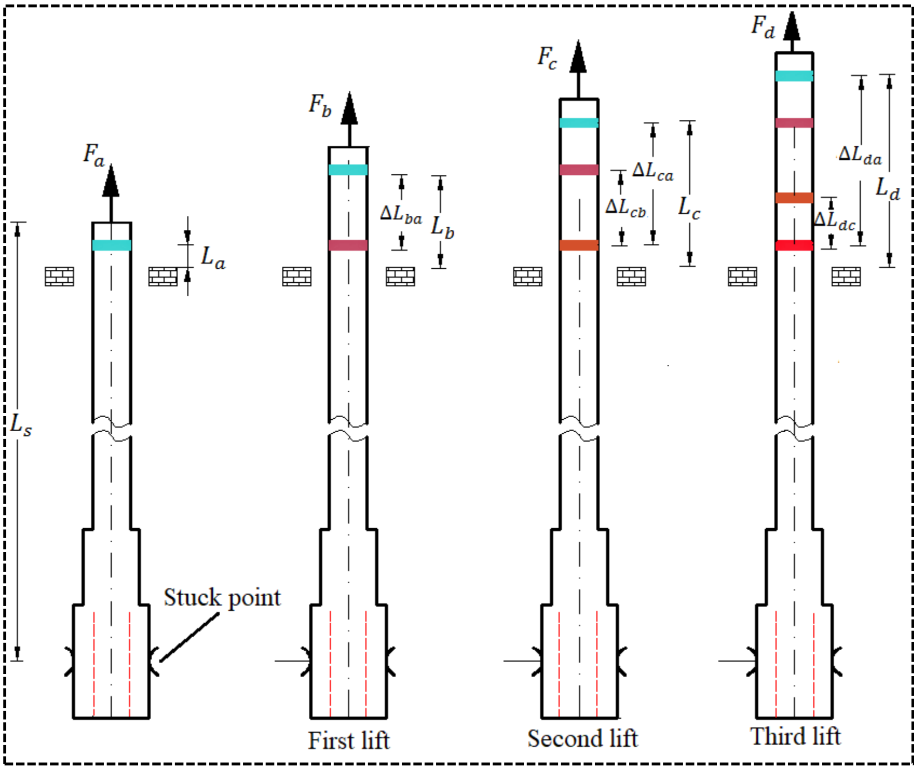

Fig. 1. Schematic diagram of multiple lifting operation method

The elongation increment of each unit body under the action of the average axial force increment $\overline{\Delta F}$ can be obtained as:

$$\Delta\lambda_1=\frac{\overline{\Delta F}_1 L_1}{E_1 K_{\lambda 1} A_1},\quad \Delta\lambda_2=\frac{\overline{\Delta F}_2 L_2}{E_2 K_{\lambda 2} A_2},\cdots,\Delta\lambda_i=\frac{\overline{\Delta F}_i L_i}{E_i K_{\lambda i} A_i} \tag{9}$$

The drill string elongation increment is:

$$\Delta\lambda_t=\sum_{i=1}^{n}\Delta\lambda_i=\Delta\lambda_1+\Delta\lambda_2+\cdots\cdots+\Delta\lambda_{i-1}+\Delta\lambda_i \tag{10}$$

When the theoretical elongation increment $\Delta\lambda_t$ of the pipe string is equal to the measured elongation $\overline{\Delta L}$, that is $\overline{\Delta L}=\Delta\lambda_t$, the free point depth L_S is:

$$L_s=\sum_{i=1}^{n}L_i \tag{11}$$

3. Conclusion

Aiming at the problem that the free point of shale gas horizontal well is difficult to accurately determine after the blockage occurs during the workover process. Based on Hooke's Law, a calculation model for the free point of the composite pipe string under pulling conditions is established in this paper. The model adopts the discrete method to calculate the length, inner and outer diameter, floating weight, inclination angle, azimuth angle, elastic modulus and other attribute parameters of each unit body corresponding to the string. Combined with the calculation analysis model of friction and torque, the increase of drill string extension and the depth of the free point under the pulling condition are established.

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