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STABILITY ANALYSES OF A DRILL STRING SYSTEM

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Summary. *To avoid stick-slip vibration, one of the most important forms of self-excited vibrations in deep hole drilling, this paper studies the stability a drill system based on a two-degree-of-freedom discrete model. It is a state-dependent delay model that could describe the non-linear dynamic characteristic of drilling systems more accurately, compared with the traditional constant delay models.*

Keywords: *stick-slip vibration; self-excited vibration; state-dependent delay*

1. Introduction

Delay differential equations often appear in various fields of science and engineering, such as control systems, lasers, neuroscience and cutting process dynamics. For cutting dynamics, the cutting effect of tools can cause vibrations in the cutting system, resulting in accelerated wear of tools and influencing the cutting process in machines (turning, milling and grinding), coal seam mining, geological prospecting and oil drilling.

In this paper, a two-degree-of-freedom model considering axial and torsional vibration was established, and the linear stability and the characteristics of Hopf bifurcation of the drilling system were studied by using the method of multiple scales.

2. Dynamic Model of Drilling System

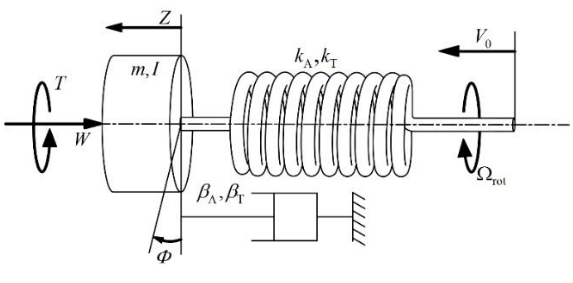

Figure 1. Dynamic model of the drill string system.

The dynamic equations of the drill string system for the SDD model and CD model can be written as:

$$m\ddot{z}(t)+\beta_A\dot{z}(t)+k_Az(t)=-\zeta saN\left[z(t)-z_\tau-\frac{V_0}{\Omega_{rot}}\left(\phi(t)-\phi_\tau\right)\right] \qquad (1)$$

$$I\ddot{\phi}(t)+\beta_T\dot{\phi}(t)+k_T\phi(t)=-\frac{1}{2}sa^2N\left[z(t)-z_\tau-\frac{V_0}{\Omega_{rot}}\left(\phi(t)-\phi_\tau\right)\right] \tag{2}$$

$$m\ddot{z}(t)+\beta_A\dot{z}(t)+k_Az(t)=-\zeta saN\left[z(t)-z_\tau\right] \tag{3}$$

$$I\ddot{\phi}(t)+\beta_T\dot{\phi}(t)+k_T\phi(t)=-\frac{1}{2}sa^2N\left[z(t)-z_\tau\right], \tag{4}$$

where $z_\tau = z(t - t_n)$, $\phi_\tau = \phi(t - t_n)$.

3. Stability Analysis

The dynamic equations of the drilling system have a stable solution, i.e., $z(\tau) = \phi(\tau) = 0$ (drilling without vibration), which is the equilibrium point of the system. The stability of the equilibrium point is analyzed in this section. The linearized homogeneous state vector equation can be obtained as:

$$\dot{\boldsymbol{x}}(\tau)-\boldsymbol{A}x(\tau)-\boldsymbol{B}x(\tau-\tau_{n0})=\boldsymbol{0} \tag{5}$$

This is a delayed differential equation, and its characteristic equation is:

$$\left|\lambda\boldsymbol{I}-\boldsymbol{A}-e^{-\lambda\tau_{n0}}\boldsymbol{B}\right|=\boldsymbol{0}, \tag{6}$$

where λ denotes an eigenvalue of the linearized system and the exponential term appears due to the time delay.

There are an infinite number of eigenvalues in Equation (6). The drill string system is stable only when all the eigenvalues have negative real part ($Re(\lambda) < 0$), otherwise the system is unstable. Pure imaginary eigenvalues ($Re(\lambda) = 0$) corresponding to a specific condition determine the stability boundaries that divide the stable and unstable regions.

There are seven lobes in the Figure 2; the upper part of the lobe is the instability of the drilling system, the lower part of the lobe is the stable interval, and the lobe represents the critical cutting depth. In the case of drilling, the appropriate control parameters Ω and ρ can be chosen through the stability lobes to realize a working condition without stick-slip vibration and improve drilling efficiency. From the figure, it can be seen that the system stability interval increases with non-dimensional rotational speed. On the other hand, the stability boundaries are higher for the state-dependent delay model than for the constant delay model. For the SDD model, the system stability interval increases with the control parameters ρ.

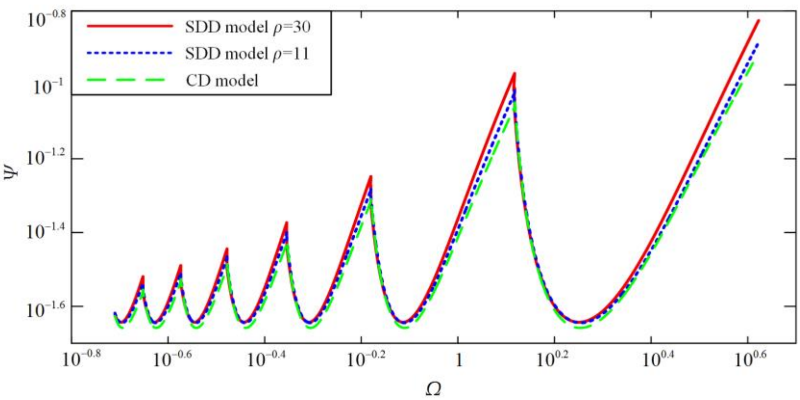

Figure 2. Stability charts of SDD and CD model.

4. Conclusions

This paper simplified the drilling system to a two-degree-of-freedom discrete model and studied the stability for two kinds of delay models (CD model and SDD model) in stick-slip vibration that are caused by regenerative cutting. The results show that the stability interval of the drilling system increases with rotational speed. In the stability analysis, the stability difference between CD model and SDD model is very small when the control parameter ρ is small. However, when the control parameter ρ become large, the stable intervals of the SDD model are bigger than those of the CD model, which means the SDD model can be applied to a wider operational range.

In conclusion, the SDD model can be applied to a wider operational range than the CD model, and can better reflect the non-linear nature of the drilling system. Moreover, the stability bounds of the SDD model are higher than for the CD model. The method and results can be adopted for deep hole drilling stability prediction and provide a reference for the dynamic optimization design.

STUDY ON THE INSULATION PERFORMANCE USING THE OPTIMIZED CHARGE SIMULATION METHOD

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Summary. *A new approach for the computation of electric fields is described, based on the response surface methodology (RSM) and geometric feature charge simulation method (GFCSM). And the novel combination of RSM and GFCSM is applied to calculate the electric field of the high voltage SF6 arc quenching chamber in this paper. The electric field distribution with higher calculation precision has been achieved. The results of the comparison between the conventional and proposed techniques are presented. Moreover, the new approach proves to be more efficient, minimizing computation of the electric field with multi dielectric medium.*
Keywords. *Electric field, CSM, RSM, SF6 arc quenching chamber*

Introduction

The numerical computation of electrics field plays very important role in analyzing the insulation performance and R&D of the high voltage electrical apparatus[1-2]. Numerical computation method of electric field covers boundary division and domain division method. In which, as one of the boundary division method, charge simulation method (CSM) has higher calculation precision[3-4]. For the application of the conventional CSM, in order to obtain the reasonable matching relationship between the fictitious simulation charges and the contour points, the number and the allocation of the fictitious simulation charges need to do many manual adjustments and amendment. However, the adjustment work is tedious. For solving the above limitations, a novel geometric feature charge simulation method (GFCSM) is proposed.

With the increase of the voltage, for the electrical appliance, the electric field calculation models become more complicated, and calculation time is relatively long. Besides, the goal variable is generally nonlinear and the field boundary is relatively complex. For solving the concrete problems, the response surface methodology (RSM) is applied. RSM can be used in many spheres[5] such as microbiol, mechanical science and food science, etc. It can be used for modeling and analyzing the response problem influenced by many variables, and the response variables are optimized. The application of RSM is to improve the calculation efficiency and guarantee the algorithm precision.

The RSM-GFCSM

The principle of RSM-GFCSM is described as follows: