Monitoring the impact of tyre inflation pressure on tensile properties of forest tractors

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Abstract

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The article discusses monitoring of the impact of tyre inflation pressure on tensile properties of forest tractors. The LKT 81 T forest tractor, manufactured by ZŤS TEES, Martin (Slovak Republic) and widely used in Slovakia, was specifically chosen as the mechanised vehicle to be monitored. Tensile properties were examined using standard tensile tests, with a Tatra freight vehicle serving as the load vehicle. Actual measurements were performed on a concrete surface and on soil characterised as gravelly loam whose average moisture was 38%. The statistical methods used to verify the impact of significance from changes in tyre inflation pressure on selected tensile indicators were multi-factor analysis of variance (ANOVA) and Student's *t*-test. Even though statistical analysis failed to directly confirm significance in the impact of changes of tyre inflation pressure on selected load indicators for a forest tractor fitted with standard tyres, positive changes can be discerned in measured dependencies. The article concludes with a discussion of the results obtained and their possible application in operational practice.

Keywords: tractive power; tensile strength; forest soil; slippage; statistical analysis

In general, choosing the correct tyre inflation pressure is a frequently underestimated issue and considered to be secondary. The important points when choosing the appropriate tyre and its optimal inflation pressure are often just the issue of max. possible load on each wheel and the purpose or work environment where the mobile industrial machine will be operating. Environmental issues related to operation and potential improved energy usage of mobile energy resources, which can be influenced by the right choice of tyre size and inflation pressure, are often ignored. At the same time, the pressure of the medium with which a tyre is filled not only contributes to an important degree to load on the wheel, but also has an impact on contact pressure at the base where the tyre meets the ground. The amount of contact pressure in the tyre's contact area is likewise one of the most important factors that affect not just damage to soil and its vegetation cover, but also tyre grip, especially on soft, pliable soils.

The positive impact of selecting the right tyre inflation pressure in mobile industrial equipment, depending on soil conditions, was referenced by a number of authors (Calek, Schwanghart 1998; Schreiber, Kutzbach 2008; Novák et al. 2009; Červinka, Bačák 2011). All of the authors emphasise the positive impact of optimally choosing tyre inflation pressure depending on soil conditions, both to improve economic and operational features in mechanised vehicles and to reduce damage to terrain.

This article primarily focuses on monitoring the impact of tyre inflation pressure on a selected mechanised vehicle to change its tensile and traction indicators. In Slovakia, tractors are still the predominantly used method in logging to tow wood. This is one of the reasons why we chose the LKT 81 T forest tractor (ZŤS TEES a.s., Martin, Slovak Republic) as the mechanised vehicle to be tested to monitor significance from the impact of changes in tyre inflation pressure on tensile properties. It is the vehicle best available to be tested at our educational institution. At the same time, it is the most widely used mechanised vehicle used in Slovakia for forest harvesting. The machine was fitted during testing with standard diagonal Barum 16.9-30 12PR tyres (Barum Continental, Otrokovice, Czech Republic) on all four wheels.

MATERIAL AND METHODS

As was mentioned in the introduction, the ZŤS LKT 81 T forest tractor was chosen to be the mechanised vehicle for monitoring. The load vehicle used was a Tatra 815 S3 26 208 6 × 6.2 lorry (Tatra a.s., Kopřivnice, Czech Republic), whose bed was weighed down with 4,000 kg of macadam.

To depict different slippage and tensile characteristics of the ZŤS LKT 81 T reference tractor, it was necessary to document impulses from sensors installed on the drive gear and tensile force for each run measured. For this purpose, a LC-IE-200 kN tensile force sensor (Kosík & Spevák s.r.o., Zvolen, Slovak Republic) was used, with a nominal force of 200 kN, along with Senzortech ISP 122 SN inductive sensors (Senzortech s.r.o., Trenčín, Slovak Republic). In order to draw tractive power curves, however, the time taken for the mechanised vehicle to proceed along a defined-length test track had to be monitored during measurement, too. A mechanical stopwatch was used to measure elapsed time.

Experimental measurements were themselves carried out as standard tensile testing in accordance with basic requirements of STN 30 0415 (1993). Experimental measuring was done in two stages. The first stage involved standard tensile testing on the concrete surface of a dispatch warehouse at the University Forest Enterprise, Technical University in Zvolen, Slovak Republic. Measurements were made at tyre inflation pressures of 240, 200 and 150 kPa. In the second phase, a standard tensile test was carried out directly in forest growth at the University Forest Enterprise, Technical University in Zvolen, Slovak Republic. Measurements were made in forest growth at tyre inflation pressures of 200, 150 and 130 kPa. At selected pressure levels, tyre inflation pressure was always kept the same on the front and rear axles of the ZŤS LKT 81 tractor. Monitored tyre inflation pressures were chosen on the basis of technical parameters provided by the tyre manufacturer and also

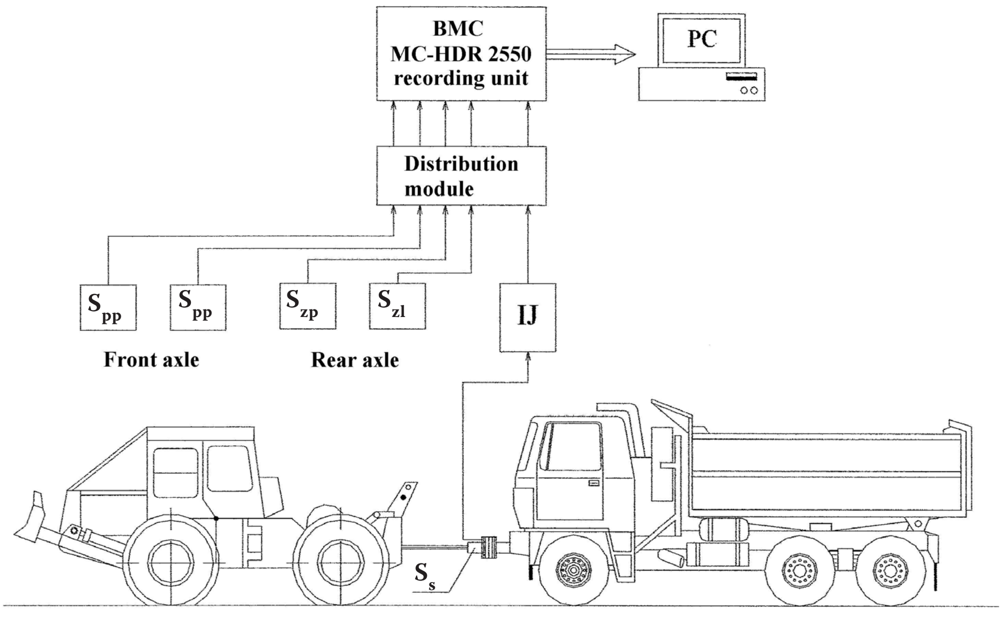

Fig. 1. Diagram of measuring and recording apparatus for tensile testing

IJ – tesile force sensor display unit; PC – personal computer; S_{pp} – right wheel speed sensor on front axle; S_{pl} – left wheel speed sensor on front axle; S_{zp} – right wheel speed sensor on rear axle; S_{zl} – left wheel speed sensor on rear axle; S_s – tensile force sensor were based on the tractor's technical parameters, so that even at max. tensile load, damage from the impact of high axle loads was avoided. Tensile testing of the ZŤS LKT 81 tractor was conducted on a concrete surface for the first three basic (indicated as N) and reduced gears (indicated as R). In forest terrain, tensile testing was conducted at the same gears as on an asphalt surface, excluding only the first reduced gear.

Prior to measurement, a 60 m long section of the test track was marked with a ranging rod. Before this section to be measured was defined, a prepared section of the test track was made available that was intended to stabilise the load environment. The length of the section was altered, depending on desired tensile resistance. The width of the test track was 3.15 metres. A measuring chain to record different variables was rigged as shown in Fig. 1. At each measuring run, tensile force was recorded along with impulses from the travelling wheels to calculate slippage and measurement time at the defined section of the measuring track. Data gathered in the BMC MC-HDR 2550 recording unit during measurements were subsequently transferred once testing had ended to a personal computer and processed using BMC's NextView 2.5 (both BMC Messysteme GmbH, Maisach, Germany) software and Statistica 7.0 CZ (Statsoft CR s.r.o., Prague, Czech Republic).

When measured in forest terrain, both basic analysis and description of soil properties were done at the spot where measurement was conducted. Based on samples taken from several places on the test track, average moisture and bulk density were determined. The forest soil measured in the terrain can be visually characterised as gravelly loam. Its average moisture reached 38% and its bulk density was 1.142 g/cm^3.

RESULTS AND DISCUSSION

Based on the measured data, all necessary variables for illustrating monitored tensile indicators were then calculated. Here we proceeded both in compliance with the applicable national standard, STN 30 0145 (1993), as well as in accordance with the methodology presented by Grečenko (1978) and Semetko (1981). A graphic representation of measured tensile indicator values for an LKT 81 T tractor on a concrete surface and forest soil is shown in Figs 2–5.

Based on the plotted slippage curves for the tractor on a concrete surface (Fig. 2), a drop in driving wheel slippage can be observed as tyre inflation pressure declines. This fall in slippage is significant especially at central and higher tensile force values, particularly among values measured at tyre inflation pressures of 240 and 150 kPa. At a lower tensile load, this decline is not as significant, but the tendency is the same.

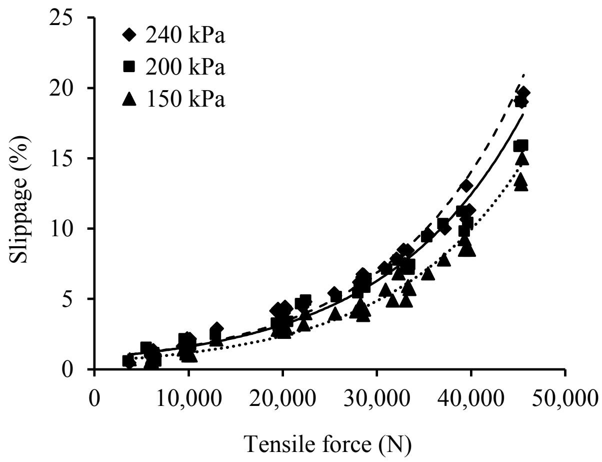

Fig. 2. ZŤS LKT 81 T forest tractor slippage on a concrete surface at tyre inflation pressures of 240, 200 and 150 kPa

Plotted slippage curves for the tractor on forest soil (Fig. 3) imply a positive impact from the decrease in tyre inflation pressure in a reduction of tractor drive wheel slippage. This fall in slippage is significant especially at central and higher tensile force values, particularly among values measured at tyre inflation pressures of 200 and 150 kPa. The maximum reaches values up to 25% for a tensile load of about 25 kN. At a lower tensile load, this decline is not as significant, but the tendency is the same.

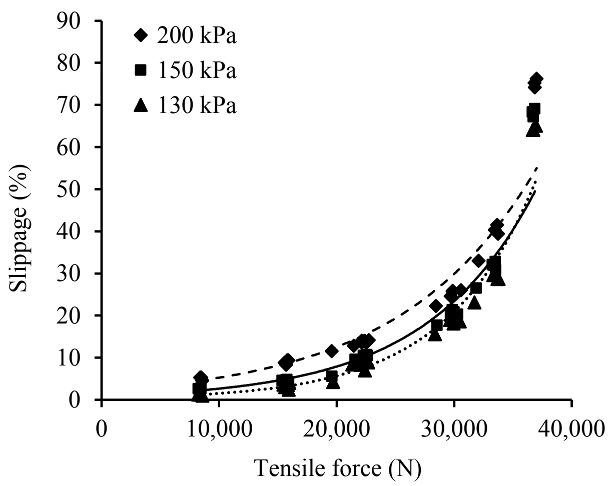

Fig. 3. ZŤS LKT 81 T forest tractor slippage on forest soil (gravel loam with average moisture of 38%) at tyre inflation pressures of 200, 150 and 130 kPa

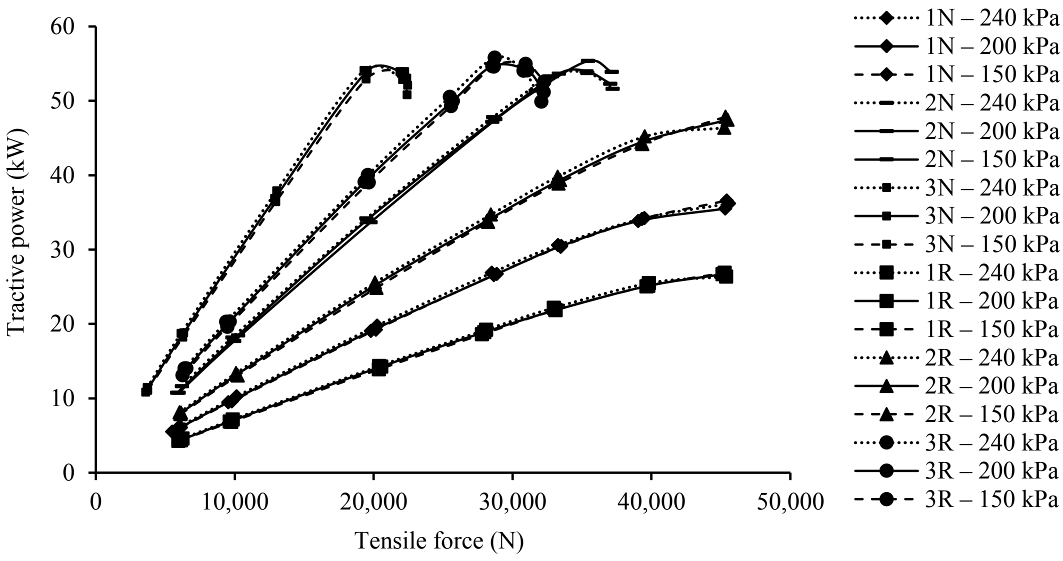

Fig. 4. ZŤS LKT 81 T tractive power on a concrete surface at tyre inflation pressures of 240, 200 and 150 kPa at different monitored gears

On the concrete surface, the tractive power plotlines (Fig. 4) show a slight drop in tractive power values achieved as tyre inflation pressure decreases at all observed gears. The fall in tractive power is especially noticeable in the engine's torque regulation characteristics. In the overload section of the torque characteristics seen in the tractor's driving engine, there is an opposite tendency as tractive power is plotted, especially at gears (2R – 3N).

The drop in tractive power values reached is more significant, especially at higher gears (2R – 3N), while it is less pronounced at lower gears (1N and 1R).

The highest tractive power values on the concrete surface were measured at gear 3R. At a tyre inflation pressure of 240 kPa, the max. tractive power achieved was 55.794 kW. At a tyre inflation pressure of 200 kPa, tractive power reached the max. value of 54.654 kW, which is 2.04% lower, while the maxi. value reached at a tyre inflation pressure of 150 kPa was 54.99 kW, a value of 1.44% lower compared to the tractive power measured at a tyre inflation pressure of 240 kPa.

Based on tractive power values on a concrete surface, it was rather expected that a fall in tractive power values would be obtained with declining tyre

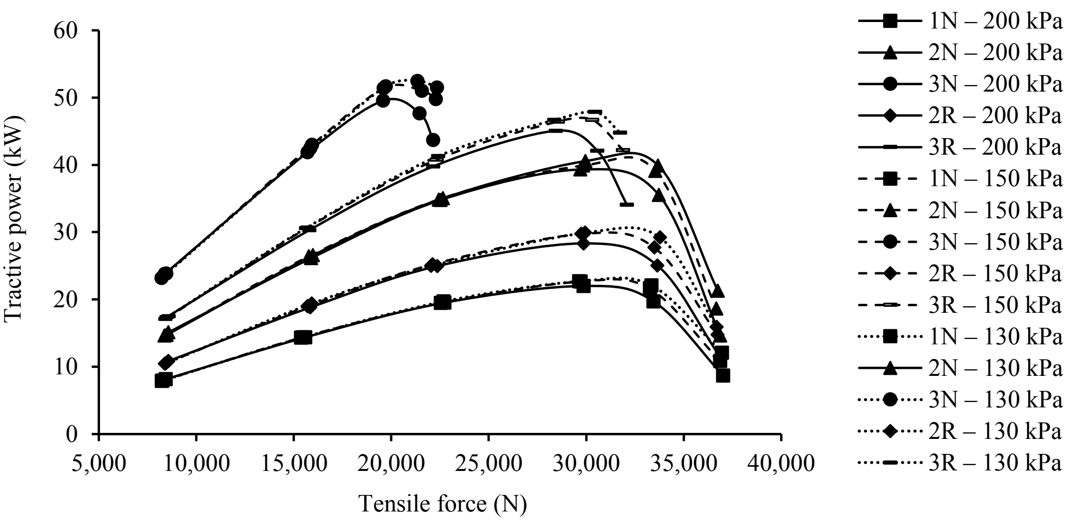

Fig. 5. ZŤS LKT 81 T tractive power on forest soil (gravel loam with average moisture of 38%) at tyre inflation pressures of 200, 150 and 130 kPa at different monitored gears

inflation pressure over the entire tractive power curves. This is due to both a decrease in the effective rolling radius of the travelling wheel tyres and an increase in rolling resistance as a consequence of lower tyre inflation pressure. When driving over a concrete surface, there is practically no outside component of rolling resistance present which would be overcome by the driving force of the tractor. The internal component of rolling resistance associated with hysteresis losses due to increased tyre distortion at lower tyre inflation pressures was not seen in the tractor's external tensile properties. Only an increase in internal losses in the tractor's running mechanism was noticed. As there was no opportunity during experimental measurement for fuel consumed by the tractor's driving engine and other operating variables to be also gauged, where the driving engine's torque load could have been plausibly described using this data, no final conclusion about the impact of tyre inflation pressure could be derived from purely tensile characteristics regarding overall energy efficiency on firm and slightly pliable surfaces. It is assumed that an observed increase in tractive power values reached at overload sections of tractive power curves resulted from the small number of measurements made in this area and also the possible occurrence of deviations when ground speed was itself defined and measured.

The highest tractive power values obtained on forest soil under given conditions were measured at gear 3N (Fig. 5). At a tyre inflation pressure of 200 kPa, tractive power reached the max. value of 49.55 kW. At a tyre inflation pressure of 150 kPa, tractive power reached the max. value of 51.40 kW, which is 3.6% better, while the max. value reached at tyre inflation pressure of 130 kPa was 52.48 kW, a value of 5.6% better compared to the tractive power measured at a tyre inflation pressure of 200 kPa. The tractive power plotlines can furthermore record a slight tendency toward rising tractive power values at individual gears as tyre inflation pressure fell. This trend is more pronounced at lower gears, where higher tensile force values were achieved. This was probably caused by a slight improvement in the gripping properties of driving wheel tyres at lower inflation pressures. Tractive power values significantly improved, especially when tyre inflation pressure dropped from 200 to 150 kPa. Differences found in tyre inflation pressures at 150 and 130 kPa are no longer so significant.

Statistical methods

Two statistical methods were used to objectify assessment of the impact of a monitored tractor's tyre inflation pressure on its driving wheels' slippage, depending on tensile load. One statistical method was multifactor analysis of variance (ANOVA), while the other was Student's t-test to compare significance of differences in regression equation parameters of the same form describing individual plotlines of measured results.

To express different functional dependencies between observed physical variables, nonlinear regression was used. In our case, it especially involved dependence of slippage on tyre inflation pressure and tensile load and also tractive power at individually monitored gears, depending on tyre inflation pressure.

As mentioned earlier, to assess the impact of tyre inflation pressure and tensile load (independent variables – factors) on slippage (dependent variable) in the tractor's driving wheels, depending on the type of surface monitored, multifactor analysis of variance (ANOVA) was used. Results from this statistical method are shown in Figs 6 and 7 for each type of monitored surface. The figures plot the dependence of the monitored ZŤS LKT 81 T tractor's driving wheel slippage on tensile load and tyre inflation pressure.

Based on the plotted lines describing dependence of slippage on tensile load and tyre inflation pressure, the conclusions below can be drawn.

For both types of surfaces, tensile load clearly has an impact on the change in slippage of the tractor's driving wheels at all monitored tyre inflation pressures. The rise in slippage when tensile load was low, roughly up to values of 10–15 kN, is very slight and has an almost linear nature.

On a concrete surface with tensile forces up to 30 kN, tyre inflation pressure had no statistically significant impact on the change in the tractor's driving wheels' slippage (Fig. 6). The first statistically significant difference in driving wheel slippage at different tyre inflation pressures emerged after tensile force had reached 30 kN. Significantly significant differences in slippage of the tractor's driving wheels are particularly pronounced among values measured at tyre inflation pressures of 240 and 150 kPa. At driving wheel slippage values measured at tyre inflation pressures of 240 and 200 kPa, there were no statistically significant differences up to a tensile load of 45 kN. At a tensile force of 45 kN and

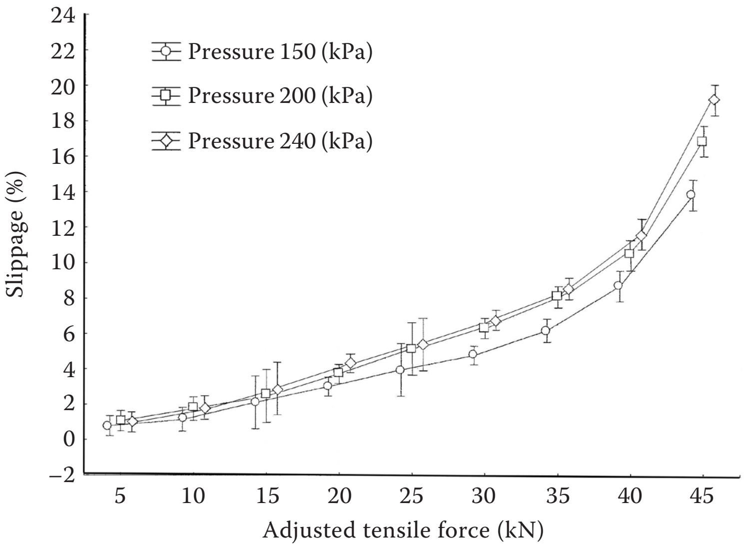

Fig. 6. Slippage depending on tensile load and tyre inflation pressure on a concrete surface (ANOVA graph)

higher, testing indicated a statistically significant impact from tyre inflation pressure on the change in LKT 81 T driving wheel slippage at all monitored tyre inflation pressure values.

On forest soil (gravelly loam with 38% average moisture), results indicated no significant impact from tyre inflation pressure on the change in the monitored tractor's driving wheel slippage over the entire observed tensile load interval (Fig. 7).

The second statistical method used was the Student's *t*-test, where significance of differences in regression equation parameters of the same type was used, describing the interdependence between the monitored variables. This statistical method was employed to assess the impact of tyre inflation pressure on the change in the ZŤS LKT 81 T tractor's tractive power and also to evaluate the impact of tyre inflation pressure on the change in slippage of the monitored tractor's driving wheels. The dependencies of tractive power on tensile force at different gears, the types of surfaces monitored and tyre inflation pressures of travelling wheels were approximated using second order polynomials. The dependencies of the tractor's driving wheel slippage on the tensile force achieved for different types of monitored services and tyre inflation pressures were approximated using exponential functions. The results from this test are quite extensive, due to the amount of processed data, so their publication exceeds the scope of this article. Based on the findings, it is possible to say that none of the results from comparison exceeded the critical value in Student's *t*-test. Based on these results, therefore, monitored changes in tyre inflation pressure have no statistically significant impact on changes in the tractor's achieved tractive power and slippage of its

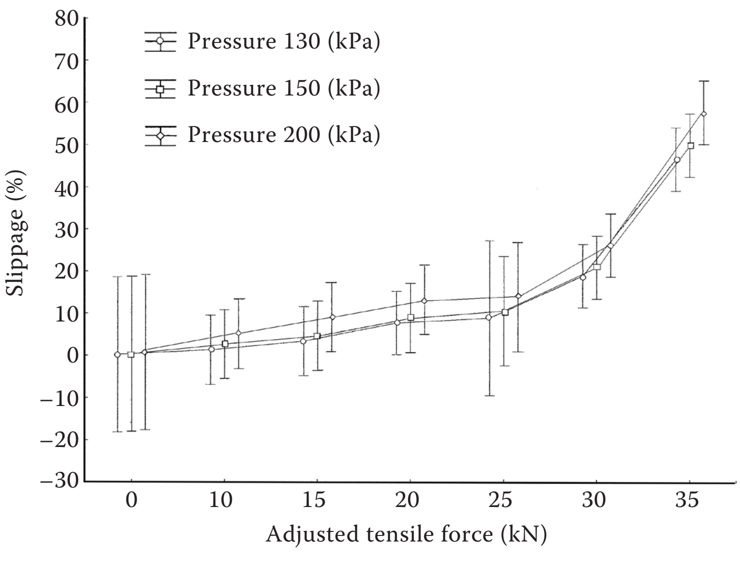

Fig. 7. Slippage depending on tensile load and tyre inflation pressure on forest soil (ANOVA graph)

travelling wheels, on both monitored surface types. The method of comparing regressive equation coefficients using the Student's *t*-test statistically compares significance of coefficients in observed regressive functions. However, it cannot exactly take into account certain local differences in the functions (such as differences in how close the distribution of monitored function values was to each other at the beginning and end). For this reason, test results comparing coefficients of regressive equations that reach values greater than half of the critical value for a given number of measurements or are very close to the critical value may also indicate that the values of these monitored functions at some intervals may be sufficiently distinct.

CONCLUSION

Based on the results presented (and despite some negative statistical analysis) changes in both surface type and tyre inflation pressure of the travelling wheels are reflected in changes in slippage characteristics and characteristics of the mechanised vehicle's tractive power. The achieved results thereby confirm the assertion that tyre inflation pressure of travelling wheels in mobile working machines is one of the important factors affecting not only energy efficiency, but also environmentally friendly mobile mechanised vehicles. In harvesting machines that bring wood in semi-trailers or in a semi-mounted position, the issue of the impact from tyre inflation pressure is not so important. These machines impair the environment much more intensely when they are towing wood than their own running mechanisms do. In addition, they operate under difficult terrain conditions and high axle loads when they are towing wood. The situation is different for tractors and special machines intended for work related to cultivation and care of plant cultures in forestry and agriculture. With these machines, the requirement is to have their adverse impact on the natural environment (i.e. the soil) be as little as possible. In this case, selecting the appropriate type, size and choice of the suitable tyre inflation pressure for the travelling wheels of such machines plays an important role.

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