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FRICTION IDENTIFICATION AND COMPENSATION IN A DC MOTOR

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Abstract: Friction modeling and identification is a prerequisite for the accurate control of electromechanical systems. This paper considers the identification and control of friction in a high load torque DC motor to the end of achieving accurate tracking. Model-based friction compensation in the feedforward part of the controller is considered. For this purpose, friction model structures ranging from the simple Coulomb model through the recently developed Generalized Maxwell Slip (GMS) model are employed. The performance of those models is compared and contrasted in regard both to identification and to compensation. It turns out that the performance depends on the prevailing range of speeds and displacements, but that in all cases, the GMS model scores the best. *Copyright © 2005 IFAC*

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1. INTRODUCTION

The problem of accurate control of electromechanical systems is very important in many industrial applications where such devices, e.g. motors, are themselves, or form essential parts of, positioning /tracking systems. In this paper, we consider a DC motor driving an inertial load with the aim of identifying and compensating the friction disturbances arising from the ball bearings.

A DC motor consists of two sub-processes: electrical and mechanical. The electrical sub-process consists of armature inductance, armature resistance and the magnetic flux of the stator. A second sub-process in the motor is a mechanical one. It consists of the inertia of the motor and a load (J). The difference in motor speed is caused by the electromagnetic moment generated by the amplifier current (τ_m), load (τ_0) and friction of the motor (τ_f). The electrical sub-process will not be discussed in this paper, which will deal with the identification, modeling and compensation of the friction in the ball bearings of the motor.

In the literature, identification of friction in a motor system usually considers only classical friction models, such as Coulomb and viscous friction. Pre-sliding motion, which is apparent in many friction investigations (Prajogo, 1999), is usually neglected. However, the Coloumb model defines the friction force only for $v \neq 0$; when $v=0$ the characteristic simply sets the friction force below the static force value, where v represents velocity. This makes the model quite complex to simulate, since it requires accurate detection of the velocity zero crossing. It is also impractical for friction compensation at motion stop and reversal, where the effect of stick-slip motion arises. In fact, motion never starts or stops abruptly and micro-sliding displacements are actually observed (Armstrong-Hélouvry, 1991).

Two different friction regimes have been distinguished in the literature: the pre-sliding regime, where the friction force appears predominantly as a function of displacement; and the sliding regime, where the friction force is a function of sliding velocity (Armstrong-Hélouvry, 1991, Canudas de Wit et al., 1995, Swevers et al., 2000, Al-Bender et al., 2004). The pre-sliding regime is taken into account in some advanced models, such as LuGre model, the Leuven model and the most recent Generalized Maxwell-Slip (GMS) model. The LuGre model offers a smooth transition of motion from pre-sliding to sliding regime and vice versa. However, it does not accommodate the unique behavior of pre-sliding faithfully. In fact, the friction force shows hysteresis behavior with nonlocal memory in that regime (Prajogo, 1999, Swevers et al., 2000). The Leuven model succeeded in including this type of hysteresis, but introduced some modelling complexities and difficulties (Swevers et al., 2000, Lampaert et al., 2002). Finally, the GMS model manages to overcome those difficulties by modeling friction as a Maxwell-Slip model where the slip elements satisfy a certain, new state equation. As a result, the GMS model is able to predict not only the friction behavior in pre-sliding regime with nonlocal memory hysteresis, but also the friction force in sliding regime, which behaves in a similar way to that in the LuGre model.

An important feature in the friction identification procedure in this paper is that we will use only a single set of experiments to identify all the unknown parameters together, using a suitable optimization method, namely the Nelder-Mead Simplex algorithm.

Once the friction models have been optimized, position control incorporating friction compensation is performed. For this purpose, the inertial force and friction behavior are compensated for using a feedforward control, while a simple (PID) feedback part is included to track set-point changes and to suppress unmeasured disturbances.

In the following, section 2 formulates the DC motor torque balance, and outlines the friction models used in this investigation. Section 3 describes the experimental apparatus, while section 4 discusses the identification procedure. The identification results are discussed in section 5. Thereafter, the friction compensation scheme is sketched in section 6, while the compensation results are discussed in section 7. Finally, appropriate conclusions are drawn in Section 8.

2. MOTOR TORQUES

In general, a DC motor can be viewed as a black box with two inputs: current and load torque, and an output angular displacement (or velocity). Torque balance for a DC motor can be written as:

$$\tau_m = \tau_i + \tau_f + \tau_0 , \qquad (1)$$

where τ_m is the motor torque generated by the amplifier current, τ_i is the inertial torque from motor armature and shaft, τ_f is the friction torque and τ_0 is the load torque.

Due to the limitation of the amplifier current in the motor, it can be shown that the motor torque $\tau_m = K_m\, sat(i, i_{sat})$; and the inertial torque $\tau_i = J_m \ddot{\theta}$. Motor torque is bounded due to the current saturation limit of the servo amplifier. The saturation function is represented by $sat(i, i_{sat})$, where it has a constant value for $|i| > i_{sat}$; and it has a slope of 1 for $|i| \leq i_{sat}$.

As for the friction torque τ_f in equation (1), which is our main concern, several models were used as described below.

1.1 Coulomb Friction

The classical Coloumb model of friction is described by a discontinuous relation between the friction force and the relative velocity between the rubbing surfaces. In this model, when the mass that is subjected to friction is slipping, the friction force will remain constant until the motion is reversed.

1.2 Stribeck Friction

The Stribeck friction consists of (i) a function $s(v)$ that is decreasing in the velocity and bounded by an upper limit at zero velocity equal to the static friction force F_s, and a lower limit equal to the Coulomb force F_c., and (ii) a viscous friction part. In this approach, the constant portion of the Coulomb model is replaced by Stribeck function. Moreover, in order to overcome the jump discontinuity of the Coloumb model, at v=0, that jump is replaced by a line of finite slope, up to a very small threshold ε, as shown in Figure 1.

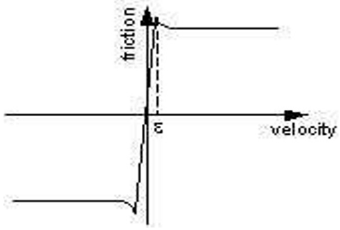

Figure 1. Friction curve of Stribeck models

1.3 LuGre Friction

The above two methods have proven to be impractical for friction compensation at motion stop and inversion, where the worst effects due to friction, namely stick-slip motion, could arise. Motion never starts or stops abruptly and pre-sliding displacements are actually observed (Prajogo, 1999, Swevers et al., 2000). Consequently, two different friction regimes can be distinguished, i.e. the pre-sliding and the gross sliding regimes, as explained in section 1. The LuGre model (Canudas de Wit et al., 1995) was the first formulation that could effect a smooth transition between those two regimes, i.e. without recourse to switching functions. It, furthermore, accounts for other friction characteristics such as the breakaway force and its dynamics. The model achieves this by introducing a state variable, representing the average deflection of elastic bristles (representing surface asperities) under the action of a tangential force, together with a state equation, governing this variable's dynamics and friction equation.

The LuGre model is very popular in the domain of control and simulation of friction due to its simplicity and the integration it affords of pre-sliding and sliding into one model. However, it has been subjected to important criticism (Swevers et al., 2000) in regard to its failure to model pre-sliding/pre-rolling hysteresis with nonlocal memory. The latter authors proposed an extension in form of the Leuven model and a subsequent improvement (Lampaert et al., 2002), however, not without introducing further difficulties.