Tire-Terrain Interaction Modeling using a Multibody Dynamics Approach for Terramechanics Studies

Shahyar Taheri*, Corina Sandu*, Saied Taheri*

* Department of Mechanical Engineering, Virginia Tech, Randolph Hall
460 Old Turner Street, Blacksburg, VA 24061, USA
taheri@vt.edu, csandu@vt.edu, staheri@vt.edu

Abstract

Assessment of the forces and moments that occur at the tire-terrain interface, and the effect of the tire motion on properties of the terrain are crucial in understanding the performance of a vehicle. In this regard, vehicle dynamic simulation plays an important role during vehicle design and development. For this type of simulation, vehicle responses to various inputs imposed by the driver, as well as the terrain, are studied. As part of the multibody dynamics software packages used for vehicle simulations, there exists a module representing the dynamic behavior of the tire. Accurate and efficient tire models for deformable terrain operations are essential for performing vehicle simulations. A direct application of an on-road tire model to simulate tire performance on soft soil is not possible. This is due to the fact that traveling on deformable terrain raises issues for which on-road tire models do not account. Moreover, the kinetics and kinematics of the tire on deformable terrains are subjected to different design and operational factors, as well as field characteristics. These factors, in addition to the uncertainties that exist in their parameterization, make the formulation of tire-terrain interaction a highly complex problem. Due to this complexity, the numbers of tire models that are usable in conjunction with multibody dynamics vehicle simulations that can capture the behavior of the elastic tire on a deformable ground, like soft soil, are limited.

The methods for modeling and evaluation of performance of the wheeled vehicles on deformable terrains are influenced by different terrain properties in addition to design and operational parameters. These methods range from very simple empirical methods to highly complex finite element methods [1]. In this study, a new framework for the process of developing a complete soft soil tire model is proposed, which can be divided into two main sub-processes of mathematical modeling and physical modeling, as shown in Figure 1.

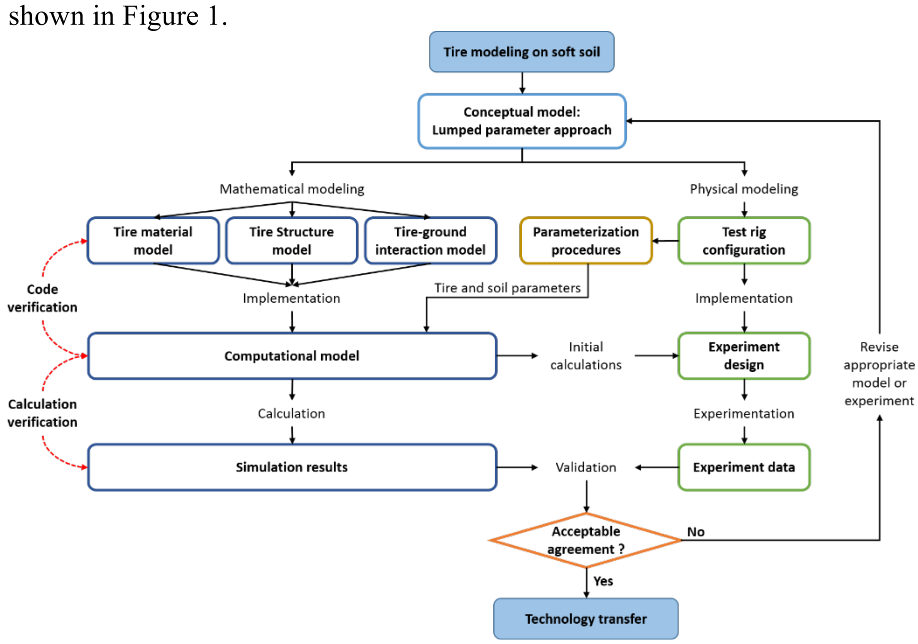

Figure. 1 - Modeling, simulation, and experimental procedures workflow.

In order to mathematically model the dynamic behavior of the tire on soft soil, a new Hybrid Soft Soil Tire Model (HSSTM) model is developed [2]; the model is basically a lumped mass discretized model augmented with a brush-type model for tire contact. In this new approach, the tire belt is discretized circumferentially in multiple belt segments that are suspended on the rim using Kelvin-Voigt elements that include variable stiffness and damping. These nonlinear elements capture the effect of the temperature and pressure changes on the tire mechanical characteristics through a set of empirical equations. Each belt segment is divided into a series of lumped masses connected to each other with in-plane and out-of-plane springs and dampers. The dynamics of these lumped masses, in addition to the dynamics of the wheel, is described in a state-space representation. To optimize the computational time of the code, different techniques were used in memory allocation, parameter initialization, code sequence, and multi-processing. This has resulted in significant improvements in the computational efficiency of the code, which now can run close to real time and therefore it is suitable for use by commercially available vehicle simulation packages.

The hyperelasticity of the tire is modeled by interpolating the tire load vs. deflection data in compression/tension loading/unloading scenarios. This approach allows us to define different loading stiffness values for loading and unloading paths. The viscoelasticity is characterized using the Kelvin-Voigt elements, for which the stiffness and the damping elements are connected to each other in a parallel configuration.

Tire parameters are obtained using a reduced finite element tire model, modal analysis, and other experimental procedures. In the parameterization step, sensitivity analysis tools were incorporated in order to reduce the redundant degrees of freedom, and to better fit parameter values based on the test data. Using the parameters that are derived for the computational model, simulations are performed at conditions similar to the experiments. The results from this step are iteratively generated and compared to the test data until the acceptable agreement is achieved. In the case that correlation accuracy is not achieved after extensive simulation iterations, a judgment is made to whether make changes to one of the sub-models, experimental setup, parameterization procedures, or all of the above.

To aid the modeling, experimental tests were performed on the Terramechanics rig at the Advanced Vehicle Dynamics Laboratory at Virginia Tech. The tests were performed on terrains such as sandy loam, and tire force and moments, soil sinkage, and tire deformation data were collected for various case studies based on a complex design of experiment matrix. These data, in addition to modal analysis data, were used to validate the tire model. Furthermore, simulations at conditions similar to the test conditions were performed on a quarter car rig to study the validity of the tire model. The results indicate a very good correlation of this model with experimental data, and a better performance when compared to other lumped parameter tire models currently available.

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References

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