A novel methodology for controlling stick-slip vibrations in drill-strings

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Abstract. Rotary drilling systems are subjected to harmful interactions between the drilling structure and the borehole, leading to component failures and reduced drilling efficiency. Recently, the authors developed a methodology for the determination of sensors locations and control gains for stabilization problems in continuous systems. The aim of this paper is to apply this technique to control the highly nonlinear problem of stick-slip oscillations in drilling systems. A translated modal form removing the rigid body displacement is proposed, rewriting the original problem as a stabilization problem. The integral error is added as a state variable, providing a simultaneous determination of sensors locations and control gains that ensures robust regulation. Both analytic and numerical analyses indicate that the proposed controller has good performance with low sensitivity, and that the controlled linearized system may be reliable to characterize the global stability of the nonlinear system.

Introduction

The conventional technique in oil and gas industry for opening a borehole in a rock formation is the rotary drilling. Due to nonsmooth and nonlinear interactions between the drilling structure and the borehole, this system is subjected to complex types of vibrations that can decrease drilling efficiency and cause component failures. Among these types of vibrations there is the stick-slip, a phenomenon associated with the torsional motion which causes large angular speed fluctuations of the drill-bit. Several techniques have been applied to control this type of vibrations, as described by the reviews [1] and [2]. Recently, the authors [3] developed a methodology, namely static output feedback control (OSOF), for simultaneous determination of sensors locations and control gains for stabilization problems in continuous systems, focusing on vibration control applications. This paper applies this technique to control stick-slip oscillations in oil-well drill-strings. The drilling system is modeled using the finite element method, in which the drill-string is represented as a circular shaft, and the bottom-hole-assembly and rotary table as rigid bodies attached to drill string ends. The bit-rock interaction is modeled using the Karnopp's model with a exponential decaying friction term (non-regularized dry friction). A translated modal form is developed to rewrite the original problem as a stabilization problem, in order to apply the technique developed by the authors. The error integral is added as a system state, yielding an integral action that ensures robust regulation.

Results

The proposed controller is applied through numerical simulations. When considering nominal parameters, simulations indicated that the proposed controller using only two sensors perfomed better than a PI controller, and also had almost the same performance as a LQR controller, that would require full instrumentation of the drill-string. A linearization also indicated that the system with OSOF could withstand a change of up to 25% in both friction coefficients, the same value obtained for the simulation with the nonlinear system for several initial conditions. The main contributions of the paper are: 1) show that the modal form provides a natural change of coordinates to transform the tracking problem into a stabilization problem, 2) propose a controller yielding better performance and robustness than a usual industrial controller, 3) show that the linearized closed loop system gives a good approximation for the characterization of the global stability of the nonlinear system.

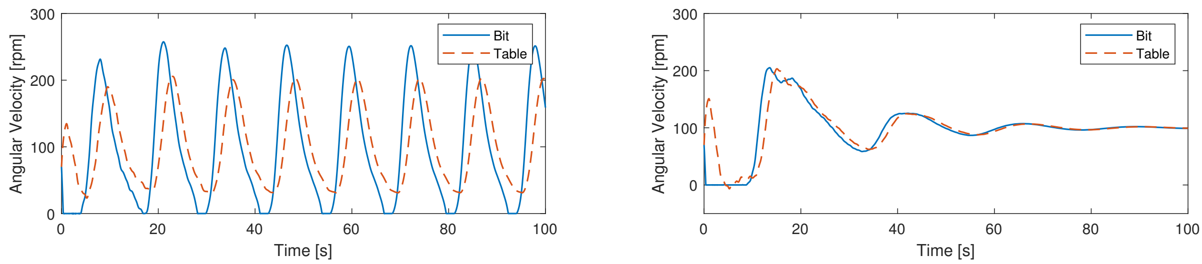

Figure 1: Bit and rotary table velocities using PI (left) and OSOF (right) controllers.

References

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