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Efficient and soil-protecting tyre-ground transfer of driving force

In arable farming high draught requirements are met by powerful tractors. Transferring the high driving forces onto the ground is associated with greater soil stress which, depending on the type of soil, can lead to compaction damage. Avoiding this lies in the interest of sustainable farming; according to § 17 of the soil protection law, this has to be avoided as much as possible. Broad tyres are part of a damage minimising strategy. With a single wheel measuring instrument tyres were tested for their drive force transfer and a mathematical model according to [7] applied for estimating ground pressure during driving operations.

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Keywords

Driving power, soil pressure, soil compaction

With rising draught force requirements in arable farming the wheel loads of tractors increases, albeit only digressively. However, these still represent up to 5 t [1] in the 200 kW power class. In most cases large-volume broad and Terra tyres are used to avoid soil compaction. These can be used at very low tyre pressures. With the same wheel load such tyres can lead to lesser average contact area pressure (Quotient from wheel load and tyre contact area kPa).

Soil protection measures moved further into the spotlight following introduction of the federal soil protection law [2]. With this as background, the concepts which could help in optimising power and performance transfer at the tyres while simultaneously contributing to soil-protection were investigated.

Methods and investigations

A concept for „Soil-protecting driving,“ suggested by Sommer [3] consisted of four building blocks:

- (1) the improvement of soil load-carrying capacity,
- (2) the further development of technical possibilities,
- (3) the adjustment of fieldwork methods,
- (4) the limitation of mechanical stress especially where the soil is susceptible to compaction.

For (4) there are currently recommendations for general thresholds. With models and through a loading quotient [4] it is possible to estimate the risk of compaction in wet areas of the field and to carry out a weak-point analysis of the farm to offer the manager medium and long-term decision aids

(e.g. with regard to the purchase of broad tyres).

So far, however, this model cannot take account of actual soil moisture changes which are of decisive importance for the soil compaction problem. This means there is a need for additional in situ decision aids for the driver regarding actual field surface drivability. A first step was the recommendation of a laser sensor for measuring beet harvester track depth [5]. An own further development was based on the online utilisation of the pressure distribution in soil during traffic operations.

Leading on from the original tractor tyre task of transferring driving forces onto the ground, four different tyres were investigated with a new single wheel-measuring instrument according to Steinkampf [6] (fig. 1) up to 6 t wheel load with regard to their traction characteristics. For calculating pressure distribution in the tyre-ground contact area and pressure expansion through the soil depth, a model from Jaklinski [7] was applied.

Parameters in this model were: wheel load G , driving force T , contact area F , track depth z_0 , tyre diameter D and tyre flattening e (fig. 2). The parameters wheel load and driving force were determined with the single wheel measurement instrument.

Normal tension σ and shear tension τ in the contact areas could be determined with the model. The angles α_0 , β_0 and γ_0 describe the shape of the tyre-ground contact area. The coefficient k_4 is a model parameter for the description of the tyre deformation in combination with ground characteristics.

Built upon the pressure distribution in the tyre-ground contact area, the depth expansi-

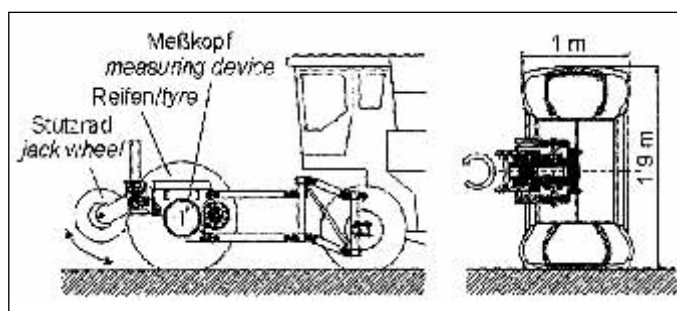


Fig. 1: Single wheel tester with wheel loads < 6 t

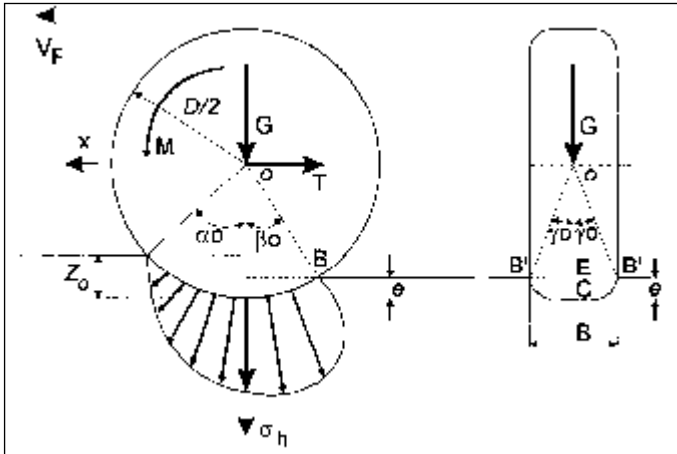


Fig. 2: Schematic view of the parameters in Jaklinski's model and the depth function of soil pressure σ_h .

on of the vertical forces $\sigma(h)$ in the soil was calculated with the model on the basis of the Boussinesq theory, Olsen modification [8] according to

((Gleichung einsetzen))

On ploughed ground or stubble surfaces in a loamy sandy soil field in Brunswick trials were carried out with wheel loads $G1 = 3.9$ t and $G2 = 5.9$ t in which the driving force-wheel slip curves of the four tyres were recorded for broad tyres calculated according to the Jaklinski model and, at the same time compared with four Bolling tube sensor (repetitions) ground pressure readings.

Results

In figure 3 the driving force coefficient - wheel slip curves for standard tyres and Terra tyres were recorded.

The four tyres used differed substantially in relation to the average driving force coefficient at wheel slip of 15%: protective tyres $\kappa = 0.22$, standard tyres (fig. 3) $\kappa = 0.46$, broad tyres $\kappa = 0.52$, and Terra tyres (fig. 3) $\kappa = 0.58$. On ploughed ground, reducing tyre pressure from 2.24 to 1.08 bar gave a κ -improvement, with the example of the standard tyres with 15% wheelslip, of 0.4 to 0.5. The average contact area pressure kPa under the trial conditions with 4 t wheel load, decreased in the following sequence: protective tyres 3.0 \rightarrow standard tyres 1.2 \rightarrow broad tyres 1.0 \rightarrow Terra tyres 0.8.

The vertical ground pressure in the z-level (fig. 2) as calculated for the depth 20 cm

Table 1: Comparison of calculated (Jaklinski-model) and measured soil pressure at 20 cm depth

| Wheel load | Soil pressure at 20 cm depth Calculation | Measurement |
|------------|--|---------------------|
| G1 = 3.9 t | 96.3 kPa | 98.6 \pm 9.6 kPa |
| G2 = 5.9 t | 150.0 kPa | 134.5 \pm 8.6 kPa |

with the Jaklinski model using broad tyres as in table 1. The ground pressure measured by Bolling sensors is given in comparison. It can be seen that with the same tyres this is associated with a wheel load increase of 51% (from 3.9 to 5.9 t), with a ground pressure increase at 20 cm depth of 55% (calculated) and 36.4% (measured). When comparing, it must be recognised that the Jaklinski calculations give a vertically applied pressure and the sensor measurements an average pressure without specific direction. This result underlines the importance of using broad tyres with inline with respective wheel load increases.

Summary

In comparison with standard tyres, modern broad tyres improve power and performance transfer at the tractor (according to the presented results the κ -value are up to 25% higher) and contribute (with the same wheel load!) to the protection of the soil structure through reduced contact area pressure. Under certain conditions these can be driven with very low inner pressures and thus reduce ground pressure. On the other hand, they require a larger volume of ground and through this higher wheel loads affect the soil deeper into the ground. In order to reduce soil compaction dangers, especially in the layers directly under the surface, in ground conditions susceptible to damage, trial measurements indicate (standard deviation between measured and calculated between 2.4 and 10.3) that the idea of indicating real ground pressure online via onboard computer to give the driver decision aids for travelling on field surfaces is a very promising one. Further research work is required for improving the sensor technology for determining the required parameters. In these current investigations the development of a drivability sensor is also included.

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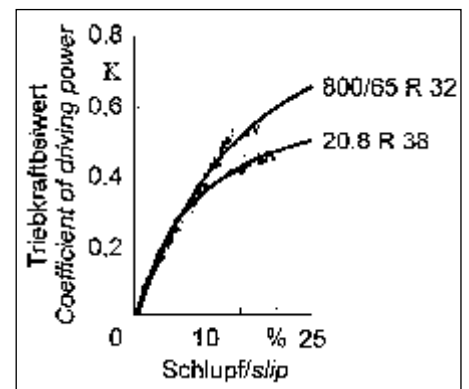


Fig. 3: Coefficients of driving power as a function of slip for wheels 20.8 R 38 with 2.24 and for 800/65 R 32 with 1.15 bar inflation pressure p_i and wheel load of 5.9 Mg on unploughed soil; measuring points and function according to [6]