

A Tire Model for Very Large Tire Deformations and its Application in Very Severe Events

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ABSTRACT

The full vehicle simulation on durability proving grounds is a well established technique in the pre-development process of passenger car manufacturers. The respective road surfaces are designed to generate representative spindle loads and typically include events that will result in large tire deformations. Depending on manufacturer and the combination of vehicle size and wheel properties, these deformations can be so large that the tire belt and/or sidewall have contact with the rim crown (protected by the tire sidewall). The current tendency to low-aspect ratio tires reduces the available deformation capability of the tire while simultaneously introducing larger nonlinearities in the sidewall behavior (see [2]).

This paper is based on a co-development project between Fraunhofer LBF and Honda R&D and is dealing with the development of a tire model, which can accurately handle very large deformations of the tire up to misuse-like applications. The model is based on the LBF tire model CDTire, where several nonlinear extensions of the belt and sidewall model have been implemented to accurately capture the large deformation behavior. These model extensions are also taking the belt/sidewall and sidewall/ rim contact into account. The paper is a consequent continuation and improvement of first modeling and validation efforts previously published in [1], which at that time were based on quasi-static tire stand-alone measurements. The main innovations are related to the implementation of a new dynamic test rig specially designed by Fraunhofer LBF for large deformation tire testing. With this test rig, new impulses could be derived for the modeling and for the parameter identification procedure. Additionally, first full vehicle

simulation results of a very severe event are shown to validate the method of approach, with comparisons to both the respective measurements and the simulation results without the model extensions. The simulations and the related measurements have been performed by Honda R&D and have not been available in [1].

INTRODUCTION

Empirically based tire models used for ride & handling are often not accurate enough for comfort and durability analysis (for example to simulate highly transient events such as curb strikes), while finite-element based models are too slow in calculation speed to be of any practical value for full-vehicle analysis. Therefore, applicable models prefer a macroscopic physical description.

The ‘macroscopic description’ implies that the actual model contains elements representing e.g. the ‘belt’, but not individual cords of the belt layers. Therefore, model parameters such as the belt bending stiffness essentially have to be determined by testing the whole tire in a number of experiments instead of assembling mechanical properties of all the individual elements of a tire such as cord stiffness, etc. For more information on the sub models, see [9,10,14]; for some application results, see [2,3,5,6,7,8,11,12,13,15].

The concept of CDTire is that the behavior of a specific tire (dimension, design) can be determined entirely from tests with this tire, i.e. there is no need to use vehicle tests for determining tire “parameters” or for validating the tire model. So far, all physical tests for CDTire parameter identification (PI) were based on tests that the tire manufacturers, OEM's or commercial test labs can perform with standard equipment, see [4].

For regular durability (or ride comfort) events CDTire has been evaluated extensively in the automotive industry, and it was proven to very successfully predict vehicle reaction in the time domain due to standard comfort and durability excitation by random or deterministic road surfaces.

In [12], the dependence of accuracy of the load prediction results in full vehicle simulation from the aspect ratio of the tire was investigated. It was shown that for high obstacles like curb strike the accuracy decreases when low aspect ratio tires were used. The reason for the decreasing accuracy is that the ratio of tire deflection to side wall height decreases when the aspect ratio decreases for otherwise constant test conditions. So if the test conditions are held to be constant, the minimal distance between belt and rim becomes smaller when aspect ratio gets smaller. Especially for curb strike events the belt can come very close to the rim, so that belt rim contact cannot be eliminated.

This paper deals with a model extension for CDTire model 40 which tries to feature the belt-sidewall and belt-rim contact with the aim to improve the load prediction results when large and very large tire deformations are expected. The tendency and also the statistic probability to such large deformations are much bigger for low aspect ratio tires than for standard tires. So this model extension is also a step forward in improving the overall simulation accuracy for low aspect ratio tires. By investigating this topic, the sidewall model of CDTire model 40 has been revised for large deformations (see [1]).

The paper closes with a validation comparison of the new modeling approach to full vehicle applications. The event compared is a one-sided obstacle generating severe in-plane wheel forces and displacements. A short description of the measurement setup is given.

TIRE STAND-ALONE TESTING AND PARAMETER IDENTIFICATION

The main tire stand-alone testing and parameter identification results for the new large deformation extension are published in [1]. These tire stand-alone validation scenarios include large deflections onto flat surface and different obstacles like rectangular cleats and ellipses, both in centered and offset conditions. Figure 1 shows such a comparison for a 205/45 R 16 tire deflected onto an ellipse with 40mm and 30mm as semi-axis's including a visualization of simulated local sidewall/rim forces for the new large deformation extension model. On the left hand side picture in Figure 1, the deformation and local sidewall forces (thick black lines) acting on the rim are shown just before the start of the progression (position in the respective global vertical stiffness plot indicated by the cross). On the right hand side picture in Figure 1, the deformation and local sidewall forces are shown 10 mm into the progression (position in the

respective global vertical stiffness plot indicated by the cross). The circumferential variation of the local sidewall forces identifies the very local phenomenon of a sharply increased force response due to belt/sidewall/rim contact.

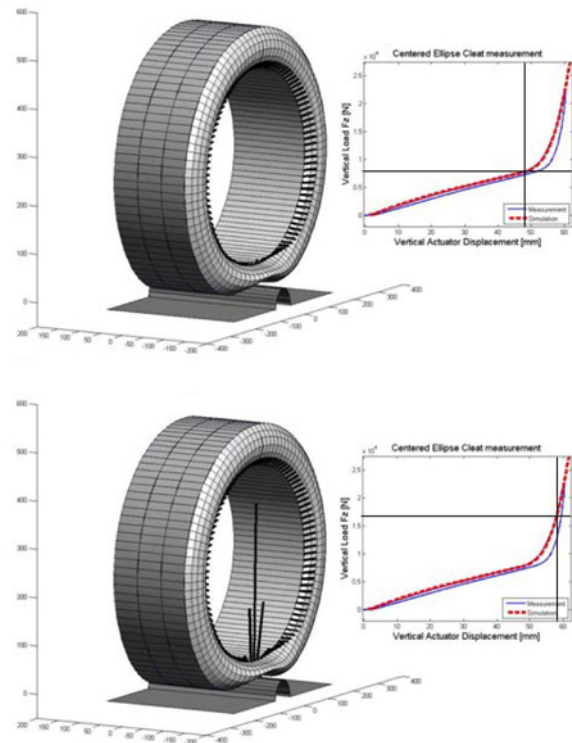


Figure 1. Visualization of simulated local rim forces and validation of resulting wheel forces

For tire stand-alone validation in a scenario which more closely resembles the tire in a state of rolling, Honda R&D developed a test rig which could not only investigate in-plane forces for quasi-static vertical deflection, but also for longitudinal displacement excitation of the obstacle surface. Figure 2 shows the principal setup of this test rig (for more information, see [1]), along with a comparison of measured in-plane vertical (F_y , dark blue stroke in, light blue stroke out) and longitudinal (F_x) forces to the simulated in-plane forces (red).

<figure 2 here>

As the stroke and velocity capabilities of this investigative test rig is limited, Honda R&D asked Fraunhofer LBF to design a test rig capable of measuring large obstacles in a tire state of rolling. In a joint effort, Fraunhofer LBF built such a test rig (see Figure 3), both for the purpose of parameter identification as well as validation.

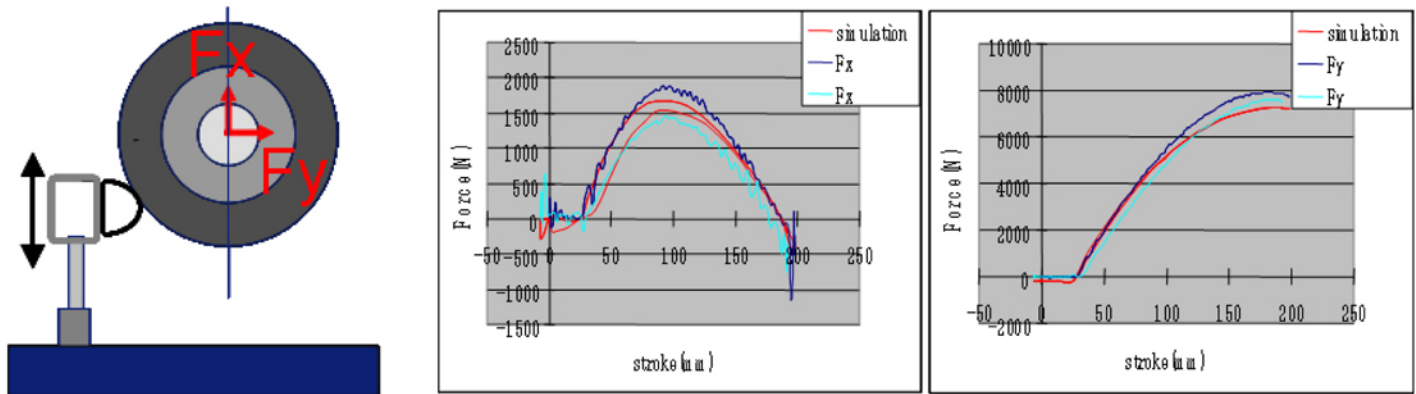
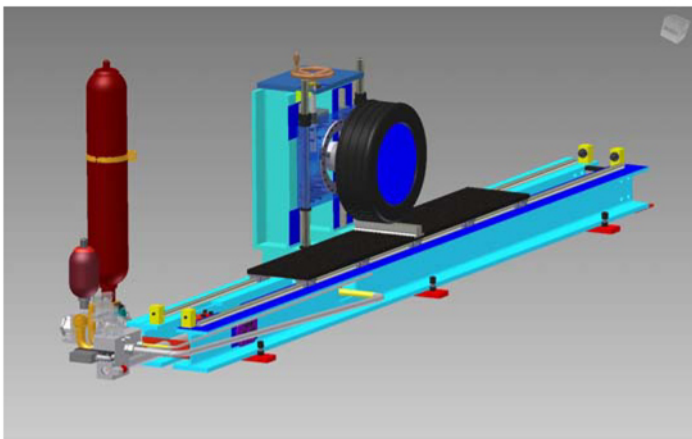


Figure 2. Principal setup of Honda R&D large deformation test rig and comparison of 205/45 R 16 results



constant velocity of up to 20 km/h during cleat crossing. In the prototype version of this test rig, a wheel load measurement system (non-rotating) was used that was limited in overturning torque (generated mainly by in-plane forces) - due to the unavailability of the targeted Kistler P530 measurement hub. At the time of writing this paper, the P530 had not yet arrived, but it is the expectation of the authors that for the SAE 2010 WC presentation of this paper, additional results can be presented. [Figure 4](#) shows a cleat crossing of an ellipse cleat (half-axis 40mm and 30 mm) for 5 km/h of the 205/45 R 16 tire.



Figure 3. Principal setup and operation of Fraunhofer LBF large deformation test rig

This newly designed test rig features a sledge of 2 m total length, driven by a long-stroke hydraulic actuator which is position and velocity controlled. This length allows for trapezoid longitudinal acceleration profiles, yielding a