

Simulating Very Large Tire Deformations with CDTire

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ABSTRACT

The full vehicle simulation on durability proving grounds is a well established technique in the 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.

After a short overview of the standard modeling technique used by the CDTire model family to handle such events, a refinement of this technique is introduced, modeling both the non-linearity behavior of the sidewall and a possible subsequent rim contact. This refinement also takes the rim deformation into account. The parameter identification procedure for the large deformation extension is explained and validation results are shown. In combination with extended post-processing functionality, this model extension enables CDTire in misuse-like simulations.

INTRODUCTION

This paper is based on a co-development project between Honda R&D and Fraunhofer LBF. Honda R&D has asked Fraunhofer LBF to extend the CDTire model, so that it can be used for simulating large deformations of the tire, for example during curb strikes. "Large tire deformations" occur in situations in which either the sidewall of the tire gets in contact with itself (due to large radial deformation), or in which the belt contacts the rim (or the interior ring, in the case of PAX-type "run-flat" tires). Since "large tire deformations" are relative to the tire dimensions, low aspect ratio tires such as "sports tires" are more likely to incur these than high aspect ratio tires.

Theoretically, large deformations of the tire may even lead to large, possibly permanent deformations of the rim. This case is excluded in this paper.

BACKGROUND: THE TIRE MODEL CDTIRE

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, the models prefer a macroscopic physical description. The CDTire model family for passenger car and truck tires consist of:

- Model 20: a rigid ring model with (global) viscous-elastic sidewall, geometrically parameterized normal contact and partial differential equation based tangential contact
- Model 30: a flexible belt, rod-type in-plane model with (local) viscous-elastic sidewall and brush type contact
- Model 40: a flexible belt, shell-type 3D model with (local) viscous-elastic sidewall and brush type contact

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 [1,2,3,5,6,7,8,11,12,13,15].

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 condition held 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.

DEFINITION OF MEASUREMENT SETUP

Before starting any modeling it is necessary to have a clear concept of how to validate the free model parameters. This fact is not bounded to the large deformation extension; it is true for every model which should be used for quantitative prediction in CAE [4]. Because the resulting tire model will be used in the development process of automotive industry, the resulting validation process should be as simple and robust as possible and the cost should be as low as possible. The definition of the measurements setup should take into account these requirements. Also the model design should be as simple as possible and as complex as needed.

From the measurement point of view it was clear from the start that the large deformation extension cannot be validated with the standard measurements used for PI, such as cleat on drum tests etc. Based on this fact, the authors have looked for a new measurement setup to validate the large deformation extension in tire model. In typical large deformation applications (i.e. curb strike) the accurate estimation of the longitudinal force is at least as important as the estimation of the vertical force. As a consequence, the measurement setup needed to take the longitudinal force into account. The second requirement was that the measurement should adapt all states of a rolling tire hitting a big obstacle in order to cover the large deformation behavior in every state. Only by reproducing all of these states, the information about the correct phasing between longitudinal force and vertical force can be obtained.

Up to the time of writing this paper, the authors are not aware of a drum test rig capable of handling the needed cleat heights and resulting high dynamic loads. For this reason, a dedicated test rig had to be developed. Figure 1 sketches a tire rolling over an obstacle with a defined and fixed distance of the spindle to the road in slow motion. Such a quasi-static setup has two characteristic inputs:

- The longitudinal distance or "offset" of the obstacle to the tire wheel center.
- The vertical distance of the wheel center to the obstacle or road.

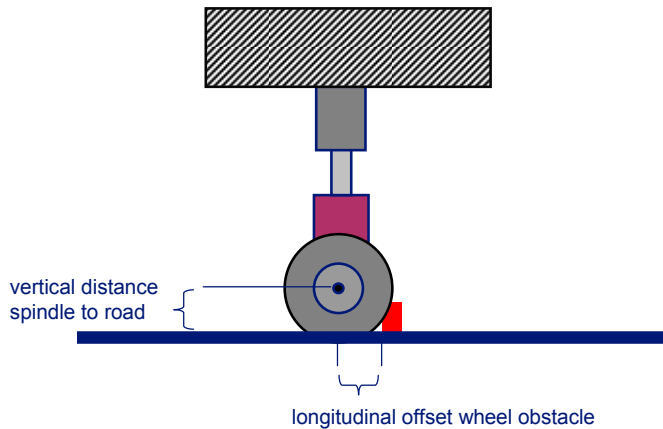


Figure 1: static states when tire rolling over an obstacle

An experimental approximation of all the states of a tire rolling over an obstacle (with the consideration of different preloads) by a series of quasi-static experiments leads inevitably to the test rig setup sketched in the following figure:

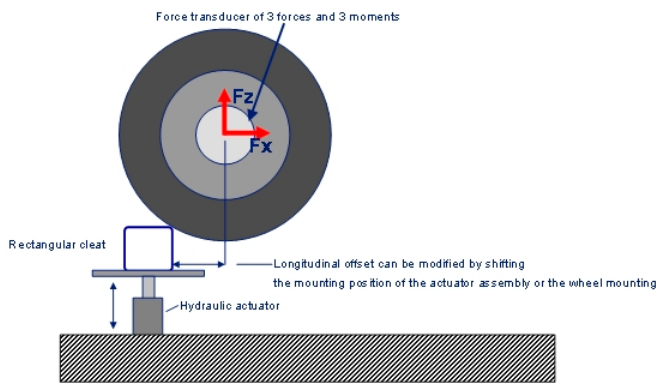


Figure 2: test rig setup to quasi-statically reproduce tire states of rolling over an obstacle

Additionally, the obstacles used in this test can also be varied in order to introduce different local curvatures. The authors have used a rectangular cleat of size 120 mm and an ellipse cleat with vertices of 30 and 40 mm. The ellipse cleat has mainly been used in centered position (with one vertex of the ellipse under the wheel center). As a final variation, tests with a flat bed have been performed. Figure 3 shows the test rig setup for ellipse cleat test and for the bed test.

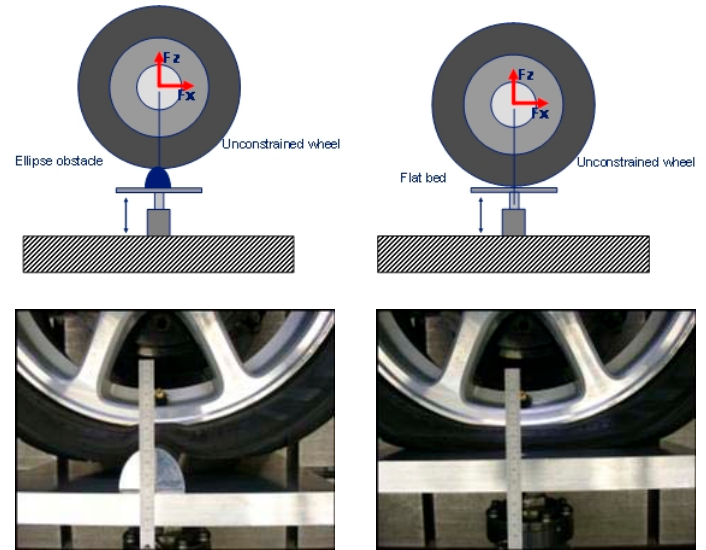


Figure 3: Test setup for ellipse cleat and flat bed testing

When setting up these tests the authors discussed whether or not the wheel rotation should be unconstrained or constrained or both for the measurements. Both parties agreed to prefer the unconstrained case because this better adapts the rolling tire.

The following figure shows typical measurement results for the offset cleat scenario (here with 80 mm offset). Due to the unsymmetrical excitation, both vertical and longitudinal forces are shown. The tire size was 205/45 R 16 and the measurements were performed with an inflation pressure of 220 kPa:

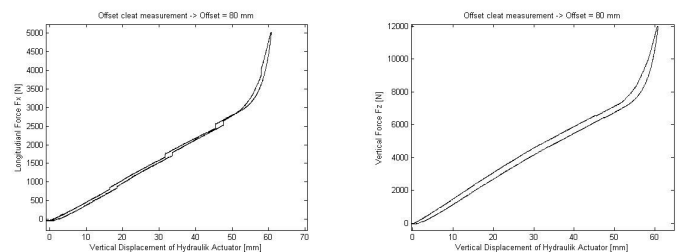


Figure 4: Static offset cleat measurement (offset = 80mm)
→ longitudinal (F_x) and vertical force (F_z)