Matthias Schreiber, Christian Brinkmann and Volkmar Schlotter, Hohenheim

Investigations on Straining Points from Resulting Forces in the Tread Contact Patch

To make multi-body simulation for the development of agricultural vehicles possible with meaningful input, simple, but sufficiently accurate partial models are needed. Till now tractor tyre driving behaviour was mostly tested on vertical and longitudinal dynamics. To have a more realistic tyre model, lateral forces must be examined more closely. Investigations on the straining point displacement from resulting forces in the tyre-soil-surface contact area are presented here. To be examined are free rolling tyres on an asphalt driving surface.

Dipl.-Ing. sc. agr. Matthias Schreiber, Dipl.-Ing. Christian Brinkmann and Dipl.-Ing. Volkmar Schlotter are Ph.D. students at the Institute of Agricultural Engineering, University of Hohenheim, Department for Mechanization in Plant production and Fundamentals of Agricultural Engineering (Head: Prof. Dr.-Ing. Dr. h.c. H.D. Kutzbach) Garbenstr. 9, 70599 Stuttgart, e-mail: *schreib@uni-hohenheim.de*.

Keywords

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The tyre model is of decisive importance in overall vehicle simulation because the tyre represents the interface between the vehicle and the driving surface. Exact knowledge of the occurring forces and their displacement is, therefore, essential for the development of an accurately detailed model. The ascertainment of the force contact points in the tyre-soil contact area is thereby the basis for determining the respective steering, or aligning and inclination torque.

Methods

Using the Hohenheim single wheel tester, which has been the basis of several research projects, the tractive or braking force Fx, lateral force Fy, and vertical force Fz, along with the inclination torque Mx, driving or braking torque My, and the aligning torque Mz can all be determined by means of a six-component hub gauge. Following already extensive research on lateral force behaviour [1], the longitudinal and diagonal displacement of the contact points of the driving, lateral, and vertical force, as well as their effects on hub torques, are considered within the boundaries of this article. All distances, forces, and torques are shown in *figure 1*.

Contact point of the tread force

To determine the effect of the driving-surface forces on the tyre, a zero adjustment for all forces and torques was performed, using the single wheel tester with the tyre elevated above the surface. The forces and torques in the tyre-driving-surface contact area can be clearly determined with the hub gauge. In this plane of contact, whose distance from the tyre centre when on asphalt is equal to r, the exact contact point of the vertical force F_z (from here on referred to as the tread contact point) is determined by the torque equilibrium around the x and y axis. Therefore:

$$e = (M_y - F_{kx} \cdot r) / F_{kz} \quad (1)$$

$$h_y = (-M_x - F_{ky} \cdot r) / F_{kz} \quad (2)$$

The lever arm of the tyre load herein is e, which has already been thoroughly investigated by Plesser [2]. Accordingly, the lever arm is lengthened with increasing velocity and tyre load and takes on values of between 10 and 25 mm on solid driving surfaces. Only minimal changes arise because of varying drift. The lateral displacement h_y of the tread contact point from the tyre centre is in the foreground of this article. Next to e, the lateral displacement is an important variable for calculating the exact tyre load while cornering; however, h_y is also significant for the tilting behaviour of a tractor. The lateral displacement becomes apparent through measurable inclination torque, which deviates from the torque produced by the lateral for-

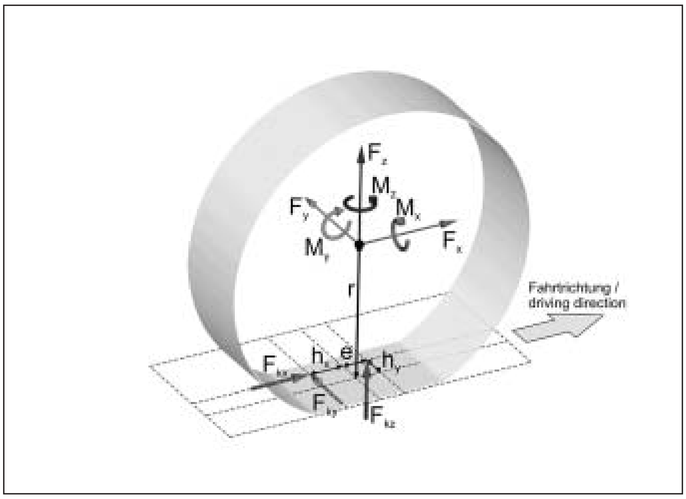

Fig. 1: Forces and torques for an agricultural tyre and their corresponding lever arms r, e, h_x and h_y

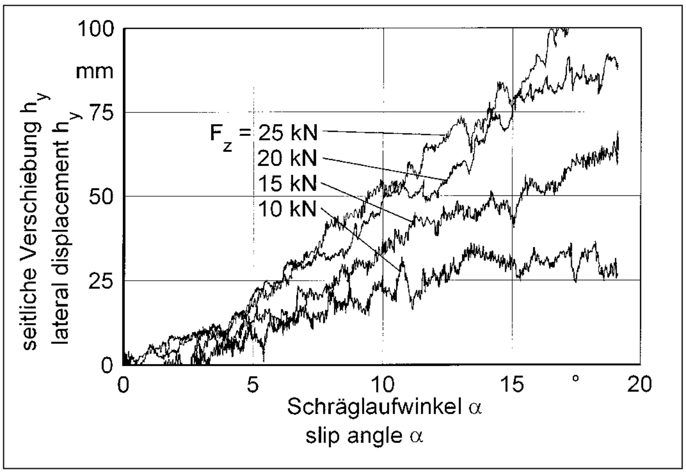

Fig. 2: Lateral displacing of h_y as a function of the slip angle for different tyre loads. (tyre: 520/70 R34, p_i = 0,8 bar, v = 5 kph, asphalt)

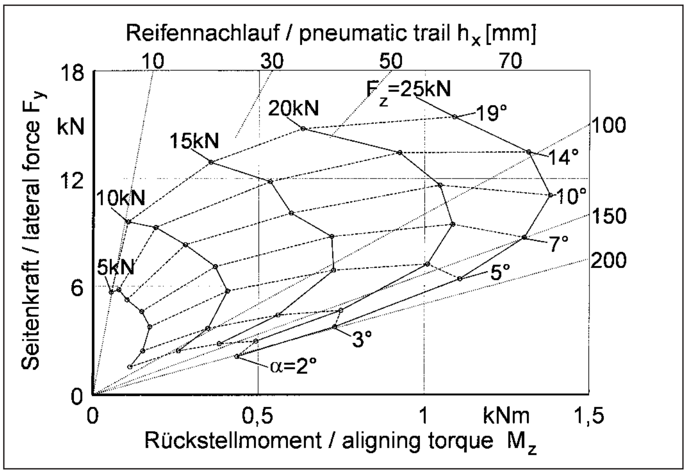

Fig. 4: Relations of lateral force, aligning torque, tyre trail, tyre load and slip angle in the Gough diagram (tyre: 520/70 R34, p_i = 0.8 bar, v = 5 kph, asphalt)

ce F_{ky} and the rolling radius. *Figure 2* shows the lateral displacement h_y as a function of the slip angle for various tyre loads.

A displacement that climbs approximately linearly to the slip angle can be seen. The larger tread-contact-point displacement at higher tyre loads is caused by correspondingly larger lateral forces. If one introduces h_y values as functions of the lateral force, the result is a nearly identical, slightly progressive, upwardly sloping curve for all tyre loads. Consequently, the lateral displacement of the force contact point is independent of the tyre load and can be viewed as being dependent on the lateral force. The number of test runs for experimentally determining the value of h_y can hereby be considerably reduced. Compared to the tread-contact-point displacement h_y, the visual evaluation of the carcass deformation shows that the offset of the contact area l_y in figure 2 takes on larger values.

This is related to the qualitatively represented pressure distribution occurring within the contact area shown in *figure 3*. The resulting normal force wanders in reference to the tread contact area towards negative y values. Since, however, the displacement of the tread contact area l_y is greater for the soft carcass of the tractor tyre as values of y increase, h_y shifts toward positively increasing values of y. In contradiction to this, h_y for automobile tyres takes on negative values resulting from higher air pressure and more rigid construction as compared with tractor tyres [3]. The consequent displacement of the tread contact point h_y is also important for the roll-over behaviour of tractors since tilting can be expected earlier through the greater deformation of tractor tyre carcasses than is the case with non-deformable tyres.

It assumed that the respective driving or braking force also affects the deformed tread contact point.

Aligning torque

The lever h_x in *figure 1*, which is also referred to as the pneumatic trail, can be calculated using equation (3).

$$h_x = (M_z - F_{kx} \cdot h_y) / F_{ky} \qquad (3)$$

For free rolling tyres, the aligning torque M_z is almost completely generated by the lateral force and the pneumatic trail. The influence of rolling resistance, which has the lever h_y, is minimal and first achieves importance by towing or braking tyres. Further influencing factors can be ignored here. The aligning torque climbs initially when the lateral force increases and reaches its maximum at just over fifty percent of the transmittable lateral force, whereby it then decreases again. A decline in the aligning torque into negative values, which is known to occur in automobile tyres [4], could not be observed in tractor tyres at slip angles of up to 20°. The relations between lateral force, aligning torque, pneumatic trail, tyre load and slip angle can be seen in the Gough diagram (*Fig. 4*).

Lines of constant pneumatic trail values were calculated using F_y and M_z. When a stationary driving condition affected by lateral force is assessed, the tyre load and the lateral force can, for example, be determined for each tyre. Based on these parameters, the aligning torque, slip angle and the pneumatic trail can then be read out of the Gough diagram. The curve shapes can be mathematically described for the development of an empirical partial model.

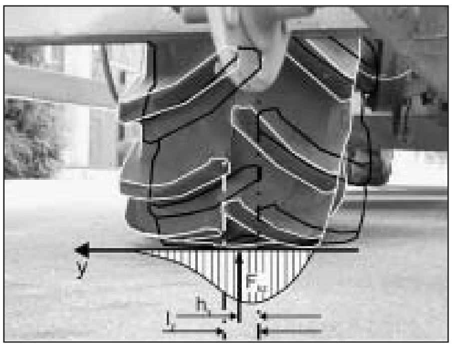

Fig. 3: Picture of a tractor tyre deformed by lateral force with qualitative distribution of pressure displayed. The black contour denotes an unstressed state.

An important fundamental for total-vehicle simulation has thereby been created for free rolling tyres on solid driving surfaces. Especially cornering on streets, where tyres experience large lateral forces and are made to adjust to the corresponding drift, can, subsequently, be well described.

Outlook

Using the methods shown, tyre behaviour in reference to the occurring hub torques can be adequately expressed. The principle geometrical statements are also applicable to driven and braking tyres on solid driving surfaces. Exact measurements for providing the corresponding data are to take place at a later date. Because no exact rolling radius can be determined for a tyre sinking into a soft, yielding driving surface, additional research on tyre behaviour must be carried out.

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