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Nonlinear System Identification of an Experimental Drill-String Setup,

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Abstract: Torsional vibration is present in most drilling operations and arises from the nonlinear bit-rock and string-wall interactions. The stick-slip phenomenon is the most severe stage of torsional oscillations. It results in excessive bit wear and reduces drilling efficiency. Therefore, proper modelling and control of the system dynamics are necessary to optimize drilling procedures. This work aims to identify the physical parameters of an electromechanical system and the model of the friction observed experimentally. The electromechanical system is an experimental setup designed to offer similar dynamic properties as a drill string with a braking device to introduce dry friction in the system, disturbing the rotating motion. For friction identification, this study tests and compares some well-known friction force models considering different friction phenomena. This study intends to be a source for further comprehension of torsional dynamics in slender structures.

Keywords: stick-slip, friction model, system identification

1. Introduction

The stick-slip phenomenon is the most severe stage of the torsional oscillations present in most drilling routines. This type of vibration results in excessive bit wear and reduces drilling efficiency. For these reasons, the comprehension and reduction of stick-slip are of great concern.

Modelling plays an essential role in the simulation, estimation, control, and monitoring of a dynamic process. Practical limitations of first principles motivate the application of system identification, which comprises a set of techniques for building mathematical models on the basis of input and output measurements [1]. In the context of system identification, dynamical systems with friction, and dynamical systems with hysteresis, contributions have been published [2, 3, 4, and 5]. This work aims to identify the physical parameters of a test rig, including the electrical parameters of the DC motor and the mechanical parameters of the rig, and to identify the model of the friction present in the experiments.

2. Experimental Setup

The rig consists of a horizontal apparatus composed of a DC motor, a planetary gearbox with a reduction ratio of 8:1 coupled to the DC motor, two solid discs, and a low-stiffness shaft, that transmits the rotation from the DC-motor to the discs. Figure 1 (right) shows a schematic of the test rig. The discs are free to rotate, and bearings constrain their lateral motion. There are braking devices placed on the discs to induce friction torque in the system. It consists of a pin that passes through the bearing support and meets the disc. The pin and disc dry contact cause friction torque. The friction torque leads the system to experience torsional vibrations and, eventually, stick-slip.

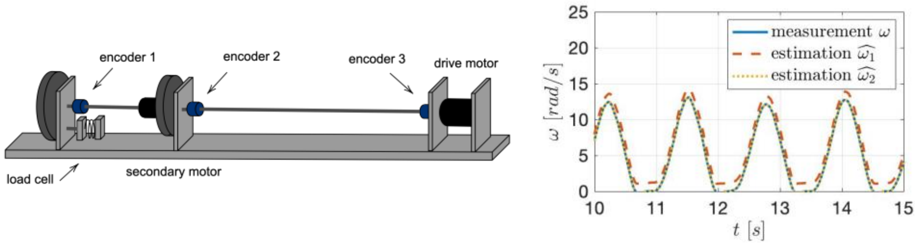

Fig. 1. (right) The schematic of the experimental setup. (left) Comparison between measured and estimated angular velocities of the disc subjected to friction.

3. System Identification

The experimental rig used in this work has a braking device placed on one of the discs to induce friction torque in the system. For friction modelling, this study intends to employ both grey and black-box approaches considering well-known friction models. The graph on the left of Fig. 1 presents some preliminary results of this work. It plots the direct comparison between measured and estimated angular velocities of the disc subjected to friction. In Fig. 1(left), ω is the measured velocity and ω_1 is the estimated velocity simulated with the model proposed in [6]. We used the error between the measurements and the simulation to build an ensemble model. The error is identified adopting a Nonlinear Autoregressive Exogenous (NARX) model. And the estimated velocity simulated with an ensemble model, ω_2, is plotted in Fig. 1(left).

Experimental results showed the existence of a hysteresis phenomenon in friction [6], which has been already observed in other tribological experiments [7]. As a continuation of [6], this study intends to identify the system friction model that better reproduces the dynamics of the experimental setup. Therefore, it tests and compares some well-known friction force models, identifying their parameters, accounting for the hysteretic aspect of the friction torque. The work also includes the analysis of ensembles of grey and black-box models.

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