International Journal of Research in Science and Technology http://www.ijrst.com

(IJRST) 2017, Vol. No. 7, Issue No. I, Jan-Mar **e-ISSN: 2249-0604, p-ISSN: 2454-180X**

MECHANISM OF STICK-SLIP VIBRATION OF DRILL STRING CONSIDERING AXIAL AND TORSIONAL OSCILLATIONS

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ABSTRACT

In new oil and gas resources mining, under the complex well structure of Deep well, multi-lateral well, directional well and high angle hole make downhole tools face more severe downhole environment and the stick-slip vibration phenomenon of the drill string is more prominent. According to the existing research results, this paper establishes a longitudinal and torsional drill string model based on the coupling effect of axial and torsional oscillations, which is more consistent with the actual situation. With the boundary conditions determined according to the drilling situation, the stick-slip of drill string results are simulated by MATLAB and Newmark-β Method, the numeral analysis cases related to WOB, RPM, and the axial vibration of drilling string are proposed to prove the validity and feasibility of the model. The research results can provide reference for the new conditions of stick slip mechanism, and the inhibition of stick slip phenomenon. On the other hand, the results have important practical significance for preventing downhole accidents and improving drilling efficiency for complex well structure.

Keywords**：** *drill string; stick-slip; axial; torsional*

1 INTRODUCTION

In rotary drilling, with the increase of drilling depth, drilling conditions become more and worse. The vibration of drilling systems is particularly important. With drilling, drill string vibrations typically include axial vibration, lateral vibration, and torsional vibration. The stick-slip phenomenon is one of the phenomena caused by these composite vibrations. Stick-slip phenomenon consists of two stages: stick and slip. Stick-slip phenomenon can sometimes cause the drill string to tighten like clockwork, suddenly release. Stick-slip phenomenon will lead to drastic deformation of the drill string, and may serious reduce the performance of drill strings and bits[1-4].

In order to find out the stick-slip mechanism, a lot of scientific researches have been carried out by domestic and foreign scholars, such as neglecting the torsional rigidity of BHA, simplifying drill string vibration system into a mathematical model of torsion pendulum, studying the interaction rule between drill bit and rock, the torsional pendulum model of stick-slip vibration is established. Considering the coupling of axial torsion and the interaction of rock and bit, the differential equation of delay is established. The Lagrangian method is used to solve the equations of motion of drill string [5-10]. In the last few years, the discrete model is established. The research of the coupling-axial, torsion and transverse vibration on the stick-slip vibration is mainly focused on the establishment of partial differential equation. The solution process is complex and the parameter change has great influence on the solving process. Based on this, this paper adopts the discrete method to discretize the drilling system, considering the stiffness and damping of the drill string by coupling the axial and axial torsion. The analytical model of stick-slip of the drill string is established. The vibration equation is solved by Newmark method. The research method provides a new idea for the study of the stick-slip phenomenon of drill string, which is of reference value for controlling the stick-slip phenomenon of drilling string and drilling speed-increasing efficiency.

2 COUPLING BETWEEN TORSIONAL AND AXIAL VIBRATIONS

2.1 Dynamic model

Drilling system including a drill floor, the drill string and drill bit and BHA, In order to facilitate the calculation, this article makes the following assumptions: (1) Weight of bit on the top of drilling rig and rotating speed is constant, respectively H_0 , w_0.(2) The borehole is vertical and the drill string is not in contact with the borehole wall and the drill bit does not move laterally in the bottom of the well. (3) The influence of drilling fluid on drill string and bit is neglected. (4) Assume that all forces are concentrated at the drill bit. The drilling dynamic model is shown in Figure 1.

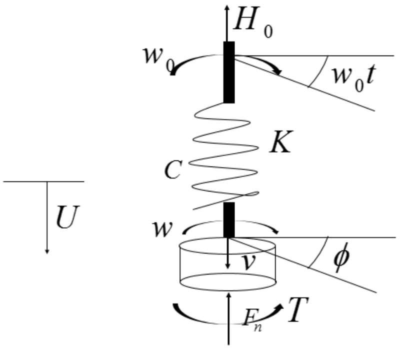

Figure1. Drilling dynamic model

2.2 Drill string system discretization

Assuming that the upper end of the drill string is fixed and considering the axial and torsion, the element stiffness matrix and the element mass matrix can be expressed in the following form:

$$M_e = \int_0^l N_u{}^T \rho A N_u dx + \int_0^l N_\theta{}^T \rho I N_\theta dx = \begin{bmatrix} \rho Al/3 & 0 & \rho Al/6 & 0 \\ 0 & \rho Il/3 & 0 & \rho Il/6 \\ \rho Al/6 & 0 & \rho Al/3 & 0 \\ 0 & \rho Il/6 & 0 & \rho Il/3 \end{bmatrix} \quad (1)$$

$$K_e = EA\int_0^l N_u{}^T N_u' dx + GJ\int_0^l N_\theta{}^T N_\theta' dx = \begin{bmatrix} EA/l & 0 & -EA/l & 0 \\ 0 & GJ/l & 0 & -GJ/l \\ EA/l & 0 & -EA/l & 0 \\ 0 & GJ/l & 0 & -GJ/l \end{bmatrix} \quad （2）$$

Since it is a vertical borehole, the nodal coordinate system is the global coordinate, and no coordinate transformation is necessary. The unit mass matrix and the element stiffness matrix are defined by partitioning:

$$[K_i] = \begin{bmatrix} K^i{}_{11} & K^i{}_{12} \\ K^i{}_{21} & K^i{}_{22} \end{bmatrix} \quad (3)$$

$$[M_i] = \begin{bmatrix} M^i{}_{11} & M^i{}_{12} \\ M^i{}_{21} & M^i{}_{22} \end{bmatrix} \quad (4)$$

According to the global coordinate system under the overall quality matrix and the stiffness matrix to get the idea of superposition of the overall mass matrix and the overall stiffness matrix is as follows:

$$[M]=\begin{bmatrix} m^{1}{}_{11} & m^{1}{}_{12} & & & \cdots & \cdots & \cdots & \cdots \\ m^{1}{}_{21} & m^{1}{}_{22}+m^{2}_{11} & m^{2}_{12} & & & & & \\ & m^{2}_{21} & m^{2}_{22}+m^{3}_{11} & m^{3}_{12} & & & & \\ & & m^{3}_{21} & \cdots & \cdots & & & \\ & & & \cdots & \cdots & & & \\ & & & \cdots & \cdots & \cdots & & \\ & & & & & & m^{n-1}_{22}+m^{n}_{11} & m^{n}_{21} \\ & & & & & & m^{n}_{21} & m^{n}_{22} \end{bmatrix} \tag{5}$$

$$[K]=\begin{bmatrix} k^{1}{}_{11} & k^{1}{}_{12} & & & \cdots & \cdots & \cdots & \cdots \\ k^{1}{}_{21} & k^{1}{}_{22}+m^{2}_{11} & k^{2}_{12} & & & & & \\ & k^{2}_{21} & k^{2}_{22}+m^{3}_{11} & k^{3}_{12} & & & & \\ & & k^{3}_{21} & \cdots & \cdots & & & \\ & & & \cdots & \cdots & & & \\ & & & \cdots & \cdots & \cdots & & \\ & & & & & & k^{n-1}_{22}+k^{n}_{11} & k^{n}_{21} \\ & & & & & & k^{n}_{21} & k^{n}_{22} \end{bmatrix} \tag{6}$$

Then the damping matrix can be shown:

$$C=\alpha M+\beta K \tag{7}$$

After applying the finite element method to the discrete-time treatment, the vibration control equation of the system is obtained by using the principle of the instantaneous minimum potential energy:

$$M\ddot{x}(t)+C\dot{x}(t)+Kx(t)= \tag{8}$$

Above formation also can be expressed in the form:

$$[M]\begin{bmatrix}\ddot{x}_1\\ \ddot{\phi}_1\\ \ddot{x}_2\\ \ddot{\phi}_2\\ \cdots\\ \cdots\\ \ddot{x}_n\\ \ddot{\phi}_n\end{bmatrix}+[C]\begin{bmatrix}\dot{x}_1\\ \dot{\phi}_1\\ \dot{x}_2\\ \dot{\phi}_2\\ \cdots\\ \cdots\\ \dot{x}_n\\ \dot{\phi}_n\end{bmatrix}+[K]\begin{bmatrix}x_1\\ \phi_1\\ x_2\\ \phi_2\\ \cdots\\ \cdots\\ x_n\\ \phi_n\end{bmatrix}=\begin{bmatrix}F_1\\ T_1\\ F_1\\ T_2\\ \cdots\\ \cdots\\ F_n\\ T_n\end{bmatrix} \tag{9}$$

2.3 Boundary conditions of stick-slip vibration

In order to solve Eq. (8), the necessary boundary conditions must be determined. Boundary conditions are divided into drilling rig boundary conditions and bit boundary conditions.
The top of the drill string rotates at a constant speed, the boundary conditions of drilling rig are given by:

$$\Omega(t) = \Omega_0 \tag{10}$$

$$\phi(t) = (\tag{11}$$

Where $\Theta(t)$ is dynamic twist angle function of drill string.

Axial force and torque are present at the bit, taking into account the axial and torque effects, the relationship between the torque T and the axial force W can be expressed as

$$T = 2\mu\, a\, W \mathrm{s\ g\ n}(\frac{d\phi}{dt} \tag{12}$$

Where The axial force W is a function of the static weight of the bit

$$W = W_0 (1 + \alpha \cos 2\pi f_a) \tag{13}$$

The model assumes that the bit is always in contact with the bottom of the well, $\alpha < 1$.

3 DYNAMIC RESPONSE ANALYSIS

3.1 Numerical parameters

Based on the above model and calculation method, the stick- slip of drill string is analyzed. The example parameters are shown in Table 1 below.

Table 1 drilling data

Drill string density $\rho\left(kg/m^3\right)$	**7850**
Drill pipe inside diameter $d\left(m\right)$	0.095
Drill pipe outer diameter D	0.127
Modulus of elasticity $E\left(GPa\right)$	210
Shear modulus $G\left(GPa\right)$	76.923

Bit diameter $R(m)$	0.2
Coefficient of static friction u	0.5

3.2 Dynamic response analysis result

In this section, we analyze the effects of rotational speed, drilling depth and WOB on the stick-slip vibration by using MATLAB.

According to Fig. 1, when the drill bit is in the stick stage, the drill bit angular speed is 0rad/s, when the bit rotation speed is 7rad / s and the WOB is 30KN. At this time, the upper part of the drilling rig continues to rotate and the torque is continuous-ly transmitted to the drill bit. When the torque reaches the maximum friction torque, the drill starts to rotate, and the instantaneous speed of the bit reaches three times at the speed of the upper drill bit, and then speed of bit decreases gradually. If the fric-tion between the rock and the drill bit is enough to prevent the bit from reversing, the speed of bit will be equal to 0rad/s, when the drill bit enters into the stick stage.

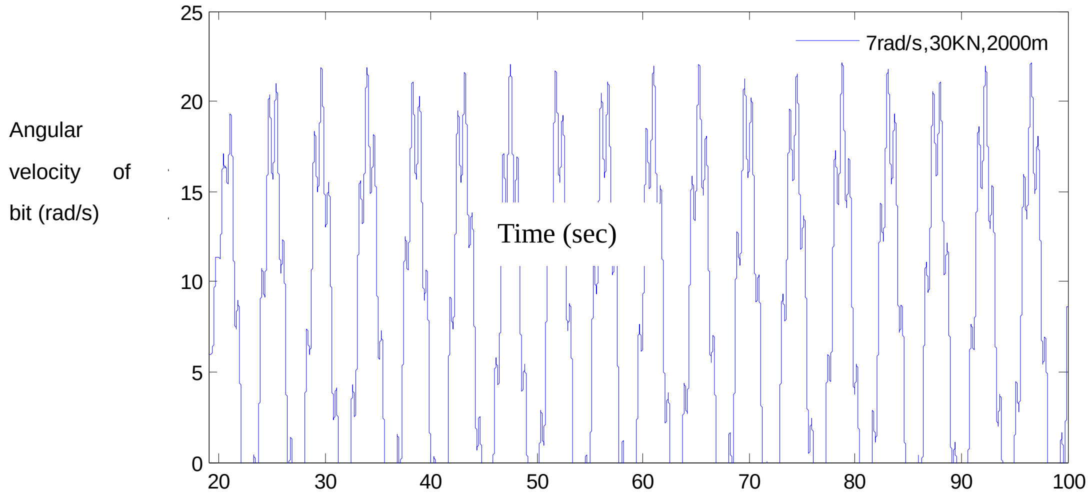

Fig 1 angular velocity of bit, ROP = 7rad/s, WOB=30kn

Figure 2 shows that when the ROP is 10rad / s, compared to 7rad / s, the drill bit does not appear obvious stick state, the minimum speed of about 4rad / s.

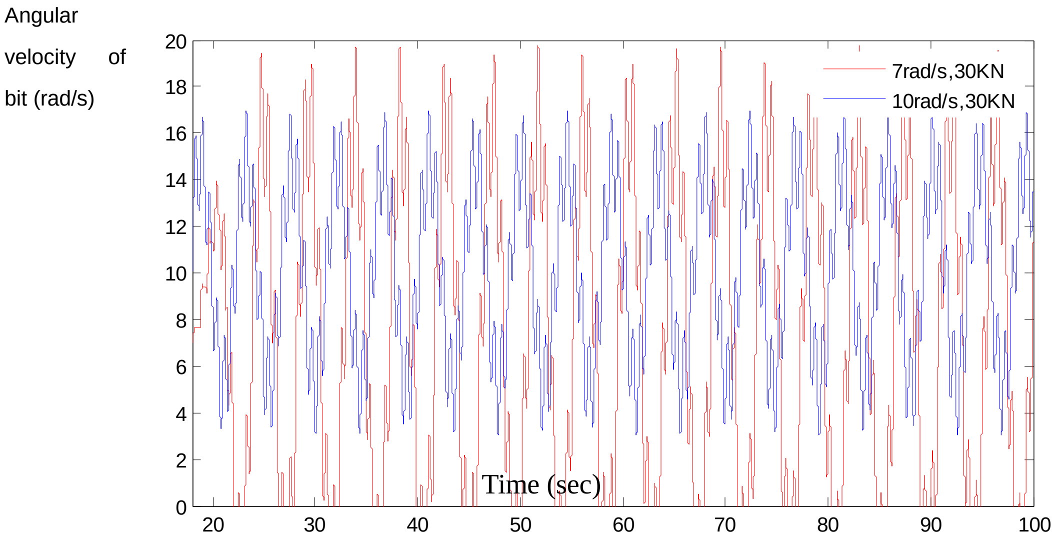

Fig 2 angular velocity of bit, compared ROP 7rad/s to 10rad/s

It can be seen from the comparison of Fig. 3 that reducing the WOB can prevent or eliminate the stick-slip vibration phenomenon. When the speed is 7rad / s, WOB decreases from 30KN to 15KN, the stick slip phenomenon disappears.

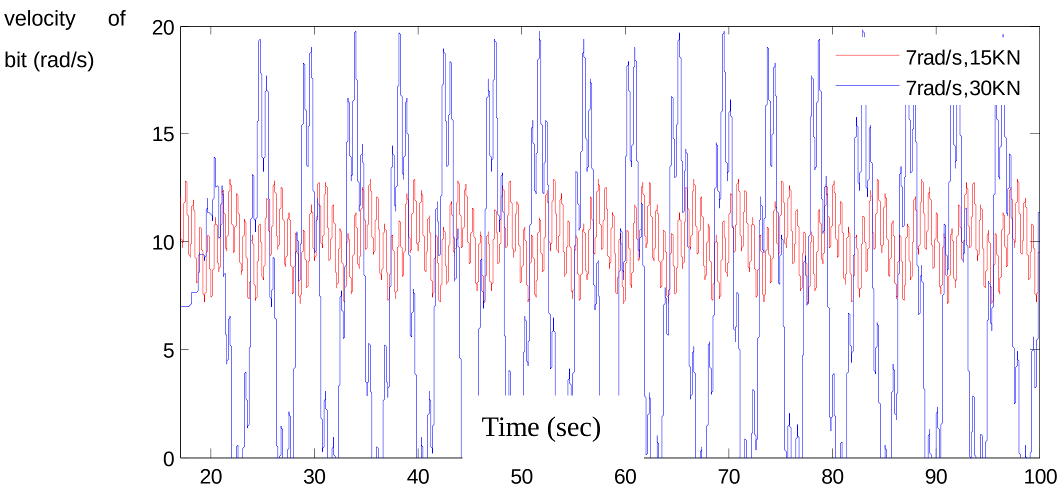

Fig 3 angular velocity of bit, compared WOB 15KN to 30KN

As shown in Figure 4, when changing the drill string length and other drilling conditions remain unchanged, with the drilling depth increases, this will increase the probability of occurrence of stick-slip phenomenon.

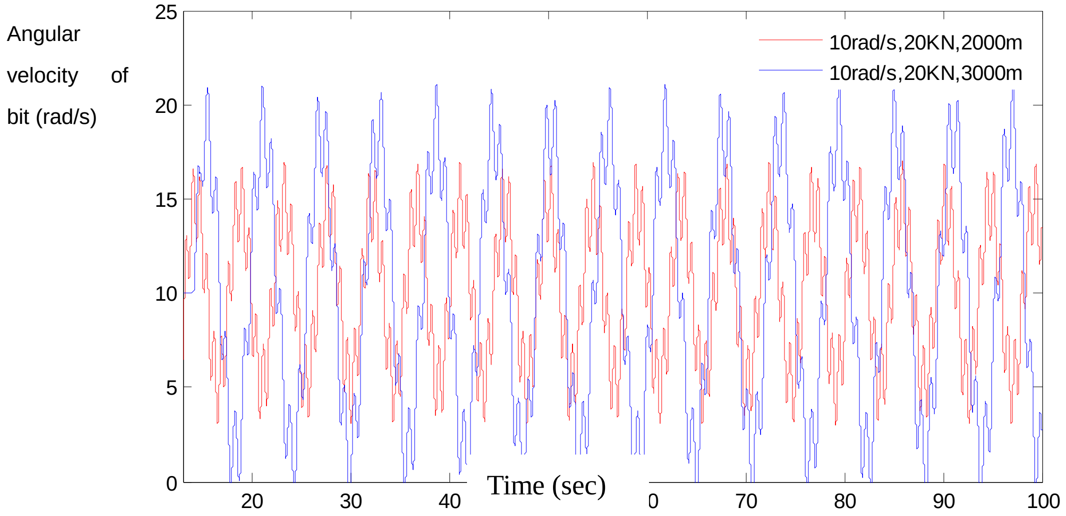

Fig 4 angular velocity of bit, compared L = 2000M to 3000

4 CONCLUSIONS

The drilling process is a dynamic process. In this paper, the numerical results show that the drill bit vibration in the downhole:

1) Increasing the drilling speed or reducing the WOB can effectively reduce or eliminate the stick-slip vibration.

2) With the increase of drilling depth, the stick - slip vibration is aggravated;

3) Axial vibration is also one of the causes of stick-slip vibration, control of axial vibration is also effective to reduce stick-slip vibration. The results also further confirm the conclusions drawn in [8] and [10].

The research methods and analytical models proposed in this paper have important reference value for oil and gas well drilling under complicated working conditions, including deep, ultra-deep and horizontal wells.

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