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Passage of obstacles with the Hohenheim Tyre Model

Driving speed of tractors has steadily increased in recent years. Modern standard tractors reach a speed of up to 60 kph. This trend puts high demands on the construction of components that are relevant to driving dynamics and comfort. Thereby simulation techniques can be a useful tool to shorten development time. A prerequisite for this is an accurate tyre model which depicts the specific properties of agricultural tyres. This contribution deals with an enhancement of the Hohenheim Tyre Model to simulate tyre behaviour during the passage of obstacles.

Keywords
Tyre, tyre model, passage of obstacles

Abstract
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6 references

With the aid of the Hohenheim Tyre Model, driving dynamics of tractors and self-propelled harvesters on solid, even ground can be simulated [1]. To the benefit of a low computation time the contact patch of the tyre is described as a single point contact. In the analysis of track caused vibrations this simplification restricts the scope of application to the passage of sinusoidal undulations with a wavelength which is at least twice as long as the contact patch [1]. Some approaches have been presented, whereby a given track profile is filtered [2; 3]. The filtered surface is then used as an input variable of a single point contact model. However, these models overestimate reaction forces in many cases [4]. More accurate results can be achieved with tyre models that describe the contact patch with a multi point contact [5].

In order to simulate the passage of cleats with the Hohenheim Tyre Model the existing approach is extended by another contact point. This publication describes the model structure and the validation process.

Model structure

The existing Hohenheim Tyre Model uses a Voigt-Kelvin Element to calculate vertical forces. Longitudinal forces are computed by another, horizontally arranged Voigt-Kelvin Element.

For the investigation of longitudinal and vertical forces during the passage of obstacles the existing tyre model is extended by another two Voigt-Kelvin Elements. One of them is fitted in between the rim and the shortest distance to the ground in radial direction (**figure 1**). The second, tangentially placed Voigt-Kelvin Element acts on the bottom of the radial element.

Within this approach the assumption is made, that the vertical spring stiffness c_{1z} of the original tyre model is distributed in equal shares to the radially placed springs. The spring parameter c_{2z} which describes the progression of the non-linear model remains unchanged. This assumption corresponds well with the observations Schlotter [6] made. Thus, the vertical, or rather the radial spring force *f* is calculated as follows:

$$F_{spring} = \frac{c_{1z}}{2} \cdot f^{c_{2z}} \qquad \text{(Eq. 1)}$$

where f is the deflection of the Voigt-Kelvin Element.

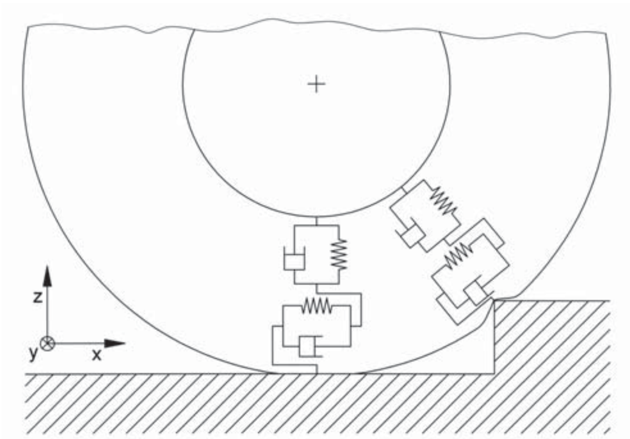
The characteristics of the radially placed damper elements and the properties of the tangentially arranged Voigt-Kelvin Elements are described by the parameters of the original tyre model in vertical and longitudinal direction. The vector sum of the reaction forces of the four Voigt-Kelvin Elements yields the resulting force. It can be decomposed into a longitudinal and a vertical component.

Validation

For validation the chosen approach experiments were conducted with the Institute owned single wheel tester. In order to compare the experimental results with the computations, a detailed Multi-Body Simulation model (MBS model) of the singe wheel tester had to be developed (**figure 2**).

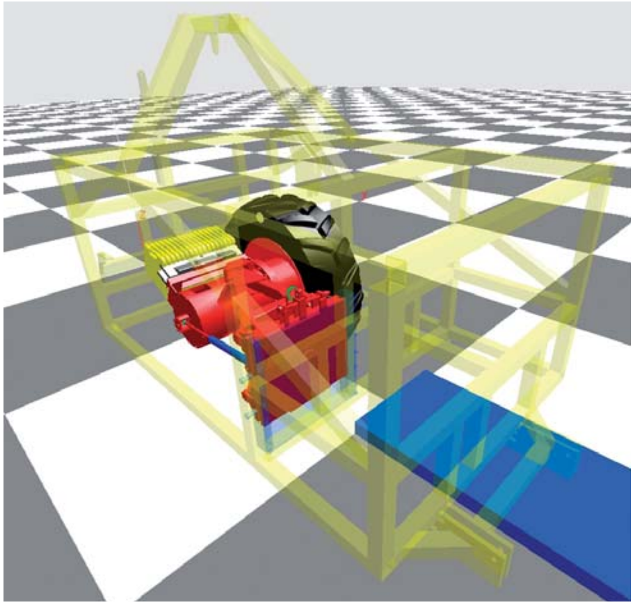
It has to be taken into account that the measuring hub of the single wheel tester acquires forces and torques in the intersection of the measuring hub and the wheel hub. Thus, the inertia forces of the wheel hub and the measuring wheel are not recorded. In contrast, the tyre model computes the reaction forces in between the ground surface and the contact patch. This implies the inertia forces of all components. In order to conclude on the wheel

Fig. 1



Modular organisation of the two point contact model

Fig. 2



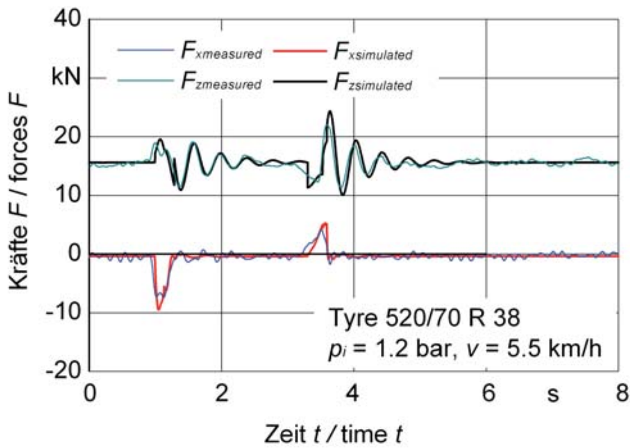
MBS-model of the single wheel tester

hub forces by knowing the reaction forces in the contact patch, the acceleration of the wheel hub is assessed in the MBS model. Once the masses of the wheel hub and the measuring wheel have been determined the wheel hub forces can be calculated.

For the validation of the model an obstacle with a length of 3.1 m and a height of 0.125 m was passed. This obstacle shape was selected as it allows an independent assessment of the reaction forces during the upward and the subsequent downward movement of the wheel. Investigations were made with a tractor tyre (520/70 R 38) which was operated with an inflation pressure of 1.2 bar. The obstacle was passed with a slip angle of 0° and a speed of 5.5 km/h. **Figure 3** and **figure 4** show a comparison in between measured and simulated vertical and longitudinal forces at different static wheel loads (F_z = 15.6 and 22.2 kN).

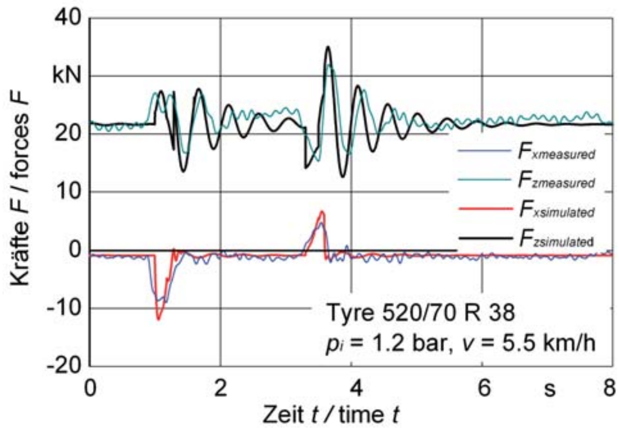
The frequencies of the measured and the simulated forces are well corresponding during the passage of the obstacle. Noticeable force variations were measured before and after the passage of the obstacle. They are caused primarily by the lugs of the tractor tyres. Furthermore, the dynamics of the test stand play a role. Those factors are not taken into account by the current model. Both measured and simulated forces show smaller variations when the tyre hits the obstacle than when it leaves the obstacle subsequently. The observed behaviour can be explained by the conversion of the potential energy that the wheel has gained during the upward movement onto the obstacle.

Fig. 3



Forces while driving over a step obstacle (F_z = 15.6 kN), measured and simulated

Fig. 4



Forces while driving over a step obstacle (F_z = 22.2 kN), measured and simulated

When the wheel leaves the obstacle this energy in converted into kinetic energy or rather potential spring energy before it is finally absorbed by the damper. This also explains the progression of the longitudinal force which has its absolute maximum by the time the tyre leaves the obstacle and is directed into driving direction. The simulated progressions of the vertical forces show a noticeable oscillation at about 1.3 s shortly after the tyre hit the obstacle. This is caused by the vertically arranged Voigt-Kelvin Element which reaches the obstacle in this moment. Due to the principle of the model the vertical force declines abruptly by the time the tyre leaves the obstacle at about 3.3 s. In this situation the vertical spring-damper element follows the contour of the surface and has no contact to the ground for a short time period.

A qualitative comparison between the results of the measurements and the outcomes of the simulations unveiled a slight overestimation of the reaction forces. However, implementing the „Fixed Footprint“ or alternatively the „Rigid Ring“ filtering approach after Captain et al. [2] into the Hohenheim Tyre Model revealed overestimations that were much higher.

Summary and outlook

The described approach depicts a simple enhancement of the existing Hohenheim Tyre Model to a two point contact model. With the aid of this extension longitudinal and vertical forces can be calculated during the passage of obstacles. Primary validation experiments with a step-shaped obstacle showed a good conformity between reality and simulation.
Moreover it can be stated that the described model obtained better results than the fixed footprint and rigid ring filtering approach. In what way this holds true for other boundary conditions needs to be investigated. Therefore tests with different speeds and various obstacle shapes will follow. In order to enhance simulation quality the development of a Flexible Tread Band model [4] is taken into consideration.

Literature

[1] Ferhadbegović, B. (2009): Entwicklung und Applikation eines instationären Reifenmodells zur Fahrdynamiksimulation von Ackerschleppern. Dissertation, Universität Stuttgart. Forschungsbericht Agrartechnik Nr. 475, Hg. VDI-MEG
[2] Captain, K. M.; Boghani, A. B.; Wormley, D. N. (1979): Analytical tire models for dynamic vehicle simulations. Vehicle System Dynamics 8(1), pp. 1-32
[3] Pacejka, H. B. (2002): Tyre and vehicle dynamics. Oxford, Butterworth-Heinemann
[4] Harth, V.; Fayet, M.; Maiffready, L.; Renou, C. (2000): Wheel-obstacle interaction models for off-road vehicles. 8th European Conference of ISTVS, Umea, Sweden, pp. 164-171
[5] Kising, A. (1988): Dynamische Eigenschaften von Traktor-Reifen. Dissertation, Technische Universität Berlin. Düsseldorf, VDI-Verlag, VDI Fortschritt-Berichte, Reihe 14, Landtechnik/Lebensmitteltechnik Nr. 40
[6] Schlotter, V. (2006): Einfluss dynamischer Radlastschwankungen und Schräglaufwinkeländerungen auf die horizontale Kraftübertragung von Ackerschlepperreifen. Dissertation, Universität Stuttgart. Forschungsbericht Agrartechnik Nr. 437, Hg. VDI-MEG

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