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Original

Analysis of tire-road contact area in a control oriented test bed for dynamic friction models

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Abstract

The longitudinal and transversal forces distributed over the tire-road contact area are experimentally analyzed to validate the use of the lumped parameters LuGre dynamic friction model for traction-braking control purposes. To perform the analysis, a test bed based on a scaled quarter vehicle model that consists of a roller, a wheel and a servomotor was designed and built. In this device, the roller represents the road and the vehicle mass, and the tire is directly coupled to the shaft of the servomotor. The distribution of forces in the contact tire-road area is measured by means of strain gages. The obtained results show the distribution of normal forces in the tire-road contact area at different vehicle speeds. They confirmed analytic studies previously reported in the literature regarding the trapezoidal shape of the force distribution in the contact area and also allow to conclude that the lumped parameter LuGre dynamic friction models is suitable for representing the friction forces for traction-braking control purposes.

Keywords: Tire-road contact forces; Models for tire-road contact; Wheeled vehicles; LuGre dynamic friction model; Trapezoidal force distribution; Traction-braking control

1. Introduction

The longitudinal and transversal forces on the tire-road interface largely influence vehicle dynamics (Rajamani, 2006). For this reason, a good number of studies have been conducted to propose mathematical models that describe these forces. A family of models is derived from empirical studies that use pseudo-static relationships for the tire-road forces. Some of the most notable examples of this kind of models are the so called “magic formula” (Bakker et al., 1987) and the models reported in Burckhardt (1993) and Kiencke (1993). Other approach, based on the physics of the friction phenomena, resort to dynamic friction models to describe the tire-road force interaction. The LuGre dynamic friction model (Canudas et al., 1995) has received particular attention in applications for traction control because it is relatively simple and yet it describes most of the nonlinear phenomena experimentally observed in friction.

From an experimental point of view, there are several test beds used to analyze tire-road interaction (see Ginn & Marlowe, 1967; Ginn et al., 1962; Bird & Martin, 1973; Carrillo, 2004, and I.T.V., 2006, for example). As it can be appreciated in Figure 1, that illustrates some of the typical installations, in all cases there is independent control of the tire and the rolling surface. By independently controlling the speeds of the two degrees of freedom, all possible longitudinal slips can be obtained. If force sensors are incorporated, once velocities reach a steady state, it is possible to measure the force of the tire-road interaction for each value of the longitudinal slip. Based on these mea-

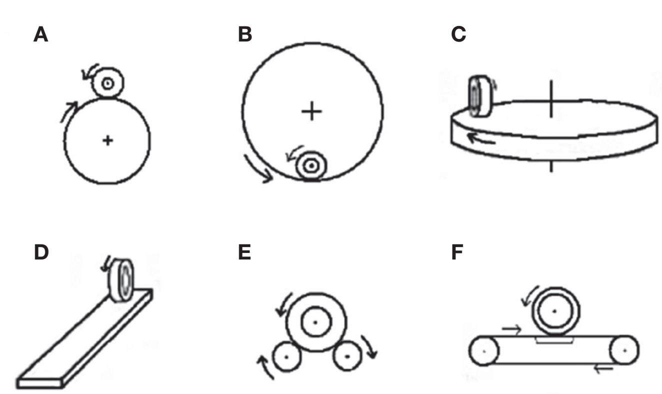

Fig. 1. Sketches of installations for analyzing tire-road force interaction.

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surements, force vs. slip or friction coeffcient vs. slip curves, similar to those shown in Figure 2, can be obtained. It is from these curves that most of the pseudo-static models are derived.

Pseudo-static models give only information of the total tire-road force. To analyze the force distribution in the contact patch, some authors use sensors in two manners. In the first one, sensors are placed on the tire resulting in the so called "smart tires" (Coleri et al., 2009; Castillo et al., 2006; Yilmazoglu et al., 2001). In the second case, sensors are placed below the rolling surface in such a way that normal forces in the contact area can be measured (Rose & Guenther, 2009; Muller et al., 2003; Ho et al., 2011). Sensors on the tire are normally piezo-

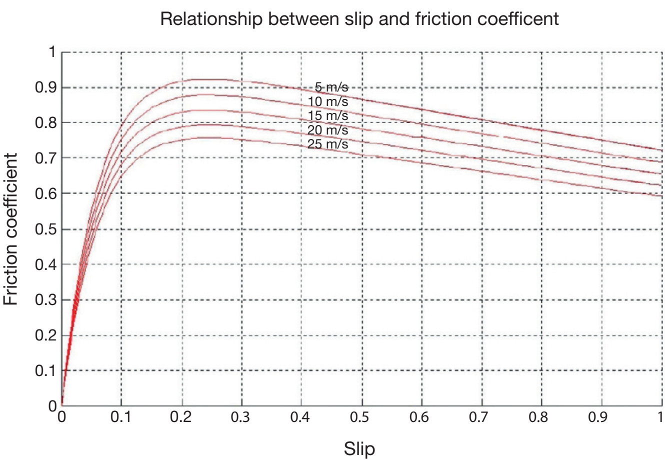

Fig. 2. Examples of slip vs. friction coefficient curves for pseudo-static models.

electric and therefore have limitations on their maximum size that oblige to use networks of sensor to fully cover the contact area. Sensors placed bellow the rolling surface can use piezo-electric or optical sensors and also consist in arrays of discrete sensors. Based on measurements obtained from these sensors, conclusions regarding the distribution of forces can be obtained. Recently, Zhang and Yi (2012) found that the shape of the force in the contact patch has a bimodal distribution and that force in the perimeter of the contact area is larger than inside it.

The use of LuGre model to describe the tire-road force was first introduced in Canudas and Tsiotras (1999). There are two families of LuGre models: lumped parameters and distributed parameters. Using this last one, in Tsiotras et al. (2004), a trapezoidal shape for the force distribution in the tire-road contact patch was proposed to carry out the force analysis. Distributed parameters LuGre models are difficult to use for traction-braking control purposes due to its complexity. For this reason, lumped parameters LuGre models are used instead. The formulation of these models is based on the assumption of an average behavior of forces in the contact patch area. There is, however, little experimental evidence on this average behavior of forces in the contact area and its relation with the LuGre model.

In this paper a test bed is designed and built with two initial goals: *a)* analyzing the shape of the contact forces at the tire-road interface, and *b)* validating the assumption on average force behavior for lumped parameters LuGre models. The test bed will also be used for experimenting with traction-braking control algorithms. To achieve all these goals, a different design to those used in the literature was proposed as shown in Figure 3, where it can be noticed that only the degree of freedom related

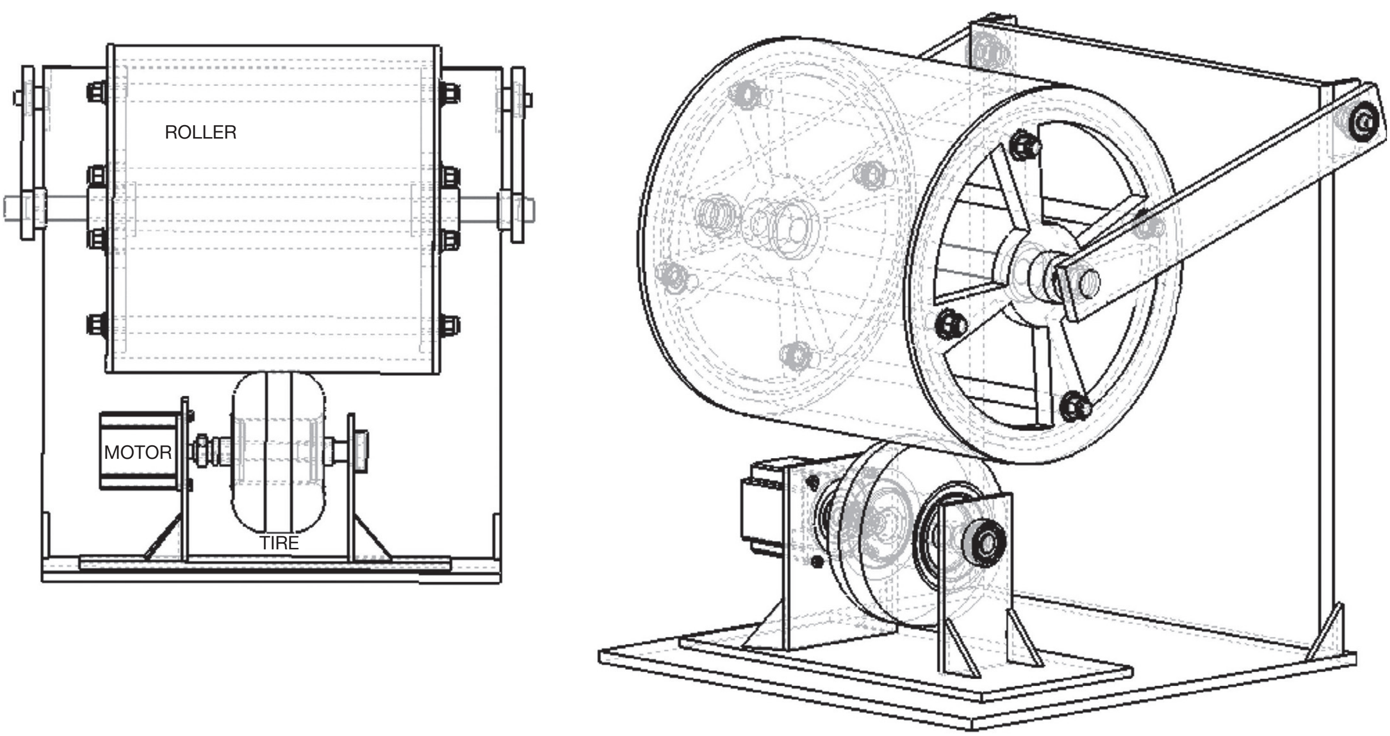

Fig. 3. Test bed design.