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DETERMINATION OF RUT PARAMETERS AT VARIOUS LEVELS OF SLIP OF A PNEUMATIC DRIVE WHEEL – LABORATORY RESEARCH

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Abstract. The paper presents the results of laboratory measurements on the determination of rut parameters resulting from the operation of a pneumatic drive wheel with a different slip. The experiment was performed on the test bench consisting of the researched wheel load simulator, a mobile soil tub and the rope slip control system. Ruts were made at the wheel slip *s*=6%, 25%, 43%, 62%, 81%, 100%, and when the wheel rolled along the ground with *s* close to 0%. The obtained ruts were mapped to the computer using the non-contact laser measuring station. Based on the mapping for the rut fragment, the surface area was calculated in a simplified variant, as a horizontal projection of a rut on the surface area and as a real three-dimensional surface area; moreover, the rut volume was measured. It was found that using a simplified method for determination of the surface area of the rut, i.e. a rut horizontal projection, a significant error is committed. For studies with only rolling a wheel, a simplified surface area accounted for only 0.6 of real surface area , and for the wheel slip *s*=25% is was only 0.5 of actual surface area. Increase of the slip results in significant increase of the rut volume. With an increase of the slip *s*=25%, the volume of the rut increased by 1.4 in relation to the variant of *s* close to 0%, and when the slip was s=43%, as much as 2.2.

Key words: surface mapping, surface area of a rut, rut volume, rut depth

Introduction

The issue of determination of rut parameters which is made by a pneumatic drive wheel is significant from the point of view of ecology as well as economy of performing works with wheeled machines in many fields of economy, in particular in forestry and agriculture. Surface area and the rut shape and in particular its depth affects the changes in the ground on which a wheeled vehicle moves, which in turn may cause unfavourable changes in the environment (Gil, 1999; Lukáč, 2005; Neruda, et al., 2008; Sowa and Kulak, 2008; Ulrich, et al., 2003). Ruts made by wheels also influence the traction properties of a vehicle

(Jakliński, 2006; McKyes, 1985; Wong, 2009). Determination of the rut parameters in case of a pneuamtic wheel is complex, because as in case when a wheel touches the ground, it is three-dimensional and it depends on the deformation of both elements which cooperate together i.e. a tyre as well as the ground (Chigarev et al., 2009; Jakliński, 2006). In typical research, the rut surface area as well as the surface area of a wheel contact with the ground is determined based on calculations, in which, for simplification it is considered as flat, i.e. a ground plan of a rut. Such a view does not include the third dimension of a rut, that is a hollow, which is made in soil (Chigarev et al., 2009; Kormanek, 2007). Unfortunately it is a considerable simplification, which influences credibility of the obtained results. The other interesting issue is how rut parameters change in relation to the slip size with which a wheel works on soil, taking into account that the slip in case of a drive wheel always occurs (Jakliński, 2006).

The objective and scope

The objective of the research was to determine changes of rut parameters which were formed during the movement of a penuamtic drive wheel, which moves on soil with a slip of the following values: s=6%; 25%; 43%; 62%; 81%; 100% and in the variant at the slip close to zero. Each variant was made in three repeats.

Rut parameters were calculated based on their computer models of mapping, which were made with the use of a stand for non-contact surface imaging. Real surface areas of ruts were calculated, which included sinking of a wheel in soil, simplified surface areas, which were formed by mapping the rut shape on the surface and the rut volume.

Material and research methods

The research was carried out with the use of a penumatic drive wheel equipped with a radial tyre designated for microtractors i.e. 165/80R13 working at the nominal load of 464 kg and nominal pumping pressure of 240 kPa (parameters of work according to catalogue recommendations, new tyre).

Soil for research was transported from a habitat mixed fresh forest with omission of surface organic layer. It was podzolic soil, composed mainly of sand 84% and silt 9%. During collection of soil for research, also additional samples of soil in the intact state were collected to measuring rings, on which gravimetric moisture content and volumetric density were determined with the use of an oven-drying method. Gravimetric moisture content of soil during its collection in the forest was at the level of 8.9% whereas volumetric density was at the level of 1.25 $g \cdot cm^{-3}$.

After bringing soil to laboratory, on account of partial loss of moisture, the soil was moistened by spraying and mixing. Then, the soil was poured to a soil tub in the form of a cuboid of the following dimensions: 1.5 m x 0.4 m x 0.4 m. A skeleton of the soil tub was made of welded steel angle irons, whereas sides were made of a sheet metal welded to the skeleton. In order to obtain soil density close to the determined in the forest, soil was artificially compressed by pouring it to the tub in stages and then pressing with a seal with the use of hydraulic press until the set mass in the known volume was obtained. On the soil prepared this way, in the soil tub, ruts were made with a test wheel on the laboratory test bench. Soil was replaced and prepared again (compressed) in each slip variant and in each repeat.

Test bench

A test bench (fig.1) is composed of a simulator of loads (Kormanek and Walczykova, 2005), which was modified through addition of a mobile soil tub and the slip control system. A load simulator is mounted to a three-point suspension system (2 and 4) of a tractor (1) and consists of a solid frame (4) and a mobile frame (6) where a test wheel was mounted on the drive shaft (20). A hydraulic cylinder (5) allows raising and lowering the moving frame (6) with a test wheel (20) whereas its pressing to soil is caused by fixed sinkers (22). A moving frame is additionally stiffened with the use of a steel pull back bar (21).

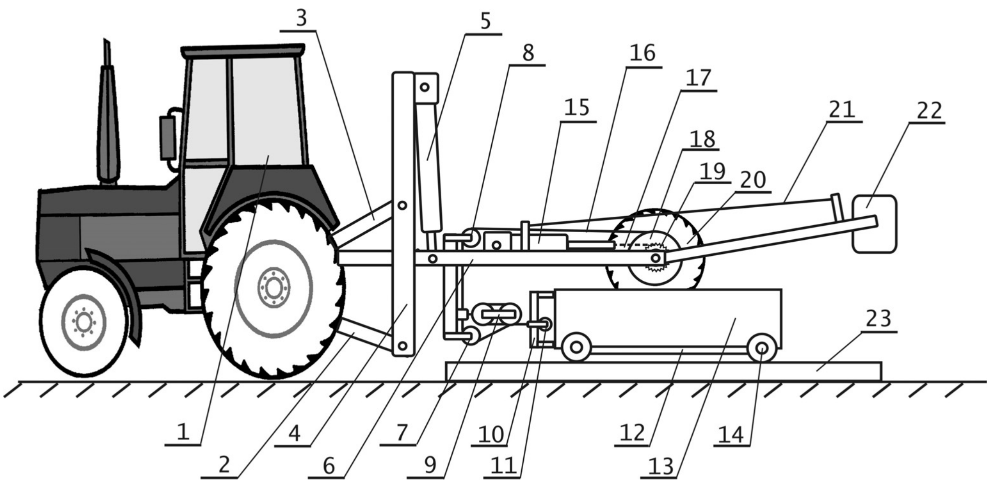


Figure 1. A load simulator with a moving soil tub: 1 – tractor, 2 – bottom arms, 3 – tree – point hitch upper connector, 5 – hydraulic cylinder of lifting a moving frame, 6 – moving frame, 7 and 8 – rope leading rollers, 9 – pulley block, 10 – roller guidebar, 11 – roll, 12 – pulley, 13 – soil tub, 14 – wheels of pulley, 15 – hydraulic cylinder of the turnover of a test wheel, 16 – steel rope, 17 – chain, 18 – rope drum, 19 – drive chain wheel, 20 – test wheel, 21 – stabilizing bar, 22 – sinkers, 23 – tracks

A hydraulic cylinder (15) by a chain (17) , geared with a chain gear wheel (19) causes that a test wheel turns (20) pressed to soil in a soil tub (13). A soil tub is placed on a pulley (12), wheels of which (14) move on tracks (23). The tub movement is limited by steel rope, which, during the turn of the test wheel, rolls out from the rope drum (18) linked with a drive shaft of the test wheel. Steel rope(16) is led to the tub with leading rolls (7 and 8). Difference of the peripheral speed of the test wheel and the speed of the box movement towards the peripheral speed of a wheel is a slip *s* of wheel on soil. In order to obtain wheel slips assumed in tests (except for slip s≈ 0% and s=100%), diameter of a drum (18) from which the rope was rolling out was regulated (16) and a gear (block) (9) with various transmissions was used. A box tap was made in the form of a roll (11), which moves on the vertical guidebar (10). This manner of connecting pulley with a rope unwinding from the pulley block was used in order to eliminate the impact of the wheel sinking in soil, on the vertical load on the test wheel (20).

In order to obtain slip which is close to zero, a steel line was disconnected (16) and the soil tub was allowed to move freely on tracks whereas in variant s=100%, a soil tub was connected to a fixed frame with a chain.

Computer device for non-contact, remote surface imaging

Rut shapes obtained in the soil tub were mapped in a computer with the use of a non-contact method with the use of a laser device (fig. 2) (Kormanek, 2007).

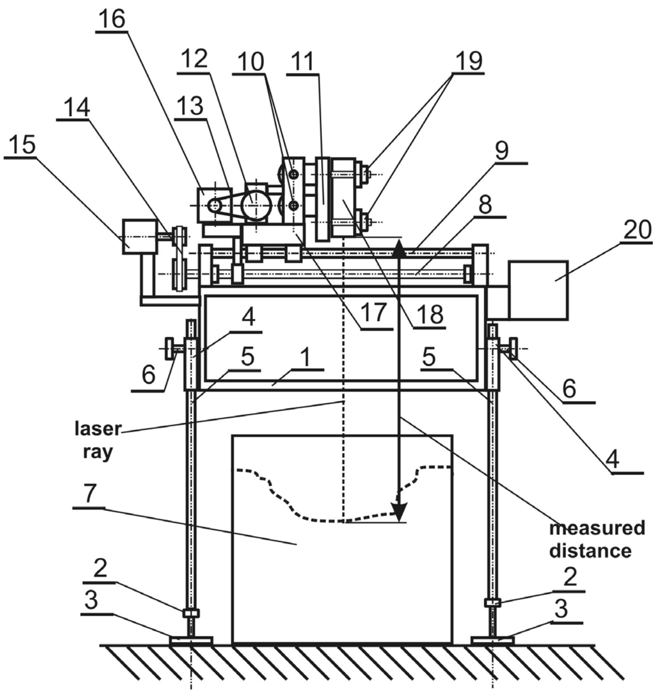


Figure 2. Device for non–contact computer surface imaging. 1 – frame of device, 2 – screw regulation of frame levelling, 3 – tongue jack, 4 – guidebars of supports, 5 – supports with regulated length, 6 – clamping screws of supports,. 7 – soil tub, 8 and 12 drive screws, 9 and 10 guidebars of a feed, 11– feed pulley X, 17 – feed pulley Y, 13 and 14 drive gear with cogbelts, 15 and 16 – stepper motors, 18 – laser rangefinder, 19 – clamping screws for mounting a laser rangefinder, 20 – control CNC of stepper motors

Device operates with sliding of a laser rangefinder (18) mounted with screws (19) to a moving slide pulley X (11), this pulley is mounted to the slide pulley Y (17). Movement of pulley X (11) on guidebars (10) is caused by a drive screw (12) driven by a gear with a cogbelt (13) by a stepper motor (16). A slide pulley Y (17) moves on guidebars (9) and its movement is affected by a drive screw (8) by a gear with a cogbelt (14) driven by a stepper motor (15). All elements of a device mounted to the main frame (1), which is supported on vertical supports of a regulated length (5) with a possibility of sliding on guidebars (4) in order to regulate the height at which frame is mounted (1). In guidebars (4), supports (5) are blocked with clamping screws (6). Detailed levelling of a frame (1) takes place on screw regulators (2) supported on tongue jacks (3). A laser rangefinder (18) during measurement is moving over the tested surface of soil in the soil tub (7) with a rope-to-rope system, where distance between the following ropes corresponds to the x coordinate. While moving on each line after a specific distance was covered, which corresponds to slide "y", a laser rangefinder stops and the distance from the soil surface is measured and the measured value is sent to a computer. A manner in which a pulley moves is determined by CNC controller (20).

As a result of using a device, presented in figure 2, soil surface in the soil tub was mapped in a computer along with the formed ruts. These were lattices consisting in points of three coordinates, of which „*x*" corresponded to the distance set along the rut axis (in tests it was accepted that x=2.0 cm), „*y*" of the distance set across the rut axis (in tests it was accepted that x=1.5 cm), „*z*" of the measured distance of a laser rangefinder from the soil surface.

Based on the obtained space points lattices, which imaged the soil surface in the soil tub, calculations of surface areas of ruts and their volume were carried out. Surface areas of each rut were calculated in two variants.

Variant I of the surface area calculation

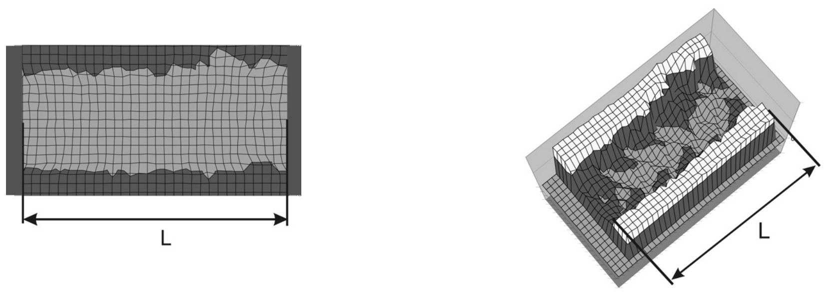
This variant consisted in determination of the surface area of a rut *Pu*,as a flat surface, which corresponds to the projection of a rut fragment on the surface (fig. 3a). Calculations, in this case, were made by summing up all "meshes" of the net of points which were obtained after imaging of the surface, for which the depth value "z" was different than the value "z" for the non-sank soil (fig.3). During calculations from the whole length of a rut, the most possible fragment *L* was selected; the beginning of the rut was omitted, when a wheel started to move and the end was omitted, when the wheel stopped. The total surface area of a rut *Pu,* was calculated per 1 cm of its length – *Puj*.

Variant II of the surface area calculation

This variant consisted in determination of the surface area of a real rut *Pr,* for the same rut fragment *L*, as in variant I (fig. 3b). Surface area was calculated as a sum of the surface area of triangles in the space of nodes determined by particular points of a net, for which the value of "z" depth was different than "z" value for non-sank soil surface area. Calculated total surface area of a rut *Pr* similarly as in Variant I was calculated per 1 cm of its length – *Prj*.

Calculations of rut volume

Calculations of rut volume V were carried out by summing the volume of cut cuboids with a triangle base, for which the value of "z" depth was different than the value "z" for the surface area of non-sank soil. Similarly as in case of the surface area, total volume was calculated per 1 cm of the rut length – *Vj*.

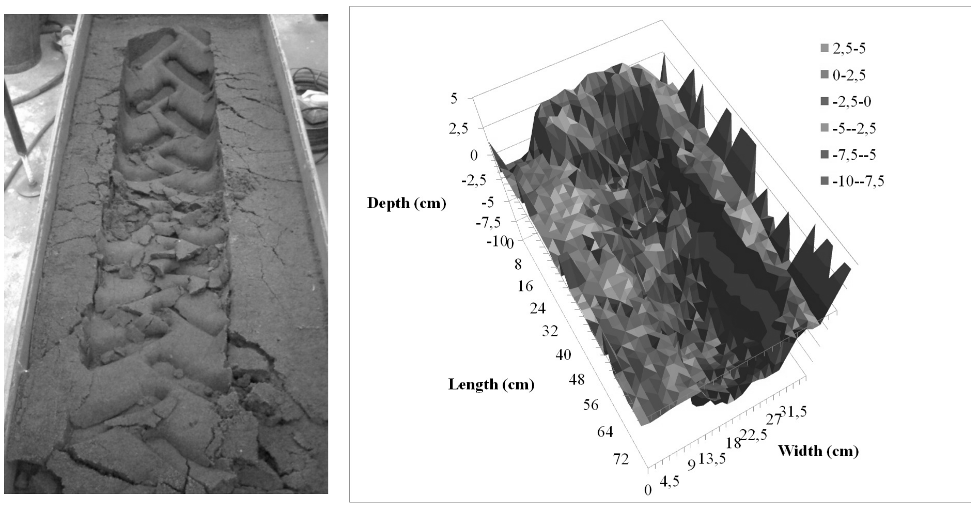


a b

Figure 3. Manner of determination of the surface area of a rut: a – simplified variant I of surface area, b – real variant II of the surface area

Results of the research

As a result of the works, which were carried out, ruts in different variants of slip in three repeats were carried out with a test wheel on the test bench (fig. 1).



a b

Figure 4. A rut in the soil tub for the wheel slip s= 43%: a – photo of a rut, b – computer imaging

The obtained ruts were then mapped with the use of a computer stand for non-contact imaging of the surface (fig. 2). Figure 4a presents a picture of an exemplary rut made in the soil tub for variant of a slip of the test wheel of s=43%, whereas figure 4b presents its computer imaging. Table 1 presents means along with standard deviations from three repeats of the rut depth measurement, which were measured along the rut axis and the mean from three repeats for results of the surface area calculations (in both calculation variants) and the rut volume. Figure 5 present relation of the rut depth (for all variants and repeats which were carried out and) from slip s of a test wheel.

Table 1
Results of the depth measurement, calculations of the surface area in both calculation variants and the rut volume depending on the slip variant s *of a test wheel*

Slip s (%)	Rut depth (cm)	Surface area of a 1 cm long rut		Rut volume 1 cm long Vj (cm^3)
		variant I simplified Puj (cm^2)	variant II real Prj (cm^2)	
0	4.5 ± 0.3	16.1 ± 0.6	27.2 ± 1.0	56.9 ± 9.4
6	6.2 ± 0.4	16.8 ± 0.9	29.7 ± 1.6	69.6 ± 7.1
25	7.5 ± 0.4	17.1 ± 0.5	33.8 ± 0.4	78.1 ± 6.2
43	9.1 ± 0.5	18.1 ± 1.6	42.2 ± 3.4	127.0 ± 10.4
62	10.1 ± 0.6	18.7 ± 0.7	46.3 ± 3.7	139.3 ± 11.9
81	11.6 ± 0.4	19.7 ± 1.0	53.5 ± 2.6	162.4 ± 13.2
100	13.0 ± 0.5	22.1 ± 1.3	59.0 ± 4.7	189.8 ± 17.0

According to table 1 and fig. 5 even rolling a wheel with a minimum resistance at the slip close to 0% caused formation of a rut of approx. 4.5 cm depth whereas slip of a wheel s, at the level 6% caused the increase of the rut depth by over 37% in comparison to the variant when slip was close to 0%. Slip of a wheel s, at the level 25%, which is considered as the maximum admissible, at which machine operation in field conditions should take place, resulted in the increase of the rut depth by approx. 67% in comparison to the rut depth, when this wheel was rolled. This value is high, taking into consideration the fact that, very often during the machine operation on the soil ground, particularly during works related to logging (especially staring, stopping, manouvring with a vehicle), a wheel works with slips of values considerably exceeding 25%. In case, the slip s=62%, was exceeded, the rut depth is over two times higher than the one, which is formed only at rolling the wheels, whereas at the slip 100% over 2.9 times higher. The applied regression line (fig. 5) has a high coefficient of determination, which proves good imaging, changes of the rut depth from the wheel slip with the use of the square function.

According to figure 6, which presents imaging of transverse profiles of ruts (mean from three repeats) for different variants of the test wheel slip s, the increase of the value of a slip causes a gradual extension of a rut along with the increase of its depth.

At high values of a slip the profile course becomes irregular, which is related to tearing bigger soil pieces by a tyre protector (which is visible even at lower slips at fig. 4a).

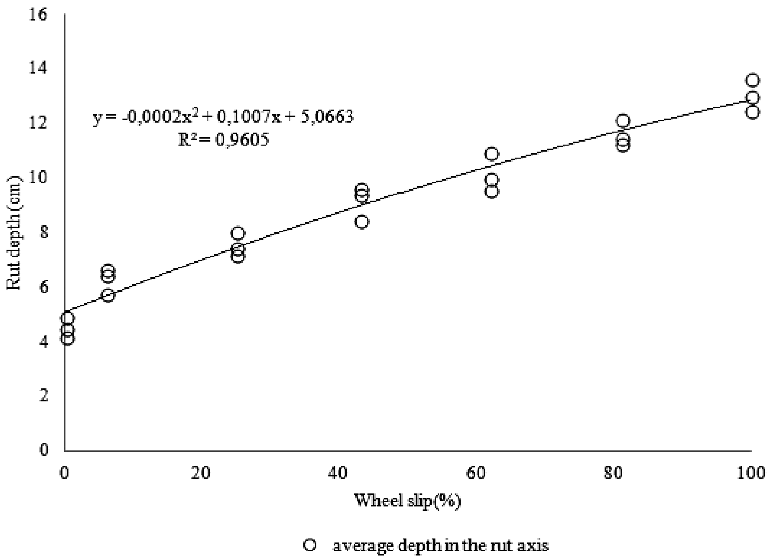


Figure 5. Dependence of the rut depth in particular measure repeats on the slip s of the test wheel

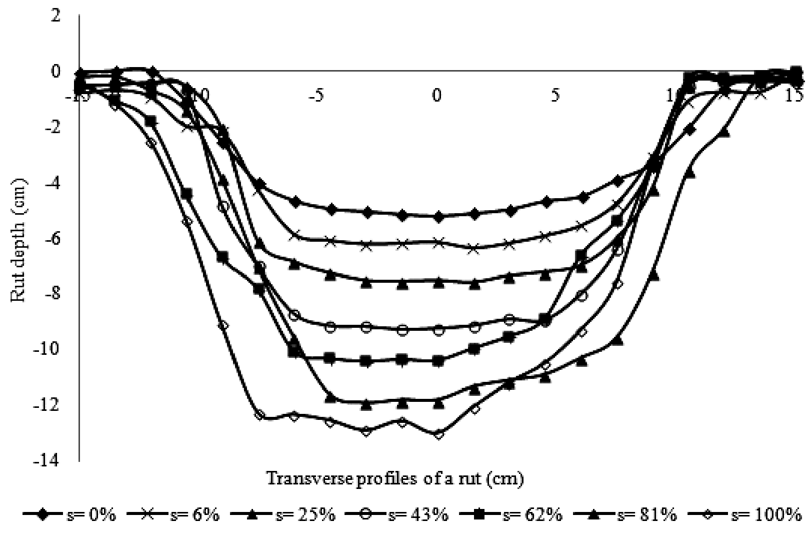


Figure 6. Transverse profiles of ruts for various variants of slip s of the test wheel

Results of calculations of the ruts surface areas (table 1 and fig. 7) show a considerable error resulting from frequently used simplification which consisted in testing the surface area of the rut in calculations as a flat one without its depth

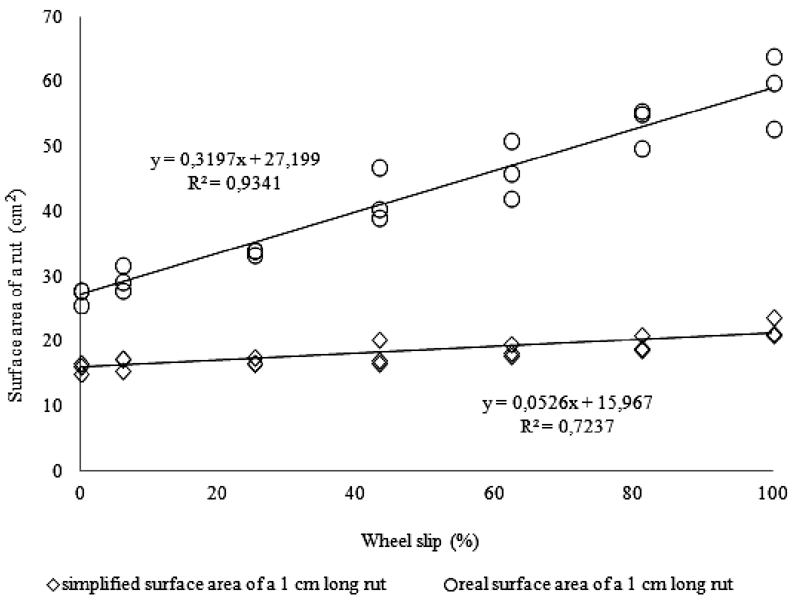


Figure 7. Simplified surface area Puj (variant I) and real Prj (variant II) of a rut at different variants of a slip s of the tested wheel

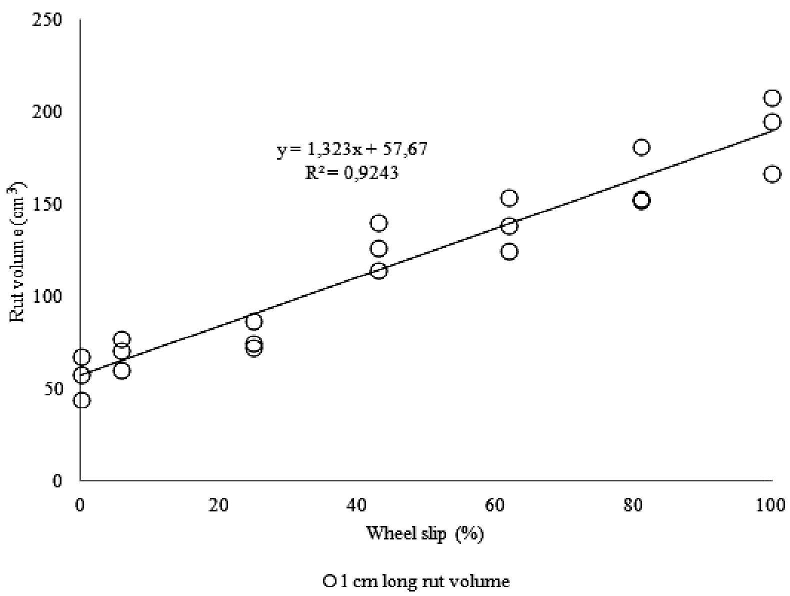


Figure 8. The rut volume Vrj at various variants of a slip s of the test wheel

Error of underestimating the surface area of a rut is considerable. Surface area of the simplified rut in case the wheel is only rolled and the slip is close to 0% constitutes 0.6 of the real surface area, for the slip 25% it is 0.5 of the real surface area for the slip 43% only 0.4 and for slip 100% this value decreases to 0.37. High increase of the rut itself is also interesting (table 1, fig. 8) at the increase of the slip value up to 25 %, rut volume increased 1.4 times in comparison to the variant for which slip was close to 0% whereas at slip 43% as much as 2.2 times. Relating the above fact with the increase of the depth one may state that the increase of the slip results in a considerable deep impact of the wheel on soil, which may result in its compression within transverse section of the rut. One cannot also forget that deep ruts in the forest environment are also harmful on account of shallowly placed roots of neighbouring trees and possibilities of their tearing or damaging (Gil 1999; Neruda et al., 2008; Ulrich et al., 2003).

Conclusions

1. In the research which was carried out the increase of the rut depth at the test wheel slip *s*=6% in comparison with the rut depth, which was pressed out by a wheel during a free rolling was 37% whereas at the slip of *s*=25% in comparison to the rolled wheel, the increase was as much as 67%.
2. Application of a simplified method of determination of the surface area of a rut i.e. projection of a rut on the plane means a considerable error. For the research which was carried out only at rolling a wheel, a simplified surface area constituted only 0.6 of the real surface area, whereas at the wheel slip *s*=25% it was only 0.5 of the real surface area.
3. Increase of the slip results in the increase of the rut volume. At the increase of the value of a rut up to *s*=25%, volume of a rut increased 1.4 times in comparison to the variant, in which the slip was close to 0%, whereas at the slip *s*=43%, it was as much as 2.2. times.

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OKREŚLANIE PARAMETRÓW KOLEINY PRZY RÓŻNYCH POZIOMACH POŚLIZGU NAPĘDOWEGO KOŁA PNEUMATYCZNEGO – BADANIA LABORATORYJNE

Streszczenie. W pracy przedstawiono wyniki pomiarów laboratoryjnych nad określeniem parametrów kolein powstałych przy ruchu pneumatycznego koła napędowego z różnym poślizgiem. Doświadczenie wykonano na stanowisku pomiarowym składającym się z symulatora obciążeń koła badanego, ruchomej wanny glebowej, oraz linowego systemu kontroli poślizgu. Koleiny wykonano przy poślizgu koła o wartościach *s*= 6%; 25%; 43%; 62%; 81%; 100%, oraz gdy koło przetaczano po glebie, a poślizg był bliski 0%. Uzyskane koleiny odwzorowywano w komputerze przy pomocy bezkontaktowego laserowego stanowiska pomiarowego. Na podstawie odwzorowań dla fragmentu kolein obliczono pola powierzchni w wariancie uproszczonym, jako pola rzutu kolein na płaszczyznę oraz rzeczywistym jako pola powierzchni trójwymiarowych, obliczono również objętość kolein. Stwierdzono, iż stosując uproszczoną metodę określania pola powierzchni koleiny tj. rzut koleiny na płaszczyznę, popełnia się znaczny błąd. Dla przeprowadzonych badań przy tylko przetaczaniu koła, pole powierzchni uproszczone stanowiło jedynie 0,6 pola powierzchni rzeczywistej, zaś przy poślizgu koła *s*=25% to tylko 0,5 pola powierzchni rzeczywistej. Przyrost poślizgu skutkuje znacznymi przyrostami objętości koleiny. Przy wzroście wartości poślizgu do *s*=25%, objętość koleiny wzrosła 1,4- krotnie w stosunku do wariantu przy poślizgu bliskim 0% , zaś przy poślizgu *s*=43%, aż 2,2- krotnie,

Słowa kluczowe: odwzorowanie powierzchni, pole powierzchni koleiny, objętość koleiny, głębokość koleiny

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