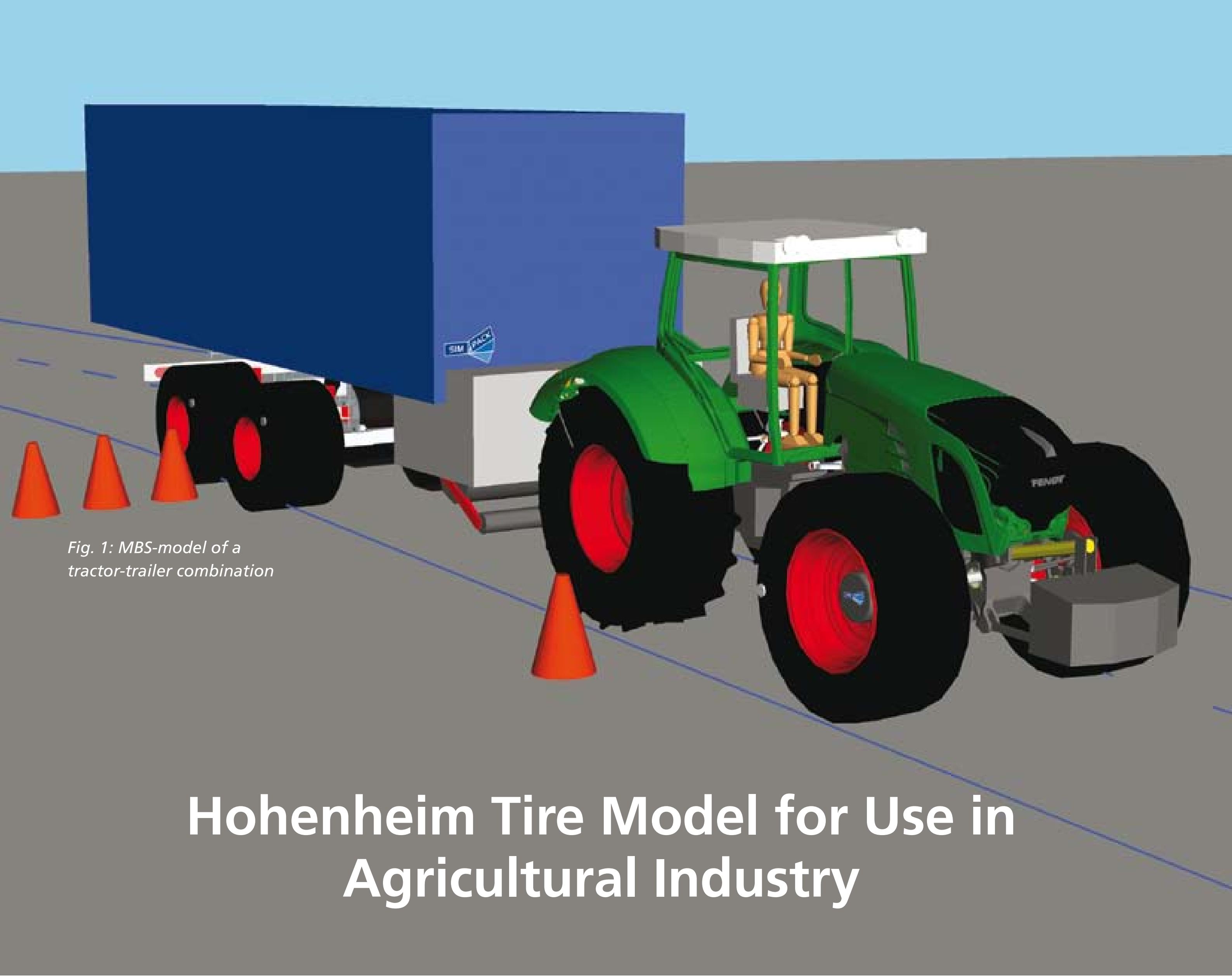

Fig. 1: MBS-model of a tractor-trailer combination

Hohenheim Tire Model for Use in Agricultural Industry

A transient tire model for the simulation of agricultural machinery has been developed at the Institute of Agricultural Engineering at the University of Hohenheim. After successful validation, the tire model is now being used to simulate the driving dynamics of tractor-trailer combinations.

GROWING DEMANDS

Tractors are very versatile machines. One of their major areas of application is the transport of agricultural goods. Due to growing demands for improved time and cost efficiency, the driving speed of these machines has increased significantly in recent years. Nowadays standard tractors achieve top speeds of 60 km/h.

Multi-body simulation (MBS) is a very useful tool in helping to understand and optimize the driving dynamics of tractors and tractor-trailer combinations. Considering that the suspension of the rear tractor axle is mainly accomplished by the tires, it is crucial that the tire model used depicts the specific properties of high volume agricultural tires accurately. The Hohenheim Tire Model [1] meets this requirement.

"The model is capable of simulating combined slip conditions and requires a low computational effort."

THE TIRE MODEL

The Hohenheim Tire Model is a transient, three dimensional model based on a semi-empirical approach. Whereas the tire-ground interaction is described by characteristic curves, the tire itself is modeled with three Voigt-Kelvin elements. The typical properties of high volume agricultural tires such as non-linear, speed-dependent spring and damper characteristics are taken into account. In contrast to car tires, it is important to consider the radial run-out of agricultural tires. Even though the radial run-out may be less

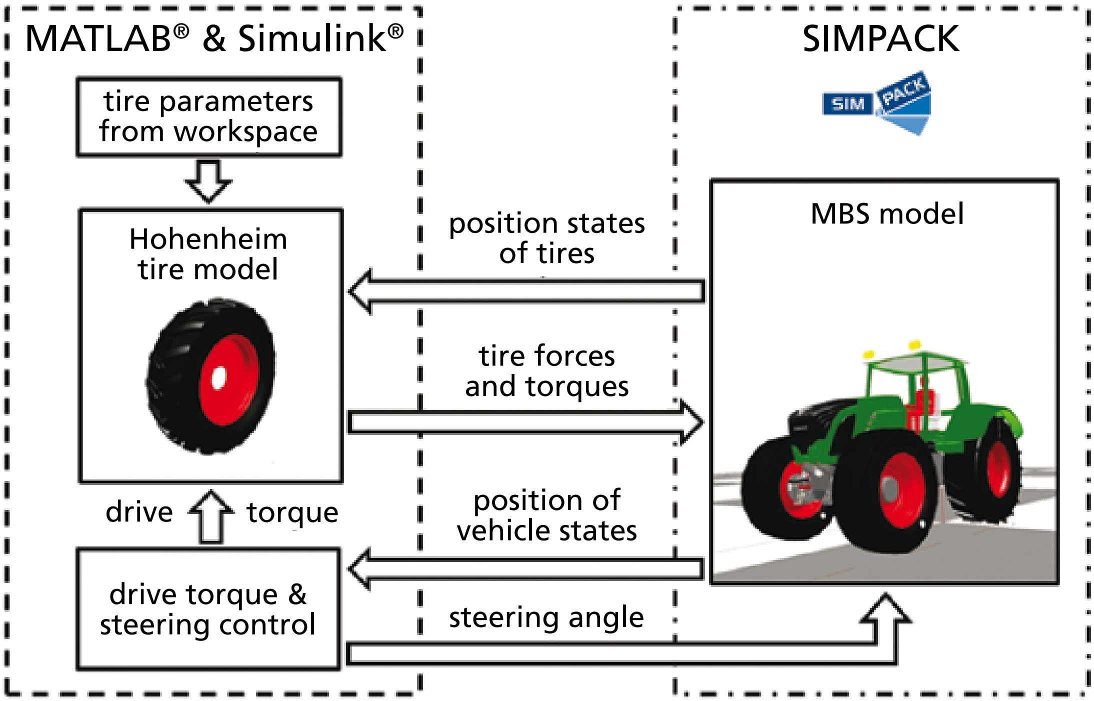

Fig. 2: Functional schematic of the dynamic co-simulation

than 2 mm, resonances can occur at certain speeds. This can have significant effects on the vehicle's driving dynamics.
The model is capable of simulating combined slip conditions and requires low computational effort. It requires a limited number of parameters which can be easily determined on the Institute's testing facilities.

VEHICLE MODELS

The presented tractor-trailer combination consists of a Fendt 936 Vario and a CLAAS silage trailer Cargos 9500.
The Fendt 936 Vario has a rated engine power of 243 kW, a dead weight of about 10 t, and a maximum gross vehicle weight of 18 t. It is equipped with a hydropneumatic, level controlled front axle suspension, a pneumatic cab suspension and has a top speed of 60 km/h. The SIMPACK model of the tractor was developed by AGCO GmbH and is based on the work of Böhler [2]. Both front axle suspension and cab suspension characteristics are defined with User Force Elements which have been written in Fortran. The characteristics of the hydropneumatic front axle suspension are modeled under the assumption that the change of state is adiabatic.
The CLAAS silage trailer was also modeled by the University of Hohenheim in SIMPACK. Required parameters were provided by CLAAS. The trailer has a dead weight of 13 t and permissible total weight of 24 t. It can be ordered with different undercarriage systems. The current MBS model is featured with a tandem axle. The user can choose between a rigid, a self-steering on a positive steering axle. All axle configurations are based on the same standard axle supplied by BPW. Under normal operating conditions the self-steering axle needs to be locked at high speeds and in reverse drive, whereas the positive steering axle is always activated.
The drawbar of the trailer is also suspended. This reduces pitch oscillations of the tractor and increases driving safety and comfort. The suspension is modeled in Simulink® and the resulting forces are transferred via the SIMAT co-simulation interface to SIMPACK.

"A co-simulation links the MBS model in SIMPACK to the tire model in Simulink."

DYNAMIC CO-SIMULATION

The mechanical systems of tractor and trailer have been modeled in SIMPACK, the tire model has been implemented entirely in MATLAB® and Simulink.
A co-simulation links the MBS model in SIMPACK to the tire model in Simulink. SIMPACK's standard interface SIMAT is used for this co-simulation. Before starting the co-simulation, tire parameters are loaded into the MATLAB workspace, and the initial conditions of the MBS model are defined. During the co-simulation, the tire model receives information about the current state of each vehicle wheel (position and velocity). With this information, the Hohenheim Tire Model then computes tire forces and torques and transmits them back to SIMPACK (Fig. 2).
The vehicle is maneuvered by means of steering and drive-torque control elements which are embedded in Simulink.
During the co-simulation, SIMPACK uses its variable stepsize solver. The data is transferred at a fixed interval of 0.002 s.

RESULTS

Various driving maneuvers such as the double lane change according to the ISO/TR 3888 standard, have been simulated with the described tractor-trailer combination. The positions of the cones which define the test track are described in the ISO standard. They are related to the dimensions of the tractor-trailer combination. Within SIMPACK, the track is defined by a Cartographic Road Track file. Vehicle guidance is performed with the Automotive Track Joint. The offset of the tractor with respect to the road definition is measured 6 m before the front axle of the tractor. This "preview length" is an input parameter of the steering control which is embedded in Simulink (Fig. 2). In order to highlight the influence of different

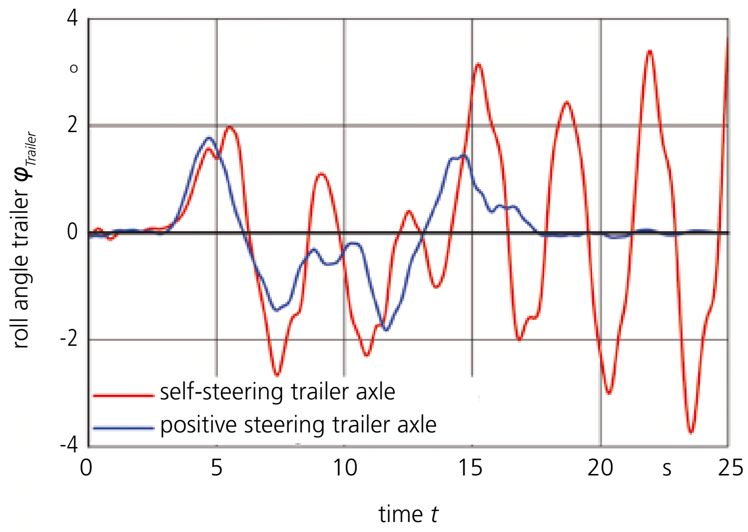

Fig. 3: Roll angle of the trailer during a double lane change

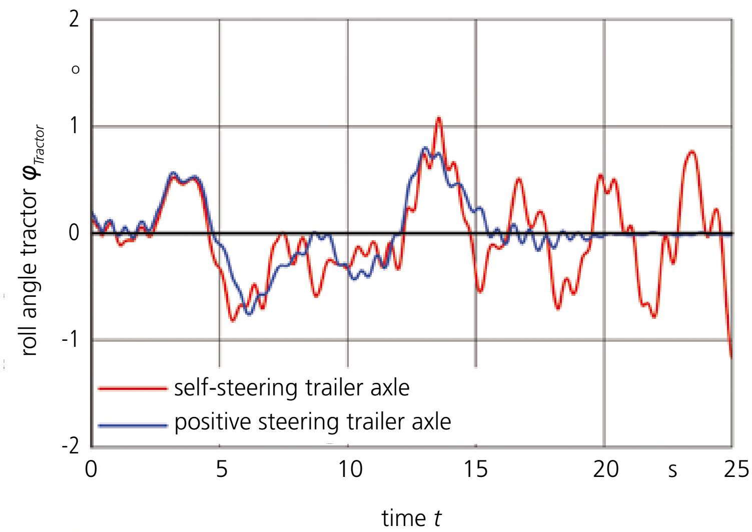

Fig. 4: Roll angle of the tractor during a double lane change (ISO/TR 3888)

trailer axle configurations, the roll angle of the tractor-trailer combination is measured and plotted.
The SIMPACK PostProcessor was used for evalutating the results. Fig. 3 and 4 show the results for the trailor and the tractor, respectively. In this way, a self-steering trailer axle configuration has been compared to a positive axle configuration. Both simulations used the same Hohenheim Tire Model. The driving speed was 20 km/h.
The trailer with the self-steering axle shows higher rolling angles. The oscillations are induced by the wheel shimmy of the self-steering axle. Due to resonance, the amplitude of the oscillation does not decay after the tractor has passed the course at approximately 20 s. Evaluating the roll angle of the tractor body reveals that the oscillation of the trailer is transmitted to the tractor. On the other hand, the rolling angle of the positive steering tractor-trailer combination is low and declines rapidly once the tractor has passed through the course.

"The realistic modeling of agricultural tires is crucial for obtaining realistic results."

The conclusions which can be drawn from the simulations confirm practical recommendations and legal requirements: for the benefit of driving safety, a self-steering axle should be locked at high speeds. The positive steering axle is more costly. However, it provides higher driving safety at both low and high speeds.

SUMMARY AND OUTLOOK

Driving speeds of tractors have steadily increased in recent years. Thus, understanding and optimizatiing their driving dynamics are becoming more important. The realistic modeling of agricultural tires is crucial for obtaining realistic results. With this in mind, the Hohenheim Tire Model has been developed and validated. The simulation results of the co-simulation between the Hohenheim Tire Model (in Simulink) and the tractor-trailer MBS model (in SIMPACK) are reasonable and confirm practical observations. However, a more thorough validation of the MBS model is required before final conclusions can be drawn.

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