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The Hohenheim Tyre Model: A validated approach for the simulation of high volume tyres – Part II: Validation

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Abstract

This publication series describes the development of the Hohenheim Tyre Model – an approach that considers the properties of high volume, agricultural tyres. The research project was conducted in accordance with the V-Model, which proposes a standardised development methodology for mechatronic systems. The previous publication described amongst others the model structure and parameterisation. This paper elucidates the validation, which is an essential part of the V-Model. Validation received special attention and is divided into three parts. First, three-dimensional tyre behaviour on level surfaces was investigated. Within the second step, single tyre behaviour is validated during obstacle passages. Similar obstacles were then used in the final step that shows up the correlation between measured and simulated whole vehicle behaviour. Throughout the validation a very high level of accuracy is achieved.

Keywords: Tyre model; Handling; Comfort analysis; Multi-body simulation

1. Introduction

At the University of Hohenheim extensive research has been conducted in the area of tyre modelling. Throughout, all tyre related projects were dedicated to the investigation and simulative description of high volume, agricultural tyres. Coming from a single point contact approach for the investigation of handling (Ferhadbegović, 2009), Witzel (2015) developed an entirely new multi-spoke tyre model. The more complex model structure was introduced in order to extend the field of application to studies relevant to ride quality. Apart from that, project aims were comparable to the goals of earlier studies. Thus, high volume tyres are still in the focus of attention. Moreover, parameterisation should be easy to conduct with the two in-house tyre test stands. Even more importantly, model quality is to be proven in a comprehensive validation. The project workflow was arranged according to the VDI 2206 (2004) standard, which proposes a v-shaped methodology for the development of mechatronic systems. The so called V-Model as well as major parts of the development process were described in part I of this publication series (Witzel, in press). This includes the description of the model structure and the parameterisation procedure. The presented contribution deals with the validation, which constitutes the final step of the development.

The Institute of Electrical and Electronics Engineers (IEEE Std 610.12-1990, 1990) differentiates between a verification and a validation process during software development. According to the standard, verification is the “formal proof of program correctness”. Subsequently, model behaviour is compared against the specified requirements defined by the aims and objectives at project start. This is accomplished by means of comparisons between measured and simulated data. Both aspects – verification and validation – are an integral part of the procedure

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Notation

F_{FR}	wheel hub force front right (N)	n	number of data point
F_{RL}	wheel hub force rear left (N)	p_i	tyre inflation pressure (bar)
F_{RR}	wheel hub force rear right (N)	t	time (s)
F_x	longitudinal force (N)	v_D	driving velocity (m/s)
F_y	lateral force (N)	v_y	lateral velocity (m/s)
F_z	vertical force (N)	α	slip angle (°)
F_{zstat}	static wheel load (N)	σ	wheel slip (%)
i	data point	y_{meas}	measured data point, here (N or Nm)
MAE	mean absolute error, here (N or Nm)	y_{sim}	simulated data point, here (N or Nm)
M_z	self-aligning torque (Nm)		

suggested in the V-Model (VDI 2206, 2004). However, this publication focuses on aspects in the context of validation. It comprises three parts:

- Single tyre behaviour on level surfaces (chapter 2)
- Single tyre behaviour during obstacle passages (chapter 3)
- Whole vehicle investigations during obstacle passages (chapter 4)

In the first part, three dimensional tyre properties are investigated, which are primarily relevant to handling. Obstacle passages were then conducted in order to demonstrate model accuracy regarding longitudinal and vertical tyre force computation on uneven ground. Both of which are closely linked to comfort investigations.

As a measure of simulation accuracy, mean absolute error (MAE) is introduced for all simulation data in time domain. MAE describes the mean absolute difference between measured data points y_{meas} and the corresponding simulated data points y_{sim}. It is computed from:

$$MAE = \frac{\sum_{i=1}^{n} |y_{meas\ i} - y_{sim\ i}|}{n} \quad (1)$$

where n is the total number of data points i.

2. Single tyre behaviour on level surfaces

The validation of single tyre behaviour is based on experimental results that were gathered in the context of Ferhadbegović (2009). Again, the in-house flat belt test stand and the single wheel tester as described in Witzel (in press) were employed. Experiments related to longitudinal and lateral tyre behaviour were conducted with the single wheel tester on a paved road (Ferhadbegović, 2009). Model accuracy is exemplified on the test tractor's rear wheel (520/70 R 38). This publication primarily focuses on aspects relevant to transient tyre behaviour. Witzel (2015) gives a more comprehensive overview that includes quasi-static results.

2.1. Validation of vertical tyre behaviour

Vertical tyre behaviour on level surfaces is investigated with the flat belt test stand. For validation purposes, measured and simulated oscillation decay are compared to each other. The procedure is well known from other Hohenheim research projects (Langenbeck, 1992; Ferhadbegović, 2009). Von Holst (2001) also used a flat belt test rig to validate vertical tyre behaviour on level ground. He applied the "Gallrein Model", which is comparable to CDTire 30, to an agricultural tyre.

The status of the presented approach is highlighted in Fig. 1. It shows an example whereby driving velocity v_D and static wheel load F_{zstat} were set to 25 km/h and 14 kN, respectively.

Measured and simulated forces are closely related to each other. Both amplitude deviation and phase shift are very little, which then also results in a small MAE.

2.2. Longitudinal force transmission

Longitudinal force transmission of tyre models is commonly validated by means of comparisons of measured and simulated traction-slip characteristics (van Oosten

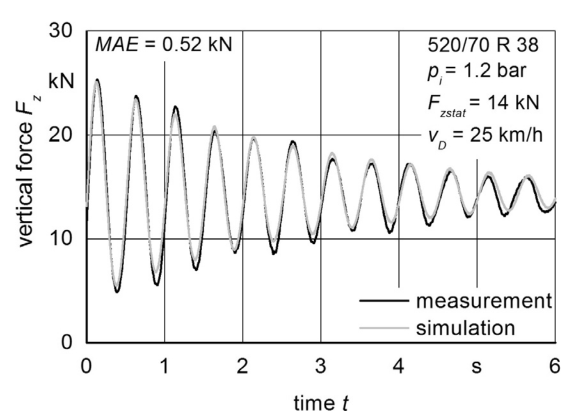

Fig. 1. Measured and simulated oscillation decay.