The 6th Joint International Conference on Multibody System Dynamics and
The 10th Asian Conference on Multibody System Dynamics
November 1-5, 2020, New Delhi, India

Performance Evaluation of LuGre and Masing Models for Steering Torque Simulator

Taichi Shiiba*, Shingo Haketa*, Katsuhide Ishii*, Sena Inoue*

* Department of Mechanical Engineering
Meiji University
1-1-1Higashi-Mita, Tama-ku, Kanagawa, Japan
[ce192002, ce192009,shiiba]@meiji.ac.jp

Abstract

Steering torque is one of the most important information inputs for a driver because it influences the driver's maneuvering. The characteristics of steering torque are affected by mechanical properties of the steering system like torsional stiffness, steering wheel inertia and the mechanical friction which occurs due to the sliding motion of the rack relative to bearings and gaskets. In particular, steering friction is very important because it determines the driving and steering response of a car [1]. When vehicle handling and stability are evaluated using a driving simulator or a steering torque simulator, it is necessary to clarify steering torque considering these effects. In order to enhance the accuracy of steering torque calculations, we used three models in our steering torque simulator: a multibody kinematic suspension model which calculates steering rack force, a 2-DOF steering model and a friction model. In this study, we investigated two kinds of friction model, the LuGre model and the Masing model, to assess their suitability in the steering torque simulator.

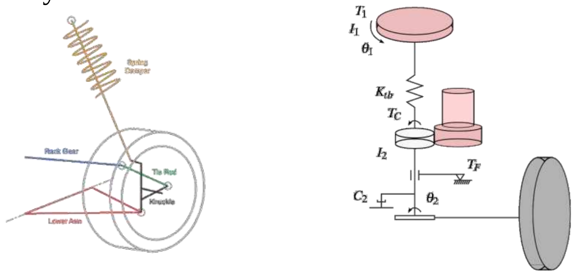
Figure 1 shows an overview of the steering torque simulator. The simulator includes a steering torque generator and two PCs which are used for a full vehicle dynamics analysis and to calculate the steering torque. The vehicle dynamics analysis is carried out by CarSim, which is a commercial software providing real-time full vehicle simulation. The vehicle model includes the dynamic characteristics of an engine, a transmission, and a brake system. A 10-DOF model is used for the vehicle dynamics calculation, and detailed suspension characteristics such as the wheel alignment change are derived from many look-up tables. In order to determine the steering rack force in our simulator, a multibody kinematic analysis was conducted. Figure 2 (i) shows the multibody kinematic model of a MacPherson strut suspension. In this model, the vertical displacement of the knuckles and the tire forces are supplied by CarSim. Multibody kinematic analysis software, written in-house in C-code, was implemented in the real-time simulation environment. This approach achieves the high computational efficiency of the steering torque calculation in conjunction with the real-time full vehicle simulation [2]. Figure 2 (ii) shows the model for steering torque calculation. The target of the steering model is a column-type electric power steering. This model consists of two degrees of freedom: the rotational angle of the steering wheel θ_1 and the rotational angle of the column shaft θ_2. The equations of motion are represented as follows:

$$I_1\ddot{\theta}_1 + K_{tb}(\theta_1 - \theta_2) = T_1 \tag{1}$$

$$I_2\ddot{\theta}_2 + C_2\dot{\theta}_2 + K_{tb}(\theta_2 - \theta_1) = T_C + T_F \tag{2}$$

where T_1 is the steering torque, I_1 is the moment of inertia of the steering wheel, I_2 is the moment of inertia of the column shaft including the assist motor, K_{tb} is the torsional stiffness of the torsion bar, C_2 is the damping coefficient of the steering, T_C is the torque of the column shaft and T_F is the friction torque caused in the steering system. T_F is calculated by a friction model.

Figure 1: Steering torque simulator



(i) Suspension model (ii) Steering model

Figure 2: Suspension model and steering model

Two friction models, the LuGre model and the Masing model, were assessed in this study. The Masing model consists of several sets of spring and friction elements connected in series as shown in Figure 3 (i). It works like a spring before a turning point, and after this point it works like a friction which generates a constant force [3]. This model can express the transient characteristics of the friction by adjusting the spring and the friction properties. In the other model, the LuGre model, the friction interface between two surfaces is considered to be the contact between bristles [4]. If a force is applied to two surfaces in contact, there will be a displacement, and the LuGre model captures this phenomenon. Equations for the LuGre model are shown as follows:

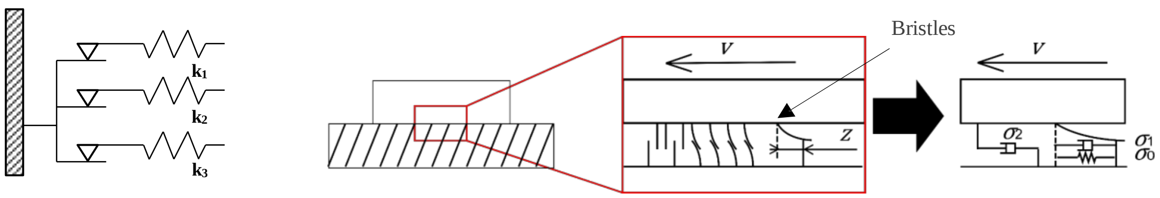
$$T_F = \sigma_0 z + \sigma_1 \frac{dz}{dt} + \sigma_2 v \tag{3}$$

$$\frac{dz}{dt} = v - \frac{|v|}{g(v)} z \tag{4}$$

$$\sigma_0 g(v) = F_c + (F_s - F_c) e^{-\left(\frac{v}{v_s}\right)^2} \tag{5}$$

where T_F is the friction torque, z is the average deflection of the bristles, σ_0 is the stiffness, σ_1 and σ_2 are the damping coefficients of bristles, v is the relative velocity between the two surfaces, F_c is the Coulomb friction level, F_S is the level of the stiction force and v_s is the Stribeck velocity [4]. The LuGre model can describe various characteristics by changing the parameters.

Figure 4 shows examples of the friction characteristics calculated by the Masing and LuGre models. While a smooth change in friction force is observed at the corner in the LuGre model, the Masing model shows step changes, which may cause instability in the real-time calculation. On the other hand, the LuGre model needs to solve an additional differential equation which requires extra time to calculate, and so may be more expensive to implement. In this study, we compared the performance of these two friction models in our steering torque simulator from the viewpoints of the accuracy of the friction characteristics and the real-time capability of the simulation.



(i) Masing model (ii) LuGre model

Figure 3: Friction models

(i) Masing model (ii) LuGre model

Figure 4: Characteristics of friction models

References

[1] M. Harrer, P. Pfeffer (2014) Steering Handbook. Springer Munich.

[2] M. Tsushima, E. Kitahara, T. Shiiba, T. Motosugi (2014) Development of Hardware-In-the-Loop Simulation System for Steering Evaluation Using Multibody Kinematic Analysis. SAE International Journal of Passenger Cars - Mechanical Systems, vol. 7, no. 2, 497-504.

[3] E. Ueda, E. Inoue, Y. Sakai, M. Hasegawa, H. Takai, S. Kimoto (2002) The Development of Detailed Steering Model for On-Center Handling Simulation. 6th International Symposium on Advanced Vehicle Control Proceedings 20024586

[4] C. Canudas, H. Olsson, K. J. Atrom, P. Lischinsky (1995) A New Model for Control of Systems with Friction. IEEE Transactions on Automatic Control, vol. 40, no. 3, pages 419-425.