Volkmar Schlotter and Heinz Dieter Kutzbach, Hohenheim

Interior contour of a tractor tyre on firm and yielding surfaces

For forecasting the forces and moments transferable by a tyre to the ground surface, precise knowledge of the contact area is necessary. A laser measurement system was integrated into the single wheel measurement station at Hohenheim University. With the laser sensor in the wheel, the distance to the interior contour in the tread contact area and also in the area of the tyre wall can be measured. First results show an extensive deformation of the tyre, occurring also outside of the contact area. This has not been taken account of in present models for calculation of contact areas.

Dipl.-Ing. Volkmar Schlotter is a member of the scientific staff at the Chair of Procedural Technology in Plant Production with Agricultural Engineering Basis at the Institute for Agricultural Engineering (director: Prof. Dr.-Ing. Dr. h.c. H.D. Kutzbach), University of Hohenheim, Garbenstraße 9, 70599 Stuttgart; e-mail: vschlott@uni-hohenheim.de

A refereed paper for LANDTECHNIK, the full-length version of which can be accessed under LANDTECHNIK-NET.com

Keywords

Tractor tyres, internal contour, laser measuring set, tyre deformation

The increasing weight of tractors and self-propelled working machinery have led in recent years to an intensified study of the interaction of tyre and ground surface. On the one hand, the construction and geometry of the tyre must be suitable for the increased performance and thus power transference demands and on the other hand, regard has to be taken of the compaction and damage to the soil that may be caused by the tyres. At the University of Hohenheim a laser measurement system was built into a tyre in order to give precise information on the tyre's deforming behaviour.

Theory

Knowing the exact contour of the tyre-ground contact area is important for judging the tyre reactions and the resulting effect on power transference. On a firm surface such as asphalt or concrete, the contact area is definitively dependant on the tyre suspension effect as the elasticity of the road surface can usually be ignored. On yielding surfaces, this straight forward thesis no longer applies because the ground also changes shape as it forms a track under the wheel. The change in ground shape is partly plastic and partly elastic so that measurements of the ground deformation afterwards only conditionally reflect the deformation exactly at the time of the passage of the wheel.

The rolling resistance of the tyre comprises an interior proportion caused by the bulging of the tyre and an exterior proportion presented through the deformation of the affected ground. While direct measurement of the exterior rolling resistance is not possible an alternative way of finding the value is through a determination of the interior rolling resistance on a firm surface and the total resistance on a yielding surface. By accepting that the interior values are the same for both types of ground surface, the exterior rolling resistance can then be calculated.

Because a precise measurement of the contact outline is time-consuming, this area in many models is represented by a rectangle or an ellipse. Thus the contact area measurement problem is reduced to a two-dimensional model of the tyre in longitudinal and vertical direction. Whilst the tyre's contact line on a firm driving surface can be represented by a secant, on a yielding surface the approximation takes place mostly via an arc with enlarged radius [1], a parabola [2], a spiral [3] or through a combination of several elements. With the contour thus calculated the resulting forces acting on the wheel can be determined.

Investigation method

The single wheel measurement station [4] at the University of Hohenheim was used, being extended for the investigation. Using a laser distance sensor, a system was developed for determining the interior contour (*fig. 1*). To avoid damage, the laser sensor was fitted through montage openings after tyre attachment. Through a stepping motor, the laser sensor can be swivelled lateral to the direction of travel so that it can be swivelled to an angle β of up to ± 85°.

Measurements were carried out at rest and in motion. During static measurements the laser sensor was swivelled by the stepping motor to show the cross sectional profile of the tyre. For measurements on the move the laser was set in a fixed position β = constant fixed and the distance signal measured over several revolutions.

Results

Static measurements

Figure 2 shows the comparison of several static measurements on firm and on yielding ground and for different wheel loads. Illustrated is the real distance of the laser from the interior contour in directions X and Y. With increasing wheel load, the suspension effect of the tyre increased whereby an increasing flattening of the contact area took place. The flattening and the suspension effect was greater on the concrete surface because the latch distance was less. Measurements on firm driving surface have shown that the position of the tyre treat bar was able to be identified in the interior area of the tyre. The pressure of the tread bar led to a deformation of the carcase and this meant that the contour in the middle area was not parallel to the horizontal driving surface but instead showed by -200 mm to -100 mm a

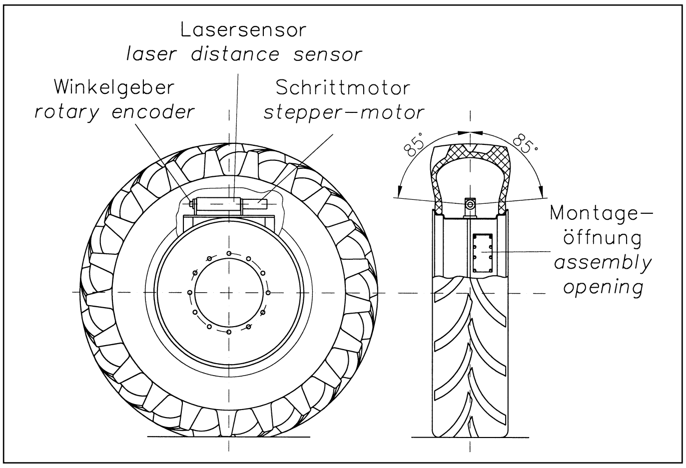

Fig. 1: Laser measuring set

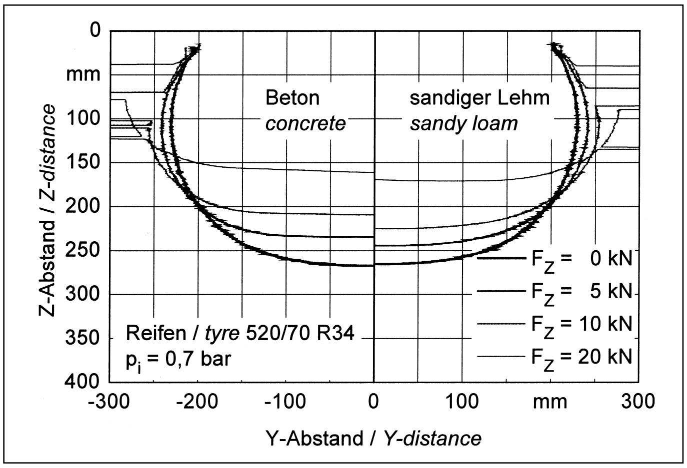

Fig. 2: Internal contour of the tyre in lateral direction

bulging. This effect was even more definite with higher tyre interior pressures in that the tyre contact surface decreased and thus the number of tread bars within the contact area. The increased bulging of the tyre flank caused by higher wheel loads, led to false signals because of the poor reflection of the laser beam on the interior wall of the tyre.

Mobile measurements

In *figure 3* the real contour determined in a mobile measurement is demonstrated. The interior contour is given by the measured distance of the laser for a wheel revolution on yielding ground. The circular form of the unloaded tyre is shaded in the illustration. Based on the interior contour, the form of the expected exterior contour was established. In this calculation the elasticity of the contact area in radial direction and the tread bars remained ignored. Usually used to mark the beginning and end of the contact area are the bow and stern angles θ_1 and θ_2.

If the contour within the contact area is compared with the theoretical steps, only limited differences are apparent for the individual models. Because of the relatively large diameter of the tractor tyre in relation to the ground contact area, the contour within the contact area represents only a small proportion of the total area. This part of the contour can be approximated satisfactorily through arcs as well as parabolas or spirals.

However, the relatively rigid tyre girdle caused a deforming of the contact area and deformation outside the actual ground contact, too. Through the deformation of the tyre there occurred a movement of the starting point of the tyre's contact area so that the real bow angle θ_{1R} is larger. In the known theoretical exercise for the determination of the contact area, the tyre outwith the contact area was approximated through the unloaded radius r_0. *Figure 4* shows, however, that this represents only a rough approximation in that the tyre also deforms outwith the contact area. In the upper area of the tyre there was an almost constant movement of the contour outwards. The angles δ_1 and δ_2 characterise the narrowing of the distance through the contact pressure in the tyre-ground area. The deformation of the tyre was not limited to the contact area and is therefore not described accurately enough by the bow and stern angles.

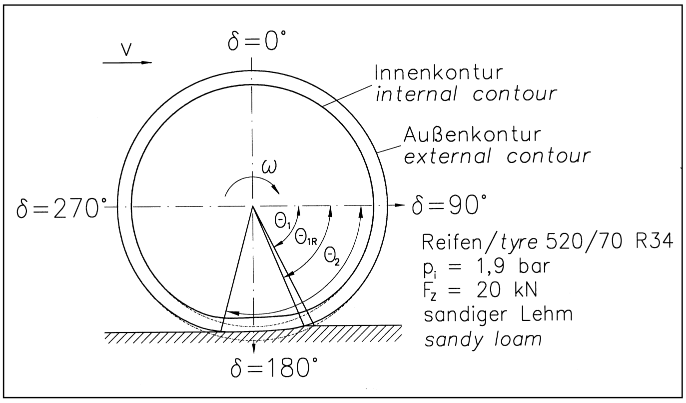

Fig. 3: Deformation of the tyre in longitudinal direction

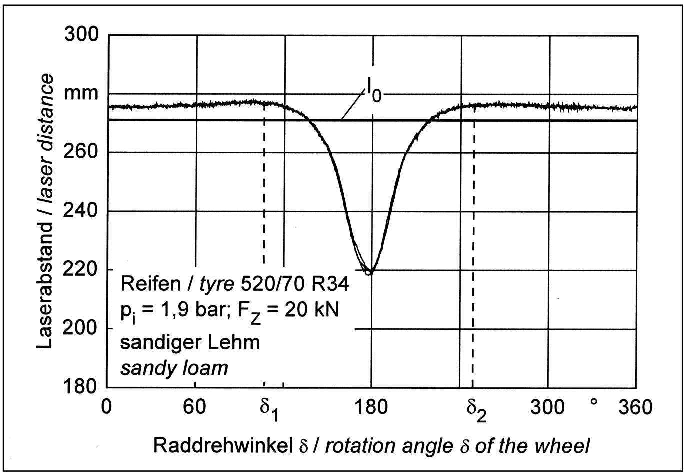

Fig. 4: Difference of the internal contour to the distance l_0 of the unburdened tyre

Conclusion

The measurements showed that models for the simulation of tyre contours up until now did not pay enough attention to the real deforming of the tyres in that the tyre was not only deformed within the contact area but instead almost over the whole circumference. On the yielding surface the tyre was deformed less. The interior rolling resistance is therefore not identical between firm and yielding driving surfaces, even where other parameters are the same. The determination of the proportional interior rolling resistance on yielding driving surface remains difficult. Through recourse to the rolling resistance on firm driving surface, the proportion of the interior rolling resistance would be too large. Future models should take account of the deformation condition of the tyres and enable a calculation of the interior rolling resistance.

Literature

Books are signified with •

[1] *Söhne, W.*: Agricultural Engineering and Terramechanics. Journal of Agricultural Terramechanics 6 (1969), no. 4, pp. 9-30
[2] *Schmid, I.C.*: Inflation pressure control to improve terrain-trafficability a model for simulation. Proceedings of the 11th International ISTVS Conference, Lake Tahoe, USA, (1993), no. 1, pp.64-75
[3] *Okello, J.A.*: Prediction of the force distribution between the soil and a pneumatic wheel. Journal of Agricultural Engineering Research 51 (1992), pp. 249-262
[4] • *Armbruster, K.*: Untersuchungen der Kräfte an schräglaufenden angetriebenen Ackerschlepperrädern. Dissertation, Universität Stuttgart, 1991, VDI Fortschritt-Berichte, Reihe