ENHANCEMENT TO THE LUGRE MODEL FOR GLOBAL DESCRIPTION OF FRICTION PHENOMENA

R. KELLY†

†*División de Física Aplicada, CICESE, Apdo. Postal 2516, Adm. 1, Ensenada, B.C., 22800, México*
rkelly@cicese.mx

***Abstract*— The LuGre model of friction —a bristle based model— predicts important friction phenomena useful for control of mechanical systems. This model accurately describes the behavior of control systems for small initial conditions. This paper proposes a simple but fundamental modification of the model in order to improve the reliability in a global sense. This improvement increases the comprehension of experimental evidences in control of mechanisms.**

***Keywords*— Control, Friction, Mechanisms, LuGre model, PD control.**

I. INTRODUCTION

The study of friction in the automatic control community has grown during the last decade (Armstrong–Helouvry, 1991; Armstrong–Helouvry, *et al.* 1994; Alvarez–Ramírez, *et al.* 1995). The reason is that friction is responsible for many undesirable phenomena observed in implementation of control systems for high precision mechanical systems such as robotic manipulators. Friction produces undesirable behaviors in control systems such as positioning and tracking errors, and limit cycles (Shapiro, 2000). Compensating for friction to attenuate these effects has been one of the main research issues in mechanism control over the years (see Lischinsky *et al.* (1999) and reference therein).

Viscous friction and Coulomb friction are by far the most popular ingredients in friction models utilized for control of mechanical systems. More elaborate models incorporate in addition to viscous and Coulomb friction also the Stribeck effect, to better capture the behavior of motion at low velocity (Armstrong–Helouvry, 1991). Although these friction models are simple because they establish that friction force or torque depends on the instantaneous relative velocity between the bodies in contact, there exist also dynamic friction models where the actual friction force or torque is a function of the instantaneous velocity but also of the previous behavior (Ludema, 1996). To the latter class belongs the LuGre model proposed in Canudas *et al.* (1995) which describes the effects of viscous and Coulomb friction but also more complex friction behavior such as stick-slip motion (Polycarpou and Soom, 1995), presliding displacement (Hsieh and Pan, 2000), and Stribeck effect.

The LuGre model for friction proposed in Canudas *et al.* (1995) seems to accommodate pretty well to expectation of improving precision in mechanisms by control based in such a friction model. Nevertheless, in this paper we present simulation evidences of a simple mechanical system incorporating this friction model which predicts unrealistic behavior when departing from certain initial conditions. To overcome this drawback, this paper proposes a simple but fundamental modification to the model allowing to match its predictions to real expectations irrespective of the initial conditions.

II. LUGRE MODEL OF FRICTION

The LuGre model widely described in Canudas *et al.* (1995) consists of a differential equation where the relative velocity $\dot{q}$ between the bodies in contact is the system input, and the friction force or torque f opposing to the bodies motion is the system output. The LuGre model can be written in a suitable form as

$$\dot{z} = -\frac{|\dot{q}|}{g(\dot{q})} z + \dot{q}, \qquad (1)$$

$$f = \left[\sigma_0 - \sigma_1 \frac{|\dot{q}|}{g(\dot{q})}\right] z + [\sigma_1 + f_v]\, \dot{q}, \qquad (2)$$

where

$$g(\dot{q}) = \frac{f_c + [f_s - f_c]\mathrm{e}^{-(\frac{\dot{q}}{v_s})^2}}{\sigma_0} > \frac{f_c}{\sigma_0} > 0, \qquad (3)$$

z is an immeasurable state variable called "average deflection of the bristles" (Canudas *et al.*, 1995) because the friction interface between the bodies is thought as a contact between bristles (Rice and Moslehy, 1997), f_c is the Coulomb friction coefficient, f_s is the static friction coefficient satisfying $f_s > f_c$, f_v is the viscous friction coefficient, and v_s is the Stribeck velocity coefficient. Finally, σ_0 and σ_1 are the stiffness and damping coefficients respectively. In sum, the LuGre model is composed by the differential equation (1) and the output equation (2).