CONTACT PRESSURE DISTRIBUTION IN TYRE TREAD PATTERN

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Abstract

The paper described a testing procedure for detection of tread pattern contact area and contact pressure under the loading simulations. The tyre contact pressure - contact area interaction includes tyre deformation that can be formulated as a function of load with respect to the specific tyre parameters under continuous load including the detection of pressure distribution within tyre lugs' contact area. The usage of tactile pressure sensors detects the uniform tyre footprint detection and contact pressure distribution that includes the determination of a contact area loaded off-road tyres for contact pressure extreme values up to 400 kPa. The construction of mechanical spin model enables to test the different types of displacements, squares and structures as well. The tested pressure sensor allows apply nominal load 34 kN for large agriculture tyres, it may correspond with 145 kN tractor total weight.

Key words: tyre, load, pressure evaluation, tactile pressure sensor.

INTRODUCTION

The general trend in soil protection is to reduce detrimental soil compaction by loaded wheels of power and transport equipment (HÅKANSSON, 1990; GREČENKO & PRIKNER, 2014). These approaches enhance evaluation of soil damage under standardized conditions that guarantee the repeatability of the testing and produce comparable results for other research.

The fact that the contact pressure of tyre contact area produces soil stress, size of tyre contact area strictly depends on tyre dimensions, inflation pressure, load dependence on external factors as vehicle speed, soil type, soil moisture content, depth of rut, etc., is generally known, (SOANE, 1983). In dynamic contact pressure measuring can be use the sensing contact surfaces strain transducer placed in tyre tread pattern (RAPER ET AL., 1995), and further e.g. (WAY ET AL., 2004; MOHSENIMANESH AND WARD, 2007). Contact pressure in loaded tyre area can produce soil stress soil up to depths 50–60 cm (SÖHNE, 1958; VAN AKKER ET AL., 2004; KELLER ET AL., 2007; O´SULLIVAN ET AL., 1999). All conclusions closely depend on individual soil-tyre interaction, therefore these outputs cannot be taken as a final. The size empirical estimation of contact area on a soft ground was published by SWANGHART (1990). The approaches based on predetermined contact area dimensions were published e.g. (HALLONBORG 1996; KELLER 2005 ETC.). Especially engineering branch used measured data in relation to catalogues tyre dimensions for empirical calculation of tyre contact area e.g. GREČENKO (1995). Laboratory scanning of tyre footprint area and contact pressure evaluation used the tactile pressure sensors (VOLF ET. AL., 1997, 2010) and it can produce more precise results then field experiments. In–situ experiments are carried out with various transducer types implemented on tyre tread pattern or commercial pressure mapping sensors with low screening resolution and application of individual soil sensors into predefined soil profile depth positions (WAY ET AL. 1995; MOHNESIMANEHS & WARD, 2007; BAROSSA ET AL., 2015; KELLER ET AL., 2007).

This paper presents results obtained at the initial development stage of implementation of pressure scanning system for heavy loaded agriculture traction tyres. The objectives of this study were: (a) to analyse relative load calibration function of selected contact areas for an adequate contact pressure value; (b) to analyse dependence between a wheel load and a contact pressures distribution on tyre tread pattern contact area.

MATERIALS AND METHODS

Laboratory testing were carried out on a part of the laboratory soil compactor and its operation were described earlier (Grečenko & Prikner, 2014). A tyre footprint attachment with hydraulic actuation and electronic scales in the platform 1 m^2 allows maximum tyre load up to 69 kN. This attachment enables direct contact area measurement and screening pressure distribution in tyre tread pattern with improved precision. The system of measuring of the contact pressure between tyre and the matrix was proposed to arrange miniature tactile pressure sensors and it was designed as a compact portable device (Volf, 1997). This equipment enables static and dynamic loading sensing regimes. The sensors are controlled by electronic circuits which control function and transmit acquired data to PC for further evaluation (Fig. 1). The pressure scanning system (Plantograf – trademark; Volf, 2010) guarantees minimization of mutual influence of matrix sensing points and maximise the matrix point sensitivity. The matrix construction is described in a patent application (Volf, 2010). The tested pressure area is fitted with 7500 pcs sensors an active area of 40 x 30 cm (approx. 6.25 pcs.cm^{-2}). The inner matrix is precisely covered with the conductive elastomer and non-conductive flexible material to prevent an outer damage and it includes a top resilient geotextile coating. The measured data were saved on internal hard disk drive (HDD) or flash drive in the system for later transfer to PC (Fig. 2). Scanning speed ranges up to 300 frames per seconds. The output from the device is a colourful raster and matrix of pressure values on tyre detected by each miniature sensors. Basic technical data of the measuring devices are described in Tab. 1.

Fig. 1. – Laboratory device for tyre testing up to 69 kN with pressure evaluation equipment; (Mitas tyre 650/65R38 RD-03, inflation pressure 100 kPa, load 9.8 kN)

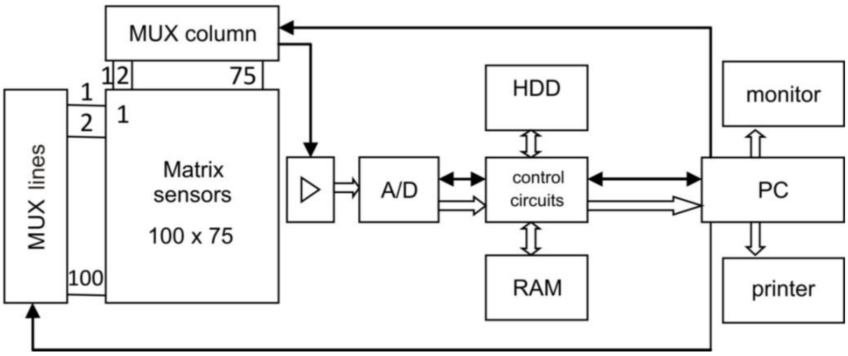

Fig. 2. – Block diagram of multiplex control circuits

In the first part of testing procedure, establishment of calibration function was provided using high load loading tests. Specific contact areas 3.8 cm^2 (25 pcs.cm^{-2}), 27 cm^2 (175 pcs.cm^{-2}) and 125 cm^2 (781 pcs.cm^{-2}) were loaded in require pressure range from 10 to 400 kPa in tolerance interval ± 2 kPa. The area sizes were selected with respect to overloading effect elimination and precise description of pressure behaviour that depends on score of sensing points per centimetre square. Adequate combinations of contact pressure q (kPa) and specific loading W (kN) were statistically evaluated. Equation for fundamental relation of relative loading RL (%) and contact pressure was obtained with the use of an exponential function. Plantoraf stiffness tests estimatimating pressure distribution in tyre tread pattern contact area were provided in two static and dynamic load regimes. Static load tests were carried out with radial tyre Mitas 650/65R38 RD-03 in load range from 1.9 to 6.9 kN per one tread pattern lug.

Fig. 3. – Dynamic contact pressure sensing with a Plantograf equipment

Fullness of tyre contact area depends on ratio of total contact area of tread pattern footprint to total contact area of tyre. The range 21-25% is obviously taken as a standard for driving agriculture tyres; however, it depends strictly on tyre dimensions. The dynamic testing allows scanning pressure behaviour directly and reducing extreme deviations in pressure distribution on sensing plate due to minimization of tyre tread pattern deformation. Tests were carried out with use of tyres Barum 14.9-24 (front) inflated on 140 kPa and 16.9-38 (rear) inflated on 160 kPa mounted on tractor Zetor Forterra 8641 (Fig. 3). Both inflation pressure levels were setup as a manufacture´s recommended standard. Front tyre load 11.5 kN and rear tyre load 13.5 kN were calculated according to standard total weight distribution on both axles as 48/52%; the total tractor weight of 50 kN produces 26 kN on rear and 23 kN front axle load. Testing pass speed was set up for 10 cm.sec^{-1}.

Tab. 1. – Technical parameters of the Plantograf

Load capacity	up to 34 kN
Range of pressures	0–400 kPa
Permanent overload	1.4 MPa
Active array sensor	40 x 30 cm
Overall dimensions of the sensor	75 x 65 cm
Number of sensors	7500 pieces
Digital output	256 levels
Number of frames per sec.	60
Sampling frequency	2.5 MHz

RESULTS AND DISCUSSION

A calibration function precisely describes relation between contact pressure and relative loading *RL* (%) in term of standardized value for the specific range of pressure distribution in a given range 0–100% under 256 bit sensing level (Fig. 4). A change of optimal range for pressure limit reading regulates a parameter *Gain* (1–5). The general trend of contact pressure and *RL* behaviour describes Eq. 1:

$$RL = 35.4615*\ln(q)-111.511 \quad (1)$$

(R^2 = 95.59; *F-ratio* = 238.25, P<0.0001)

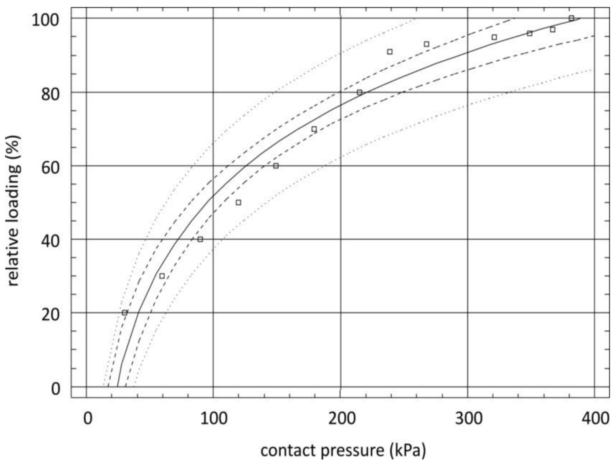

Fig. 4. – Calibration function for contact pressure range from 20 to 395 kPa

Size of tyre contact area and contact pressure values depend on actual vertical load. In this calibration step, tyre load was function of contact pressure and contact area S_x (Eq.2) as well:

$$F = \int_{q_0}^{q_{max}} S_x(dq) \qquad (2)$$

First tests (static tyre load) were performed with the use a large tyre 650/65R38 mounted in laboratory stand (Fig. 1). Primarily, tests were performed in order to establish maximal load capacity of the Plantograf. Tyre total load 35 kN confirmed required load capacity for further heavy load tests. Tyre inflation pressure was set up on 100 kPa due to better lug footprint spreading on sensing plate and also recommended inflation pressure level for field operation.

A maximal contact pressure in tread pattern was verified. Tyre tread pattern was loaded 29 kN (as standard operation load when tyre is used for total tractor weight 92 kN). When tyre tread pattern fullness is 24 %, a number of lugs 4 ± 0.25 can be placed in contact area (approximately 700 ± 10 cm^2) under 29 kN load. Thus contact pressure in specific lug areas can be increase up to 400 kPa indisputably. The combination confirmed optimal load 6.9 kN per 175 cm^2 as a maximum for standard operation conditions. Documentation of acceptable load capacity, one lug footprint (175 cm^2) for total tyre load 29 kN and inflation pressure 100 kPa shows Fig. 5.

The contact pressure size corresponds with estimation of total tyre contact area according GREČENKO & PRIKNER (2014); e.g. when tyre 650/60R38 was inflated on 100 kPa and loaded 29 kN, size of total tyre contact area achieved 2900 cm^2 approximately, thus a mean contact pressure 93 kPa corresponds with results described previously. Very similar results were published by JUN ET AL. (2004), KELLER ET AL. (2007) and MOHNESIMANEHS & WARD (2007). The advantages of presented approach are evident. Fig. 6 presents dependence between tyre load and contact pressure.

A linear trend can be achieved if contact area of lugs is unchangeable (in the praxis can be consider in specific combination $W - p_i$); however these results describe real behaviour for selected lug contact areas reliably. Fig. 7 presents the confirming effect of tyre lug number on relative loading scale that can be obtained from calibration function behaviour. The value of relative loading 100 % occurs in the event and corresponds with a nominal contact pressure 395 kPa.

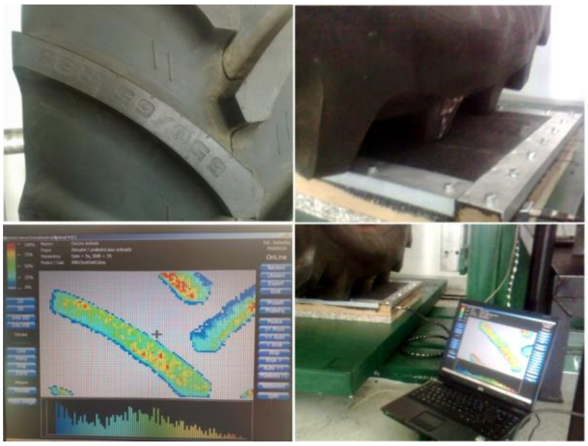

Fig. 5. – Accuracy at pressure screening of the lug text (tyre 650/65R38, total tyre load 29 kN, average lug loading 6.9 kN, p_i = 100 kPa)

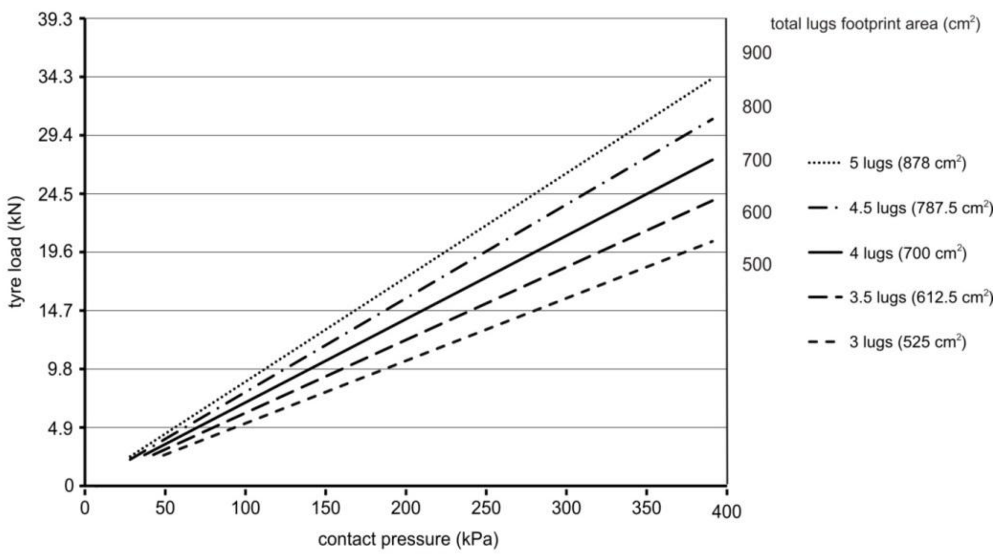

Fig. 6. – Linear dependence $W = f(q)$ for lugs contact area (lug area 175 cm^2)

The obtained outputs of dynamic tests declare previous idea of better lug footprint spreading on sensing plate when tyre is underinflated or contact pressure is sensing under dynamic conditions. Generally, distribution of maximal pressure range in the relative loading scale 75–85% for bias-ply tyres shows effect of high toughness. A maximum of contact pressure can be found for 20-25 % of lugs contact area approximately (see Fig. 8), but it is necessary to remark that some extremal shapes can cause a rubber friction on used a geotextile cover.

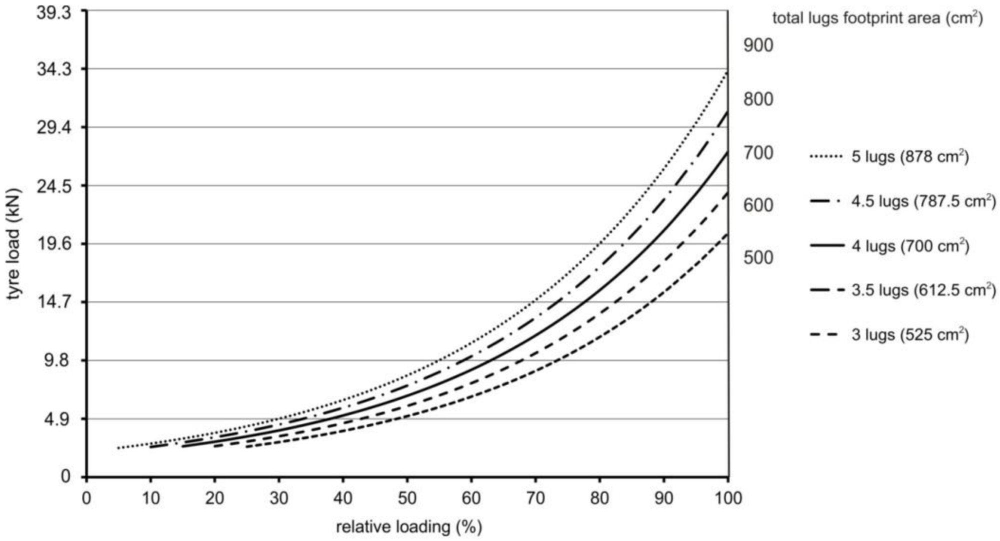

Fig. 7. – Exponential behaviour $W = f(RL)$ of pressure distribution trend in the tyre tread pattern for selected lugs contact area (lug area 175 cm^2)

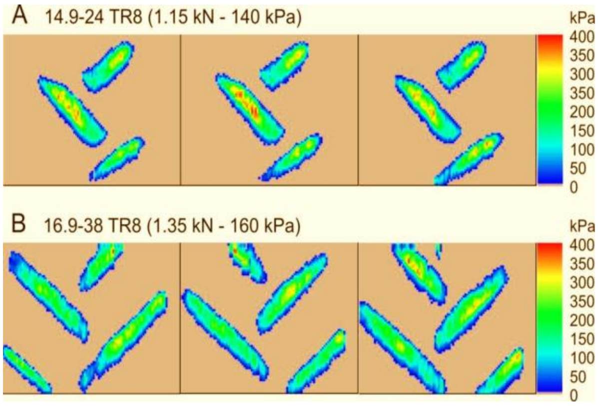

Fig. 8. – Example of selected static positions of pressure distribution in tyre tread pattern of bias ply tyres under dynamic measuring regime; (passage speed 10 cm.s^{-1})

The comparison of all results prove that tyre thread pattern of radial types can dispose more flexibility and higher contact area depending on contact area of lugs including fullness of tread pattern. Total area of lugs and contact area of tyre has a strictly dependence on lug design and tread pattern spreading on elastic surface. The elaboration doesn´t close inflation pressure of tyre as main parameter; however, this significantly affects tyre mechanical properties. Notice; both tyre size types were used for testing of usability of the Plantograf device primary in the first step of research.

CONCLUSIONS

The paper demonstrates a progress achieved in mapping and screening of contact pressure distribution of agricultural driving tyres contact area. The calibration function of relative loading depends on a lug contact area size and on fullness of tyre tread pattern. The evaluation accuracy is reliable when different contact areas are compared for specific contact pressures and number of sensing points is specified. A static load can cause some differences in pressure distribution on the contact area due to friction rubber – plate cover when tyre tread pattern spread out on the sensing plate. It is possible to conclude that the dynamic pressure sensing produces acceptable outputs; however tyre tread pattern contact area is not precisely described due to short contact time.

It is evident that sensing matrix withstands high load up to 35 kN. Planned experiments will use a large sensing matrix 50 x 50 cm (16800 pcs sensors, approx. 6.72 sensing point.cm^{-2}) in the future. The sensing matrix with 7500 pcs sensors (approx. 6.25 sensing point.cm^{-2}) corresponds with similar commercial product (Tekscan, XSensor etc.); thus tested high load capacity and dynamic testing confirmed using in experiments under terrain conditions; e.g. direct measurement of actual contact pressure in contact area of moving wheel with tyre with different depth rut etc.

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