Characteristic Analysis of Collision Between Drill String and Well Wall

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Abstract. In order to improve the security of drilling progress and reduce the reliability impact which caused by the collision between drill string and well wall, the finite element analysis software ADINA is used to establish a finite element model to simulate the change of drill string stress after the collision between drill string and wellbore under different factors. The results show that the existence of drilling fluid with higher viscosity, lower revolution speed and autorotation speed of drill string and larger annular space is conducive to reduce the stress value caused by collision between drill string and wellbore and improve the security and stability of the drill string.

Keywords: Drill string; Collision; FEM; Characteristic analysis

1. Introduction

Every year drill string failure could produce a large number of drilling accidents and cause great economic losses. The dynamics of the drill string in the wellbore are complicated and there are many kinds of vibration forms. The collision between drill string and well wall is the leading cause of premature failure of the drill string. In order to improve the security and stability of drilling, analyzing the factors influenced the collision between drill string and well wall is necessary and the analysis results also play a guiding role in the actual drilling process.

At present, among the analysis of drill string mechanics, the drill string dynamic is one of the key research directions. Millheim and Apostal[1-3] applied D ’Alembert principle to analyze dynamic characteristics of BHA. They also studied the influence of factors such as stabilizer, bit force, buoyancy. Hayat[4] studied BHA dynamic characteristics through experiment and calculation simulation, mainly analyzed the influence of friction coefficient on vortex motion trajectory. Through the establishment of the experimental model of drill string, YangLie Zhang[5] finds that the drill string reversal movement causes the variety of adverse consequences, and drill string failure often occurs downhole. By using experimental method and numerical simulation, Qingyou Liu[6] calculated the magnitude and law of collision in the drilling process under different parameters, which provides a theoretical basis for effectively preventing the early failure of drilling tools and reducing the loss caused by collision. The research of Li Maosheng [7] shows that the propagation of bending stress waves caused by collision is an important reason for the combined failure of drill string and the alternating stress of drill string, and the transfer and superposition of stress waves will cause great
stress at local position. Y. A. Khulief[8] used a continuous force-displacement law to simulate the impact of the effect in a short time interval, which determined by energy conservation material compliance and the damping coefficient. The Lagrange method and finite element method are used to establish the dynamic model of the rotating drill string, the time response of the drill string system is obtained. Shangyu Yang[9] utilized explicit integration and nonlinear finite element to simulate the collision between the drill string and formation. Qingyou Liu[10] established a dynamic model of drill string, and used the latest numerical solution method based on CA to solve the model, the stability of the BHA is evaluated by the position of tangent points and their forces.

In this paper, a dynamic simulation is carried on to study the collision process of the drill string and well wall. The presence of the drilling fluid, the drill string revolution and autorotation speed, annular gap and the influence of drilling fluid parameters on the collision process is analyzed which could provide the theory basis for the selection of drilling parameters for the actual drilling process.

2. Method of collision between drill string and well wall

2.1 The calculation equation of collisions between drill string and borehole wall

In the process of the drill string collision wall, the control equation of the drill string can be expressed as using Lagrange algorithm.

Momentum equation:

\[ \sigma_{ij} + \rho f_i = \rho \ddot{x}_i \]  

Mass conservation equation:

\[ \rho = J \rho_0 \]  

Energy equation:

\[ E = V S_j \varepsilon_j - (p + q) V \]  

Where, \( \ddot{x}_i \) is accelerated velocity; \( \sigma_{ij} \) is Cauchy stress tensor; \( \varepsilon_{ij} \) is Strain rate tensor; \( S_{ij} \) is deviator stresses tensor; \( f_i \) is unit mass volume force; \( V \) is the current volume; \( \rho \) is the current density; \( E \) is the current energy; \( \rho_0 \) is the initial density; \( J \) is the rate of volume change; \( p \) is pressure; \( q \) is viscous resistance; \( \delta_{ij}=1 \) when \( i=j \) and \( \delta_{ij}=0 \) when \( i\neq j \).

2.2 Calculation equation of the fluid

The ALE method is used for fluid flow calculation, its basic thought is that the grid is no longer fixed and the grid isn’t attached to the material particles, and it can do arbitrary motion. The continuity equation and momentum equation of fluid are as follows:

\[ \text{div} \, \nabla = 0 \]  

\[ \rho \gamma v + \rho \gamma \nabla \cdot v - \text{div} \, \sigma - \rho \gamma b = 0 \]  

Where, \( \rho \gamma \) is fluid density; \( v \) is fluid velocity; \( b \) is force on unit mass; \( c \) is convection velocity; \( \sigma \) is fluid stress tensor.
2.3 Collision calculation method with fluid-structure interaction

Fluid-structure interaction is a strongly nonlinear problem, its solving process involves iteration method. The synchronous alternating method is adopted in this paper, the idea of the method is to alternate solving process of the synchronous alternating method into the iterative process, thereby time difference between the fluid domain and solid domain is eliminated in order to prevent the accumulation of error. As shown in Fig.1, The results of fluid domain and solid domain is calculated alternately at time t, The results of the next moment will be calculated when the accuracy of results is higher than expected, thereby the fluid domain and solid domain was solved synchronously.

3. Model parameter selection

Simulating the collision process with the finite-element analysis software ADINA to explore the influence of different drilling parameters on the collision effect. The model diagram established is shown in Fig.1, in which the simulation parameters are as follows:

(1) Geometric parameter
Using the diameter of 127mm drill string for the simulation model of drill string, the joint diameter is 177.8 mm, the outer diameter of rod body is 127 mm, the inner diameter of the drill string is 108.6 mm, length of the drill string is 10 m and the joint length is 0.4 m.

(2) Material parameter
Steel is selected as the drill string material, young's modulus $E = 206$GPa, Poisson's ratio $\mu = 0.3$, the material density $\rho = 7850$ kg/m$^3$.

Drilling fluid is non-Newtonian fluid, and the power law model is adopted, the expression is as follows:

$$\tau = K \gamma^n$$  \hspace{1cm} (6)

Where $\tau$ is the shear stress; $\gamma$ is the shear rate, $K$ is the consistency coefficient, $n$ is the power-law index.

(3) The boundary conditions
Borehole multiconstraining; Drill string is constrained by the well wall and the axial displacement, can translate and rotate in the well hole; The axial force of end face of the drill string was imposed on 50kN to simulate the drill press supported by the drill string in the hole; Axial pressure and speed driving are imposed on drilling fluid end face to simulate flow of drilling fluid and the well wall is the rigid body.
(4) Element selection
The simulation model of collision between drill string and borehole consists of three parts, respectively are the drill string, well bore and drilling fluid. The drill string fluid adopts 3-D Solid element, and the drilling fluid adopts the FCBI-C element. A mapping mesh is created to improve the computing speed and accuracy, and refine the grid in the location where the collision may occur.

![Whole model](image1)

![Fractionated gain](image2)

Fig. 2 the model of collision between drill string and well wall

4. The finite-element analysis of dynamic characteristics of collision between drill string and well wall
The numerical simulation is carried on from the influence of the factors such as drill string collision speed, rotation speed, drill string annulus clearance, the existence of the drilling fluid and drilling fluid viscosity, etc. on the collision between drill string and well wall.

4.1 The influence of drill string rotation speed on collision simulation
The numerical simulation is carried on to study the effect of drill string autorotation speed on the collision model. And the drill string speeds are 44.5 r/min, 75 r/min and 92 r/min.

![Radial displacement of the central point](image3)

![Major principal stress of the central point](image4)

Fig. 3 Radial displacement of the central point  
Fig. 4 Major principal stress of the central point

Fig. 3 and Fig. 4 show that with the increase of drill string rotation speed, the radial displacement and principal stress in the middle of drill string do not change significantly. However, with the increase of drill string rotation speed, the frequency of drill string alternating stress increases, which may increase the possibility of drill string fatigue damage.

4.2 The effect of drill string collision speed on collision simulation
The numerical simulation is carried on to simulate the collision simulation to study the effect of the drill string collision speed, and the speeds respectively are 3.27m/s, 7m/s.
As shown in Fig. 5, with the increase of impact speed, the amplitude and frequency of impact stress increase. And as shown in Fig. 6, with the increase of impact speed, the variation range of radial displacement in the middle of drill string also increases, which leads to the increase of bending deformation and deformation speed. The simulation results show that the reduction of collision velocity can significantly reduce the bending deformation and bending stress, and improve the safety of drilling process.

4.3 Influence of annular clearance on collision model
The hole diameter are 215.9mm and 254mm respectively (annulus clearance are 38.1mm and 19.05mm respectively), and the impact of annulus clearance on the collision model is numerically simulated to study the impact of annulus clearance on the collision model.

As shown in Fig. 7, the increase of annular space reduces the collision speed between drill string and borehole wall, resulting in the decrease of stress variation range, which may reduce the impact stress and alternating stress of drill string. And as shown in Fig. 8, the increase of the annular space gap increases the radial displacement of the drill string, but when the peak value of the radial displacement reaches the middle of the drill string, the deflection value of the drill string decreases, i.e., the deformation and the bending stress of the drill string is reduced. Hence, the increase of annular space is beneficial to reduce the overall stress value of drill string and improve the safety and reliability of drill string.

4.4 Influence of drilling fluid on the collision model
The influence of drilling fluid on the collision model is studied by considering whether there is drilling fluid in the annulus.
Fig. 9 Major principal stress of the central point
As shown in Fig. 9, when there is no fluid in the annulus, the drill string will vibrate violently after collision. When there is fluid, the vibration of drill string is relatively gentle after collision, and the variation range of radial displacement of drill string is greatly reduced, which may reduce the amplitude and frequency of bending deformation and bending stress. Fig. 10 shows that the existence of drilling fluid significantly reduces the amplitude and the frequency of the strain change in the middle part of the drill string, so the stress amplitude and change frequency of the drill string will also decrease dramatically.

Without considering the fluid interaction, the stress variation rule of model is consistent with the stress variation rule obtained through the experiments by Yanglie Zhang [3], which indicates that numerical simulation in the collision process can be simulated effectively by the simulation model of collision of drill string and borehole wall established by ADINA. The simulation results show that the existence of drilling fluid can significantly reduce the vibration and alternating stress of drill string after the collision between drill string and borehole wall, which may greatly reduce the possibility of drill string fatigue failure and improve the safety of drilling process.

5. Conclusions
(1) With the increase of drilling rate, the impact stress and bending deformation of drill string is not significantly altered, but the change frequency of alternating stress will increase. The possibility of drill string fatigue failure can be reduced by properly reducing drilling rate.
(2) The increase of annular space will accompany the reducing of the collision speed, which will reduce impact stress and the change frequency of stress, and is beneficial to improve the reliability of drill string.
(3) Because the damping effect of the drilling fluid can reduce the impact of the drill string stress and deformation of the drill string, the presence of drilling fluid can obviously reduce the impact stress, so as to improve the safety and reliability of the drill string. Compared with the air drilling, the traditional drilling method still has some advantages, which is beneficial to reduce stress value of drilling column in the drilling process. In addition, drilling fluid properties can be improved with increasing its viscosity, in order to improve the safety of the drilling process.

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