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Non-smooth models of wheel-road interactions based on piecewise-linear luz(…) and tar(…) projections

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Abstract: Vehicle modeling is often practiced on the concept of partial models created independently to describe the dynamics of longitudinal movements (related to drive and braking processes), the dynamics of lateral movements (related to the vehicle handling processes), the dynamics of vertical movements (related to the effects of road unevenness and suspension work). The paper presents a set of three innovative non-smooth dynamical models describing the interaction of the pneumatic wheel with the road in terms of the longitudinal, lateral and vertical dynamics of the vehicle motion. They are based on simple two-mass substitute physical model. The presented mathematical models use piecewise-linear luz(...) and tar(...) projections. Thanks to these projections and their mathematical apparatus, the developed models are useful for simplifier description and analysis of strong nonlinear non-smooth processes, including the most difficult ones related to wheel locking, wheel sudden slipping, or wheel detachment from the road surface.

Keywords: Tire wheel - road interactions, dynamics, mathematical modeling, projections.

1. Introduction

Mathematical modeling of tire wheel - road interactions is still the subject of scientific research, despite the fact that in the literature on Vehicle System Dynamics there are mathematical models (physical based and experimental, static and dynamic) with an established reputation (e.g. Dugoff model, "Magic Formula" model, "LuGre "model, etc.) [2]. These models were designed to describe the wheel-road interactions in normal states (without sudden changes accompanying full skid or wheel detachment from the uneven road), and usually they have been parts of complex models expressing vehicle “smooth dynamics” (in standard situations). Note, that in many cases the vehicle dynamics is analyzed by partial models created independently for longitudinal movements (drive and braking processes), for lateral movements (handling processes) and for vertical movements (effects of road unevenness and suspension work) and therefore the models of tire wheel - road interactions have the same character of partial description. Despite a number of simplifying assumptions such models have rather sophisticate forms and require many parameters.

2. Results and Discussion

The paper presents a set of three dynamical models describing the tire wheel - road interactions in terms of longitudinal, lateral and vertical dynamics of the vehicle motion. These new models are intended to describe non-smooth effects (sudden changes accompanying full skid or wheel detachment from the uneven road).

The substitute physical model of a tire wheel (Fig.1) adopted in the study is a cylinder (wheel rim) with an applied ring (tire) treated as rigid body rolling elements. Both elements can be twisted relative to each other (in the plane of the wheel and transversely) according to linear torsion models, and they can also shift relative to each other (non-linear model, used in the description of drift). The rigid cylinder represents the inner part of the wheel that is acted upon by driving torque (from differential driven wheels), braking torque (from brake) and rolling resistance torque (from the bearings). The ring represents the outer part of the wheel along with the tire tread. For description of vertical dynamics, it can be assumed that the ring is an elastic structure (rheological properties of the Kelvin-Voight type). The outer side of the ring is a friction system with a road surface, with anisotropic properties specified for longitudinal, transverse and torsional movements. The road tire contact is treated pointwise without entering into the description of the force distribution in the actual contact area. The modeling of wheel dynamics did not take into account the geometry of wheel position in king-pin mechanism (it is "hidden" in parameters and disclosed in the description of the stabilization moments).

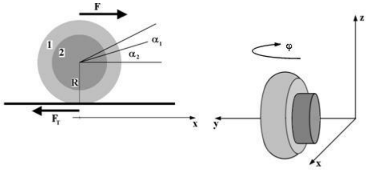

Fig.1. Idea of substitute physical model of a rubber wheel

For description of friction effects the classic Coulomb theory is applied. So the models have to have variable-structure forms expressing kinetic and static friction. Due to the presence of two connected elements in the wheel model, there is no fear that static indeterminacy problems appear.

The models are built with using special piecewise-linear luz(...) and tar(...) projections (Fig.2) and their original mathematical apparatus [3]. Note, that luz(...) and tar(...) can be applied also for the friction characteristics expressing Stribeck effect, for characteristics with non-symmetry, etc.. The forms of models are “compact” and clear for analytical interpretation. Thanks to these, the developed tire wheel models are very useful for description and analysis of strong nonlinear non-smooth processes, including the most difficult ones related to wheel locking, sudden slipping, or wheel detachment from the road surface. An application of the method for suspension analysis shown in [1].

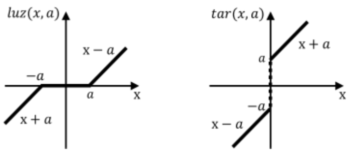

Fig.2. Geometric interpretations of the luz(…) and tar(…) projections

3. Concluding Remarks

The luz(…) and tar(…) projections seem to be very efficient for modeling non-smooth wheel-road interactions and mechanical systems which are engaged in control of the car. Aggregations of partial models enables simplified describing of wheel-road dynamic interactions in 2D and 3D space.

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