Effect of wear flat length on the global dynamics of rotary drilling

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Abstract. The regenerative effect developed by the variable thickness of cut in rotary drill system yields self-excited vibrations. These vibrations are the main cause of excessive wear on the tool edge. This cause a wear flat to develop behind the cutting edge. Interaction between the wear flat and rock surface results in a normal force and frictional torque which can effect the overall dynamics of the drill system. We have included a wear flat in the bit-rock interaction model and have considered a lumped parameter model with two degrees of freedom for this analysis. Numerical simulations have been done to analyze the effect of wear flat length which shows the linear stability of the system is not affected by the wear flat length for steady-state conditions. However, the global dynamic behavior of the drilling system varied with the wear-flat length. Here we have studied the effect of various parameters such as coefficient of friction, wear-flat length and damping ratio on the system dynamics.

Introduction

Rotary drilling systems are used to drill deep borewells which are used in exploration and extraction of tract fossil fuels. It consists of a rotary table, a series of hollow pipes (drill-string), a drill collar, and a drill bit. Self-excited vibrations resulting from the regenerative forces are often manifested as bit-bounce and stick-slip vibrations. Gupta and Wahi [1, 2, 3] have studied the effect of various parameters on the stability of the system assuming a sharp edge cutter. A linear stability analysis has been studied by Zhang and Detournay [4] wherein they consider a multi-dimensional model with a wear flat length. However, the global dynamics of drill systems with worn tools have not been studied yet to the best of our knowledge. This model incorporated the various case of normal reaction force acting on the cutter. A simplified rotary drill system with two degrees of freedom is considered; one is in the axial and the other in the torsional direction. The forces and torque between the tool and the rock surface can be considered as reported in [5]. When the normal reaction force is fully mobilized with the surface, the equation of motion in the non-dimensional form of the lumped parameter model is

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\begin{aligned}
&\ddot{x}(\tau) + 2\zeta\beta\dot{x}(\tau) + \beta^2 x(\tau) = \\
&\qquad n\psi\delta_0 - n\psi\delta(\tau)H(\omega_0 + \dot{\theta}(\tau))H(\delta(\tau)) + \Lambda_1 l\left(1 - H(v_0 + \dot{x}(\tau))H(\delta(\tau))\right), \\
&\ddot{\theta}(\tau) + 2\kappa\dot{\theta}(\tau) + \theta(\tau) = \\
&\qquad n\delta_0 - n\delta(\tau)H(\omega_0 + \dot{\theta}(\tau))H(\delta(\tau)) + \Lambda_2 l\left(1 - H(v_0 + \dot{x}(\tau))H(\delta(\tau))\mathrm{sgn}(\omega_0 + \dot{\theta}(\tau))\right),
\end{aligned} \tag{1}
$$

where n is the number of cutters, β is the ratio of axial and torsional frequency, ζ and κ are the axial and torsional damping coefficient, δ_0 is the steady thickness of cut, ω_0 is the non-dimensional angular velocity of the rotary table, τ is the non-dimensional time scale, l is the non-dimensional wear flat length, Λ_1 and Λ_2 are non-dimensional constants. The instantaneous thickness of the cut is modelled as reported in [1] where the cut surface function L is defined between two simultaneous cutters. The function L is governed by the partial differential equation (PDE) reported in [1] with the apporpriate boundary condition. These coupled ODE and PDE can be converted into a finite set of first-order system of ODEs with a reduced Galerkin approximation method. Now we have done the numerical analysis to study the effect of parameters on the system.

Results and discussion

We have first considered that the normal reaction force is fully mobilized, i.e., the normal reaction at the wear flat is constant irrespective of the depth of cut and the numerical simulation has been done. It is found that the linear stability analysis of the steady drilling state has not been affected due to the wear-flat on cutters in the non-dimensional parameter space. However, the fully mobilized assumption leads to chattering phenomenon at the inception of the bit-bounce vibrations, i.e., when the cutter is about to leave the rock surface ($\dot{x} + v \leq 0$). Hence, we have incorporated the case when the normal reaction force is linearly varied with the depth of cut before the reaction force is fully mobilized. This leads to a gradual reduction in the normal force when contact is about to be lost and suppresses the chattering behavior. Details of these will be presented at the conference.

References

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