Heribert Jacke and Andreas Ebel, Göttingen

Pressure distribution under forestry tyres

In Göttingen, the contact area pressure of 70 common forestry tyres in Germany, which were chosen on the basis of a market analysis, was measured statically. During these measurements, the tyre inflation pressure and the hydraulically simulated wheel load were varied specifically. In order to take the space between the lugs into account, the pressure was registered under a 20 cm thick layer of sand. An e-function allows the cross sections of the bell-shaped pressure distributions to be equalized with excellent precision. It is possible to describe any pressure distribution with the aid of only two model parameters, which can likely be used as a valid basis for the evaluation of soil protection and tractive capacity.

Prof. Dr. Heribert Jacke is director of the Institute for Forestry Work Science and Process Technology of the University of Göttingen, Büsgenweg 4, D-37077 Göttingen; e-mail: *hjacke@gwdg.de*.
Dr. Andrease Ebel was a scientist working at the same institute. He wrote his dissertation on the above-described topic.

Keywords

Contact area pressure, tyre inflation pressure, load per wheel, pressure allocation, forest tyres

Literature

Literature references can be called up under LT 06414 via internet http://www.landwirtschaftsverlag.com/landtech/local/literature.htm.

In a high-wage country like Germany, the cost-effective harvest of weaker timber assortments in particular requires a high degree of mechanization. The masses of the harvesters used for such harvesting techniques vary between 10 and 20 t. Afterwards, special forwarders haul the short wood assortments stacked by the harvesters at the edge of the log trail from the woods to forest roads practicable for trucks. When loaded, forwarders of the stronger category reach axle loads of more than 20 t. Hence, each of the four wheels (per bogie construction) transmits a force of (more than) 50 kN to the forest soil. The pressure load thus provoked leads to alterations in the soil which are considered critical, in particular a reduction of the large and medium pore volume in cohesive substrates.

Fundamentals

Until the end of the 90s, soil-ecological studies regarded the "contact area pressure", which is calculated based on the quotient of the wheel load and the "stamp area" of the mounted tyre, exclusively under technical aspects. Especially when standard and low-section tyres were compared, this evaluation led to implausibilities, which ultimately required a detailed examination of pressure distribution on such contact areas.

A market analysis of self-propelled forestry machines in Germany from the year 2001 was intended to provide more concrete data in order to determine the size of the sample to be examined. This analysis indicated 70 tyres, which were different in their design (standard – low section tyres), their carcass construction (diagonal – radial), and their carrying capacity (expressed by the load index at SI = A8) and, hence, of course in their measurements (wheel diameter, rated width…). Courtesy of the tyre industry, which took over the expenses, complete wheels with new tyres were delivered to the institute workshop in Göttingen and disposed of after the measurements. The largest part of the forestry tyres came from the factories of two northern-European manufacturers.

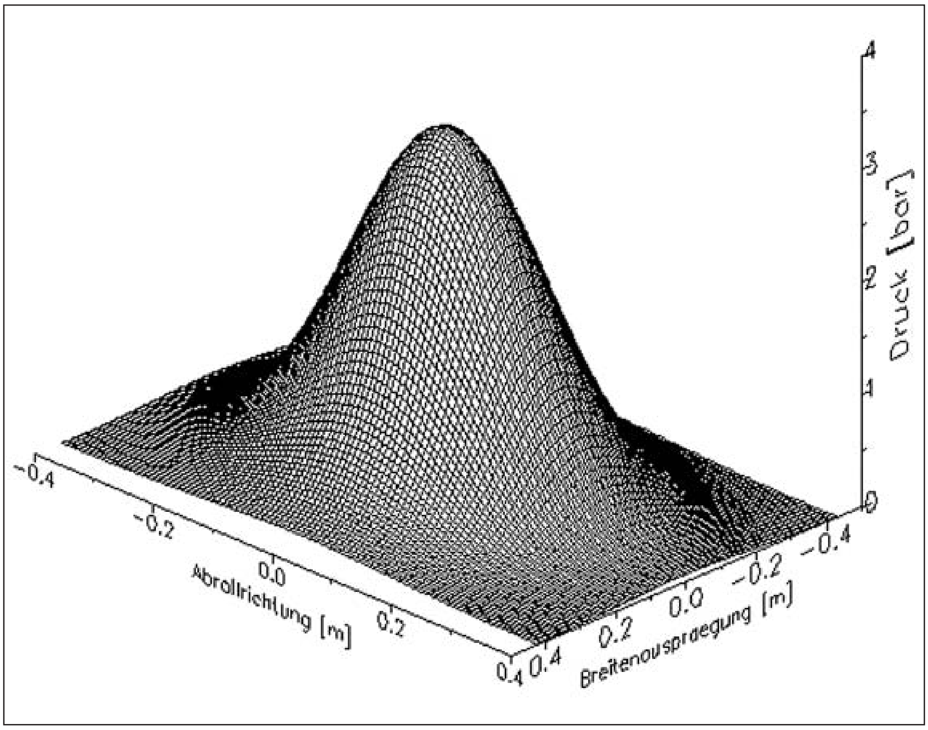

Fig. 1: Exemplary distribution of contact area pressure under a 20 cm thick sand layer

Measuring techniques

First, the 70 tyres were flexed over a distance of 5 km, which means that they were run in under laboratory conditions (i.e. turned over a pair of steel rollers corresponding to the dynamic wheel radius at a deflection of 20% of the rated height). Afterwards, pressure distribution was measured on hard ground and under a 20 cm thick layer of fine sand. Here, the measurements under sand are reported on because it was an important goal of the project to determine the pressure on grown soils, where the area between the lugs (the negative tread) also serves to carry the wheel load. For later analytical-statistical evaluation, the pressure was registered by the sensor mats of the US-American manufacturer TEKSCAN, which contain up to 9,152 measuring cells. In a simulator specially built for these purposes, the wheel loads, which ranged from 10 to 50 kN (in 10 kN steps), were generated hydraulically. In the individual steps, the tyre inflation pressure was set at 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, and 5.0 bar. Under the 70 wheels, the seven inflation pressure- and five wheel load steps led to 2,450 pressure distributions to be interpreted.

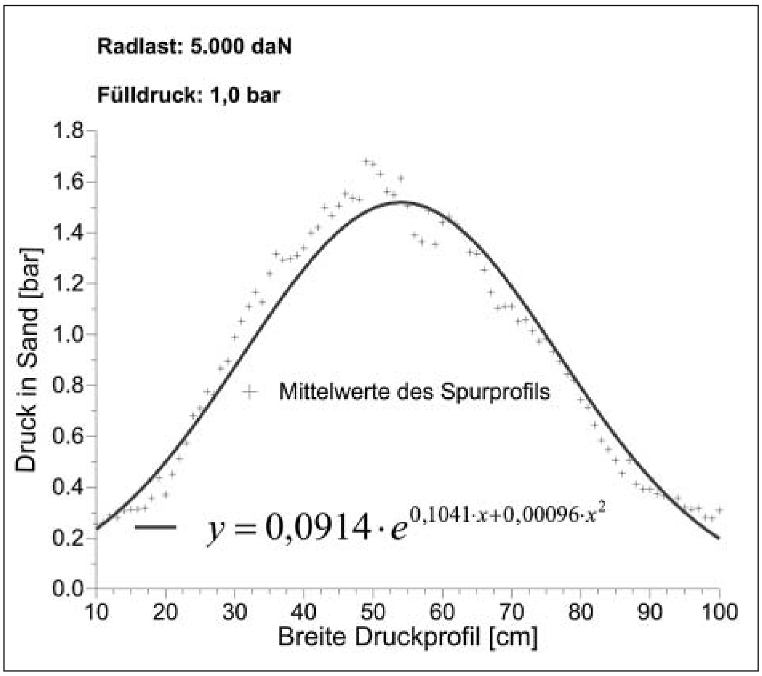

Fig. 2: Average values and equalization bell of the pressure averaged in the width section of the tested tyre N30

Results

All measurements under the sand layer led to pressure distributions which are similar to the bell shown in *Figure 1*.

This bell ultimately corresponds to a horizontal section through the pressure bulb in sandy soil. This three-dimensional pressure distribution can be characterized by the (two-dimensional) summit bells in both the width section of the tyre and the rolling or travel direction. The summit bells follow the functional model:

$$y = a \cdot e^{b \cdot x + c \cdot x^2} \quad (1)$$

If this function is expressed as a logarithm (with e as a basis), this leads to the following equation:

$$\ln y = \ln a + b \cdot x + c \cdot x^2 \quad (2)$$

This is an equation which in this transformed stage can be treated as a polynom of the second degree in x. Both the pressure values in the width section and the values in the rolling direction of the wheels can thus be equalized using an (actually) linear double regression and afterwards be retransformed from model equation (2) to the "bell equation" (1). This equalization can be carried out with an average adaptation quality of ~ 90% (assessed using determinateness R^2 at the logarithmic stage). In an exemplary manner, this effect is illustrated in *Figure 2*. If in the next step the origin of the (Cartesian) system of coordinates is shifted under the bell summit by means of calculation, equation parameter "b" disappears, and parameter "a" quantifies the ordinate of the summit value, i.e. the (equalized) maximum pressure. Now, parameter "c", the coefficient of squared x, solely characterizes the width section of those distribution bells. Thus, it is possible to describe the distributions of the contact area pressure under a wheel with an excellent quality of adaptation using only two numbers (a and c).

The above-described arithmetic procedure can be applied with identical quality of equalization for both pressure values averaged in the main directions and the pressure peaks (ultimately the "silhouettes" of the measured pressure in tyre width and rolling direction). The equalization peaks of the maximum pressure exceed the (arithmetically) averaged values by the factor 2.7.

If the influencing factors due to the operating status and the design of the tyre on the parameters a and c of the maximum pressure distributions are intended to be determined in the next step, co-variance-analytically oriented autoselective regression can be used, for example. If the influencing factors which are still significant though minimal with regard to their explanation quality (i.e. those factors which only provide an increase in model determinateness in the parts-per-thousand range) are not considered in such a model, this leads to the (very plausible) dependence relations listed in the table.

Future prospects

If the regression coefficients of the model equations (which are published elsewhere) are known, the distribution curves of the contact area pressure for the population of forestry tyres can be estimated. Determinateness for the prognosis of parameters reaches a remarkable 70 to 80%.

In addition, we are currently carrying out studies to determine whether an arithmetic connection between parameters a and c enables conclusions with regard to the tractive behaviour of the tyres and consequences for soil ecology to be drawn. If such connections lead to valid parameters in this respect, the procedure described here could provide an approach for the evaluation of tyres under these criteria even beyond the sector of forestry technology.

Table 1: Factors influencing the parameters of the e-function. The influencing potential corresponds to the ranking of the factors.

Parameter	a (pressure maximum)	c in the direction of tyre width	c in the rolling direction
Factor 1	wheel load	rated width	wheel load
Factor 2	inflation pressure	inflation pressure	inflation pressure
Factor 3	rated width	wheel load	wheel diameter
Factor 4			rated width