High-Fidelity ANCF-LuGre Tire Model Uusing Continuum Mechanics Based Shear Deformable Laminated Shell Element

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Abstract

Tire models play an essential role in virtual prototyping of ground vehicles and existing detailed explicit finite-element tire models have been successfully used for predicting stresses in tires as well as the contact pressure under steady-state rolling conditions. However, these models are not suited for the analysis of the transient tire dynamics under severe braking and cornering conditions, in which the nonlinear coupling between the dynamic tire structural deformation and its transient tire forces comes into play with history-dependent friction-induced hysteresis. Furthermore, it is assumed in most vehicle handling simulation that the normal contact pressure distribution is constant due to small load transfer that occurs during the steady-state vehicle maneuvering. In the transient braking and cornering analysis of tires, however, the structural tire deformation due to the large load transfer causes significant change in normal contact pressure distribution and it has a dominant effect on the transient braking and cornering force characteristics. To account for the dynamic coupling of the structural tire deformation and the transient tire forces considering the history-dependent friction hysteresis, a flexible tire model based on the absolute nodal coordinate formulation has been developed and applied to the evaluation of the longitudinal tire dynamics under severe braking scenarios by integration with LuGre tire friction model [1,2]. In this model, the structural deformation of the flexible tire model is dynamically coupled with the LuGre tire friction model [3] in the final form of the equations and it allows for fostering better understanding of the tire force characteristics under various transient braking conditions.

In this study, the spatial high-fidelity flexible tire model that can be integrated into multibody vehicle dynamics simulation is developed. Since tires have complex structure that consists of layers of belts and plies embedded in rubber, detailed description of tire cross section geometry as well as material properties is of crucial importance in successful development of tire models. Furthermore, since the number of layers as well as the fiber angles of fiber reinforced rubber (FRR) in the tire structure vary across the tire cross section, highly nonlinear anisotropic material behavior is exhibited. Use of the fully parameterized plate element of the absolute nodal coordinate formulation, however, leads to severe locking problems and overly stiff bending behavior is exhibited. For this reason, the locking-free laminated composite shell element based on the absolute nodal coordinate formulation with the transverse slope coordinates is utilized for developing a flexible tire model in this study. The shell element accounts for the complex deformation coupling exhibited in fiber-reinforced composite

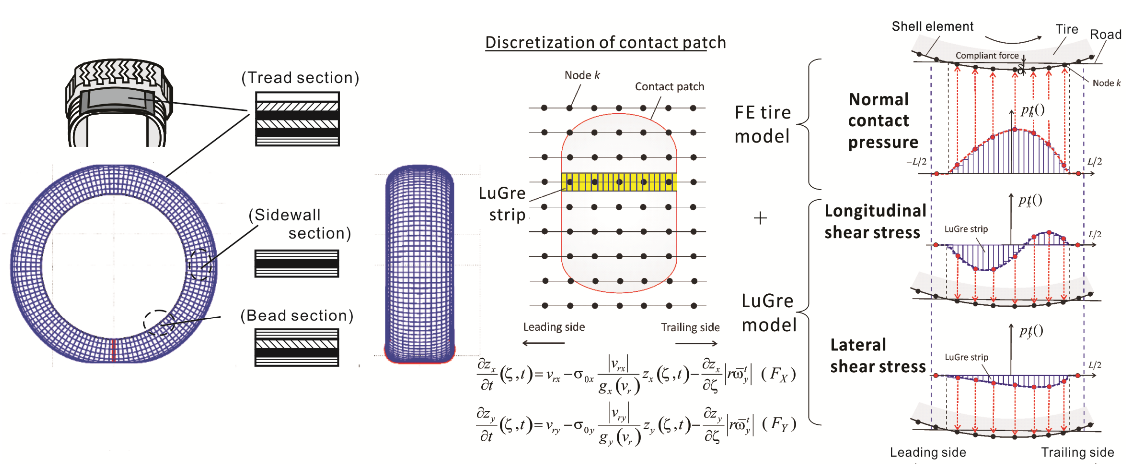

Figure 1: Integrated physics-based flexible tire model for transient maneuvering analysis.

rubber materials used in tires, and the element lockings are systematically eliminated by the assumed natural strain and enhanced strain approaches [4,5]. Due to the element parametrization and the non-incremental solution procedures utilized in the laminated composite shell element, the flexible tire model is integrated into the general multibody dynamics computer algorithm without resorting to linearization of the shell kinematics [5]. The load-deflection curve and the contact patch lengths are validated against the test data to ensure that the fundamental structural tire properties can be correctly captured by the tire model developed in this study.

To account for the transient tire forces with history-dependent friction-induced hysteresis, the distributed LuGre tire friction model that accounts for transient tire forces under combined slips is integrated into the flexible tire model. To this end, the contact patch is discretized into small strips across the tire width first and then each strip, called LuGre strip, is further discretized into elements in the longitudinal direction. In other words, the state of friction of each LuGre strip is defined by the partial differential equations of LuGre tire friction model expressed in terms of two LuGre friction parameters associated with the longitudinal and lateral shear stresses. The partial differential equations of distributed LuGre tire friction model are converted to a set of first-order ordinary differential equations and they are solved together with the equations of motion of the flexible tire model. That is, the normal contact pressure and tangential slip distributions predicted by the structural tire model are mapped onto LuGre strips and elements in the contact patch to evaluate the shear stresses distribution, and then the tire forces evaluated in LuGre strips are given back to the structural tire model equations as the generalized tangential contact forces. By doing so, the structural deformation of the tire model and the LuGre tire friction force model are dynamically coupled in the final form of the equations, and these equations are integrated simultaneously forward in time at every time step. Several numerical examples are presented in order to demonstrate capabilities of the tire model for transient braking/traction and cornering analysis of multibody vehicle systems.

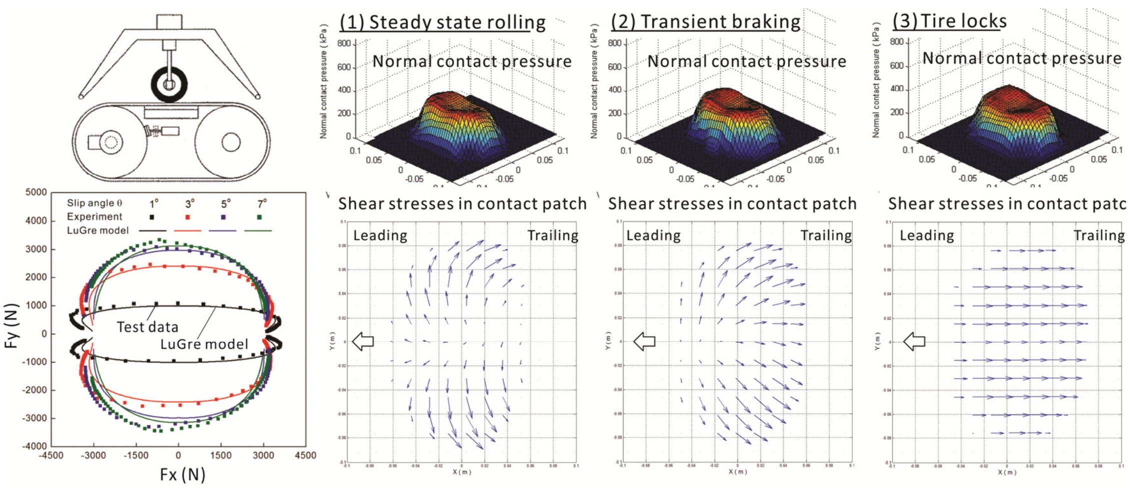

Figure 2: Tire shear stresses and contact pressure in transient braking scenario.

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