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Identification of side force-slip angle characteristic from road tests with an agricultural tractor

Driving dynamics simulation of modern agricultural tractors becomes more and more important due to increasing top speeds, rising loads and shorter developmental periods. Agricultural tyres hit diameters of up to 2.15 m and they are the most important suspension component on standard tractors with unsprung rear axles. For a sophisticated simulation the exact knowledge of spring and damping characteristics as well as maximum transmissible forces is necessary. However, the measurement of very large tyres is possible on only few test stands. For this reason an alternative method to acquire tyre parameters is presented in this contribution.

Keywords
Tyres, simulation, tyre model, driving dynamics

Abstract
Landtechnik 65 (2010), no. 6, pp. 426-428, 6 figures, 10 references

In the last years the institute's tyre test stands have delivered valuable knowledge about the behavior of agricultural tyres and supported the development and validation of the Hohenheim tyre model [1-7]. Though, for the measurement of very large tyres, both the test stands and the test environment are limited (2 m diameter, 600 mm width). Larger test facilities would align with enormous cost and space efforts [8].

In a joint project of the University Hohenheim together with its industrial partners Goodyear Tires S.A., AGCO GmbH and Kistler-Igel GmbH the identification of tyre parameters from road tests is investigated. This article focuses on the determination of the steady state side force-slip angle characteristic, a basic parameter for most tyre models, presented for the left front wheel (Goodyear Optitrac R+, 650/65 R34, 1.6 bar). Core piece of the investigations is a modern high horsepower tractor, which is widely equipped with measurement instrumentation, **figure 1**. On the left side two modular measuring wheels from Kistler are mounted, which are tested the first time in this dimension [9; 10].

Analysis of measured values

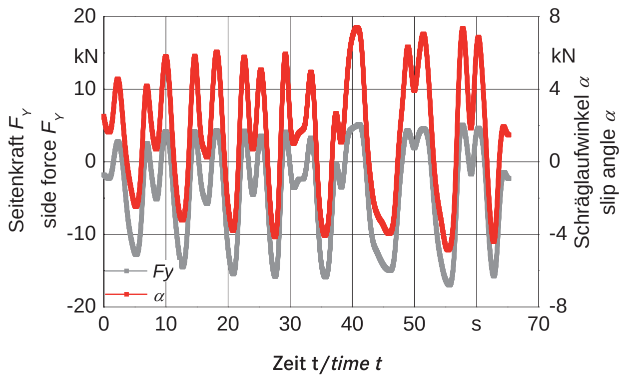
Different driving maneuvers with varying wheel loads and inflation pressures on tarmac were progressed with the test vehicle. In this article the results of a random course with velocities between 46 and 53 km/h are depicted. A data preparation initially filters the measured values and corrects the measured wheel load, as the sensor is located in the wheel cup and does not capture the masses of tyre and rim ring. **Figure 2** shows side force F_Y and slip angle α over time. These values cannot directly be taken as results, but need an additional analysis of the boundary conditions. Barrelmeyer and Schlotter showed that high slip angle rates and wheel load rates lead to delayed force increase and decrease and cause deviations from the steady state characteristic [5; 6]. Complete elimination of dynamic effects is not possible but thresholds can be defined. A meaningful choice of these thresholds can be derived from test results of the past with smaller (480/70 R24 and 520/70 R38) agricultural tyres. Generally, the influence of the slip angle rate decreases with increasing driving velocity. As the measured side force sensibly reacts on slip angle rates, only data within +/-1°/s were taken into account in this analysis, **figure 3**. High wheel load rates also falsify the side force. The chosen threshold within +/-10 kN/s is arranged on the upper limit of admissibility, **figure 4**. Compared to the rear axle the wheel load variations on the front axle range on a significantly lower level. This is presumably due to the sprung front axle.

A superposed longitudinal force, evoked by traction and rolling resistance forces, leads to a reduction of the maximum transmissible side force, also known as friction circle. An earlier measurement on a 520/70 R38 tyre has shown that a superposition of longitudinal forces up to +/-3 kN almost doesn't affect the side force transmission. The test vehicle Fendt Vario 936 was used in this test on rear wheel drive, so the front wheels only had to deal with the rolling resistance force in longitudinal direction. The measurements with an average of around –900 N have completely been taken over after filtering, **figure 5**.

Fig. 1

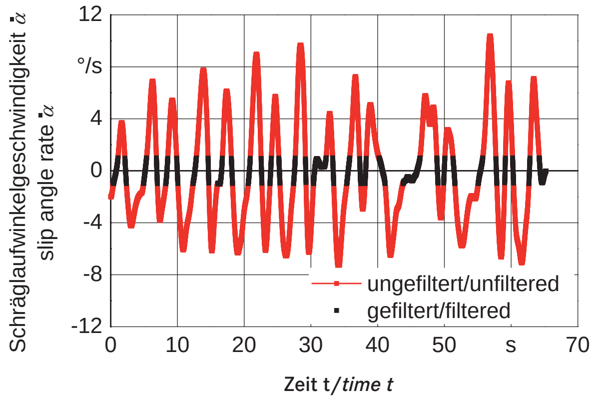
Fendt Vario 936 test machine with Kistler measuring rims

Fig. 2



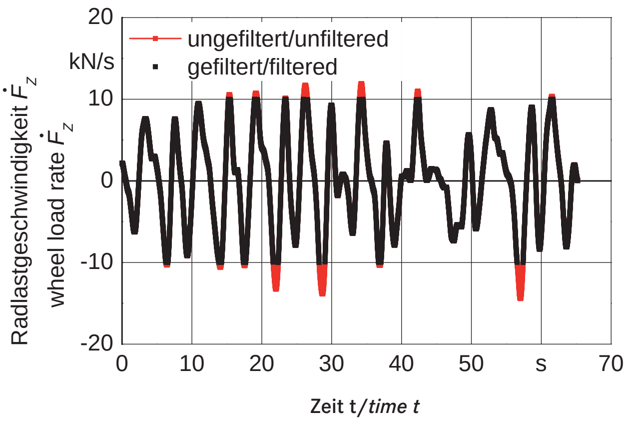
Side force and slip angle at front wheel over time during test run

Fig. 3



Slip angle rate, unfiltered and filtered

Fig. 4



Wheel load rate, unfiltered and filtered

View on results

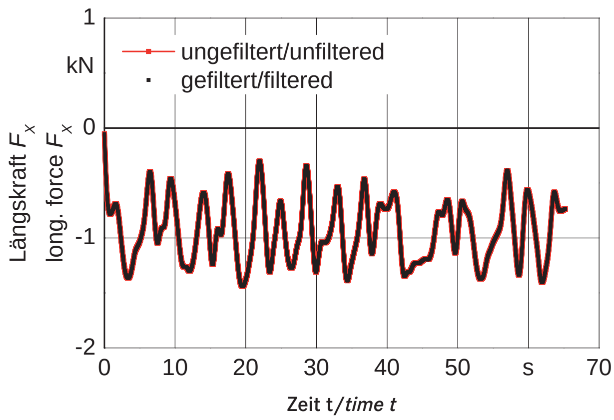
Setting the thresholds is always a dilemma. Very restrictive treatment of the thresholds increases the quality of quasi-steady state measurements, but also reduces the data basis for the subsequent curve regression, especially at high slip angles. In this case 91 % of all values are within the thresholds. **Figure 6** shows the result of the data analysis for the above-mentioned thresholds for longitudinal force, slip angle rate and wheel load rate. For comparison, the data without any filtering are also depicted. The strong asymmetry of the illustration is generated by dynamic wheel load variations while cornering. The left front wheel experiences a load application in right curves (negative slip angle) and load relief in left curves, evoked by lock of the oscillating mode of the front suspension (Fendt stability control). Though, a wheel load is assigned to each measuring point. In a future step several test series with varying ballasts will be summarized to conclude to characteristics at constant wheel load.

Figure 6 plainly shows the limitations of this procedure. The vehicle reached its driving limitations during the test runs. Nevertheless large slip angles were not reached. For most driving simulations this range is sufficient. For the test of extreme situations (e.g development of driving assistance systems) an extrapolation of the curves is necessary. Furthermore camber is not considered. This is negligible for agricultural tyres and small camber angels according to [7].

Conclusions

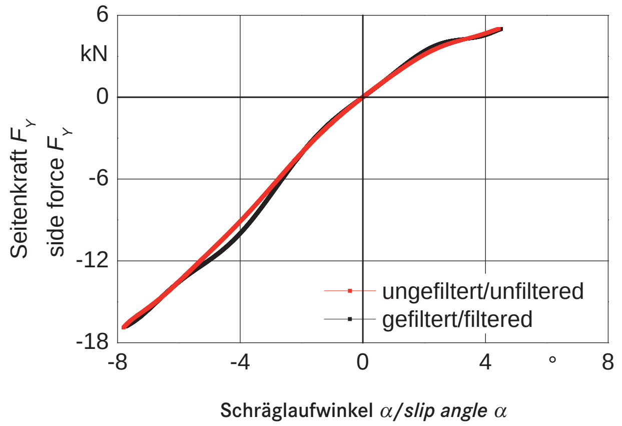
The identification of side force-slip angle characteristics from road tests is in principle possible. Due to narrow driving limitations of tractors (upset of the vehicle) measuring results are only acquirable in a small window. The validation of the results on the test stands will follow at a later date. Advanced tests will take place in the future under special consideration of parameters needed for the Hohenheim tyre model. The front wheel will also be measured on the institute's test stands to validate the quality of the results and the method.

Fig. 5



Superposed longitudinal force, unfiltered and filtered

Fig. 6



Side force over slip angle, unfiltered and filtered

Literature

[1] Schrogl, H. (1989): Dynamische Eigenschaften von Ackerschlepper-Triebradreifen bei höheren Rollgeschwindigkeiten. Dissertation, Universität Hohenheim, Forschungsbericht Agrartechnik VDI-MEG, Nr. 159

[2] Langenbeck, B. (1992): Untersuchungen zum Fahrverhalten von Ackerschleppern unter besonderer Berücksichtigung der Reifeneigenschaften. Dissertation, Universität Stuttgart, VDI-Verlag Düsseldorf, VDI Fortschritt-Berichte, Reihe 14, Nr. 55

[3] Plesser, J. (1997): Dynamisches Verhalten von Ackerschlepperreifen in Vertikal- und Längsrichtung auf fester Fahrbahn. Dissertation, Universität Stuttgart, VDI-Verlag Düsseldorf, VDI Fortschritt-Berichte, Reihe 14, Nr. 83

[4] Armbruster, K. (1991): Untersuchung der Kräfte an schräglaufenden angetriebenen Ackerschlepperrädern. Dissertation, Universität Stuttgart, VDI-Verlag Düsseldorf, VDI Fortschritt-Berichte, Reihe 14, Nr. 53

[5] Barrelmeyer, Th. (1996): Untersuchung der Kräfte an gelenkten und angetriebenen Ackerschlepperrädern bei Gelände- und Straßenfahrt. Dissertation, Universität Stuttgart, VDI-Verlag Düsseldorf, VDI Fortschritt-Berichte, Reihe 14, Nr. 79

[6] Schlotter, V. (2006): Einfluss dynamischer Radlastschwankungen und Schräglaufwinkeländerungen auf die horizontale Kraftübertragung von Ackerschlepperreifen. Dissertation, Universität Stuttgart, Shaker Verlag Aachen, Forschungsbericht Agrartechnik VDI-MEG, Nr. 437

[7] Ferhadbegović, B. (2009): Entwicklung und Applikation eines instationären Reifenmodells zur Fahrdynamiksimulation von Ackerschleppern. Dissertation, Universität Stuttgart, Forschungsbericht Agrartechnik VDI-MEG, Nr. 475

[8] Kutzbach, H. D.; Witzel, P.; Schreiber, M. (2009): Single wheel field tester for farm tractor tyres, a review. 11th European Regional Conference of the International Society for Terrain-Vehicle Systems, Bremen, 2009

[9] Schulze Zumkley, H.; Böttinger, S. (2009): Tyre parameter identification from road tests with agricultural tractors. 11th European Regional Conference of the International Society for Terrain-Vehicle Systems, Bremen, 2009

[10] Schulze Zumkley, H.; Böttinger, S. (2009): Modular measuring wheels for high horsepower tractors. Tagungsband VDI/MEG-Tagung Landtechnik, Hannover, 2009, VDI-Berichte Nr. 1503, S.33-39

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