An Enhanced Tire Model for Dynamic Simulation Based on Geometrically Exact Shell

Michael Roller#, Peter Betsch *, Axel Gallrein #, Joachim Linn#

Fraunhofer ITWM
Fraunhoferplatz 1, 67663 Kaiserslautern, Germany
Axel.Gallrein@itwm.fraunhofer.de
Joachim.Linn@itwm.fraunhofer.de
Michael.Roller@itwm.fraunhofer.de
* Institute of Mechanics
Karlsruhe Institute of Technology
Otto-Amman-Platz 9, 76131 Karlsruhe, Germany
Peter.Betsch@kit.edu

Abstract

Acting as an interface between car and road, the tire model plays a crucial role in dynamic vehicle simulations. In commercial and scientific applications there exist several different modeling approaches for tires. When the tire model has to be embedded into a multi body system (MBS), lumped parameter models of varying complexity consisting of springs and dampers [3] are used, as well as simple data curve fits [6]. Likewise, very detailed but computationally demanding three dimensional finite element (FE) models are used for crash and misuse simulations [7]. However, a coupling of such 3D–FE tire models to MBS simulations is mostly not feasible due to the large number of degrees of freedom (DOF). Our purpose is to develop a continuum mechanical based structural modal, which requires only modest amounts of computational resources so that a coupling with a MBS simulation is viable.

In *ECCOMAS Thematic Conference on Multibody Dynamics 2013* a tire model [8] based on the geometrically exact shell theory of [9] was presented. Its spatial discretization is done with finite elements, like in [1]. The tire model is able to handle pressure loads as well as frictionless contact with a rigid road surface. Also a special kind of orthotropic material is available, where one principal direction is parallel to the normal of the midsurface. The tire model is able to interact with a MBS simulation via co-simulation, with the rim forces and displacements as interface.

We enhance this discrete shell based tire model to allow frictional contact. This is realized with a Coulombs model, where the distinction between stick and slip is done by a decomposition of the tangential slip $\mathbf{g_T}$ into an elastic $\mathbf{g_T^e}$ and a plastic part $\mathbf{g_T^p}$ [10]. This approach comes from the theory of plasticity and could be interpreted as a regularization of the stick condition. The discretization of the contact area is done with a segment to segment strategy, where the road surface is given analytically. The contact surface of the discrete shell is interpolated locally by Hermite polynomials. Additionally, to the discrete points of the midsurface also the discrete directors are utilized. This approach is similar to [4], where lower order polynomials are used, that are not able to handle turning points inside the element [5]. The contact is evaluated inside the elements at the Gaussian integration points. The evolution of the plastic slip $\mathbf{g_T^p}$ in each contact point is calculated by the radial return algorithm [10].

Another enhancement to [8] is the possibility of handling different material layers in the thickness direction. This approach is adopted from [2] and transferred to our discrete shell formulation. With these improvements, we are able to simulate realistic dynamic forces on the rim. In Figure 1 an example of a standard tire test is given. Hereby the rim is driven with a fixed velocity and is cornered about the so called slip angle α. Therefore, a lateral force is acting on the rim, due to the frictional forces in the contact patch.

In this contribution we present the results of dynamic tire simulations and compare them to real measurements. Also the coupling to a simple MBS simulation of a quarter car will be presented.

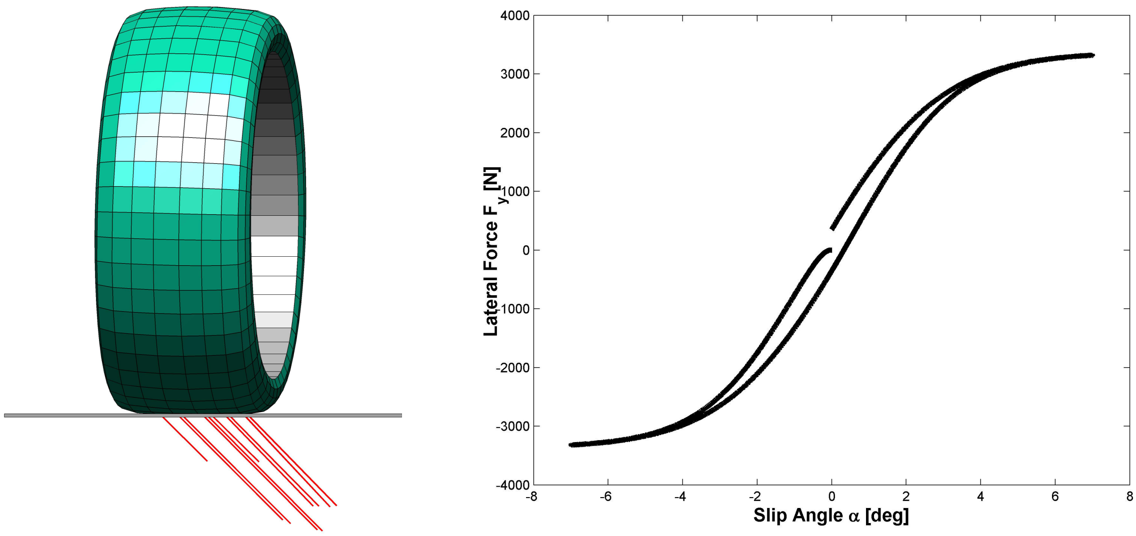

Figure 1: **Left:**Tire running at a speed of with 10 $[m/s]$ a slip angle of 7°. The red arrows indicate the reaction force on the road due to frictional contact. **Right:** Lateral force acting on the rim plotted as a function of the slip angle.

References

[1] P. Betsch and N. Sänger. On the use of geometrically exact shells in a conserving framework for flexible multibody dynamics. *Computer Methods in Applied Mechanics and Engineering*, 198(17):1609–1630, 2009.

[2] B. Brank, F. Damjanić, and D. Perić. On implementation of a nonlinear four node shell finite element for thin multilayered elastic shells. *Computational Mechanics*, 16(5):341–359, 1995.

[3] P. Lugner and M. Plöchl. Tyre model performance test: first experiences and results. *Vehicle System Dynamics*, 43(sup1):48–62, 2005.

[4] T. Nagata. Simple local interpolation of surfaces using normal vectors. *Computer Aided Geometric Design*, 22(4):327–347, 2005.

[5] D. Neto, M. Oliveira, L. Menezes, and J. Alves. Improving nagata patch interpolation applied for tool surface description in sheet metal forming simulation. *Computer-Aided Design*, 45(3):639–656, 2013.

[6] H. B. Pacejka and E. Bakker. The magic formula tyre model. *Vehicle system dynamics*, 21(S1):1–18, 1992.

[7] M. J. Poldneff and M. W. Heinstein. Computational mechanics of rubber and tires. *Modeling and Simulation in Polymers*, pages 385–403, 2010.

[8] M. Roller, P. Betsch, A. Gallrein, and J. Linn. On the use of geometrically exact shells for dynamic tire simulation. In *Multibody Dynamics*, pages 205–236. Springer, 2014.

[9] J. C. Simo and D. D. Fox. On a stress resultant geometrically exact shell model. Part I: Formulation and optimal parametrization. *Computer Methods in Applied Mechanics and Engineering*, 72(3):267–304, 1989.

[10] P. Wriggers. Finite element algorithms for contact problems. *Archives of Computational Methods in Engineering*, 2(4):1–49, 1995.