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DETERMINATION OF FOREST SOIL TRACTION PARAMETERS*

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ABSTRACT

Wheel tester was adopted to mate with computer data acquisition card. Some physical properties of the forest stand soil, as well as its shear forces caused by the pneumatic wheel were measured. Based on the knowledge of those forces, it was possible to present shear stresses in relation to the soil horizontal deformation and slip against the coefficient of adhesion.

Key words: soil shearing, wheel tester, wheel slip, coefficient of adhesion

INTRODUCTION

Quantification of vehicle-terrain interaction on a given surface makes possible a proper match of tractors, according to requirements of the combined machines and working conditions [9]. Consequences of a badly matched traction might be mobility problems, like high motion resistance caused by deep ruts, lower gross tractive efficiency, and inevitable soil damage, e.g. excessive compaction and soil erosion [4, 5, 6, 7, 12, 13]. Most mobility variables are strongly dependent on the wheel slip of the running gear [1]. When dealing with mobility problems on hard and deformable surface concerning agriculture tractors a method of estimating slip on the basis of coefficient of adhesion under given soil and terrain conditions is available [2, 3]. Lack of such data for the forest stands, and generally very fragmentary application of terramechanical approach to the forest mechanised works, lead the authors to undertaking research on mobility and trafficability in the forest. The presented paper describes a part of those research objectives.

METHODS

First, modifications of the existing wheel tester used for measurements of tyre operational parameters and development of circumference driving forces on the measured wheel at given vertical loads [10] were made. The tester was redesigned in such a way that the computer recording of the experimental data with a high frequency became possible.

For the natural forest stand the following characteristics were determined:

- shear force dependant on the wheel turning angle,
- shears stresses in relation to the soil horizontal deformation under the measured wheel,
- slip as a function of coefficient of adhesion,
- maximum value of coefficient of adhesion for the measured forest stand.

Identification of the measured soil environment was made by determination of the soil mechanical composition and its basic physical and mechanical properties.

Description of the wheel tester design

The modified tester is made of two frames. The static one is mounted on the MF 235 tractor 3-point linkage. One end of the moveable frame is fixed to the transport hitch, the other end is connected to the static frame through a hydraulic cylinder. Another hydraulic cylinder is used to apply torque to the tested wheel. The tested wheel is mounted in the middle of the moveable frame. In the modified tester, vertical loads are not applied hydraulically [10] but by dead weights, placed on the additional beam in the rear part of the frame. A chain transmission alters the movement of the second hydraulic cylinder piston rod into the torque of the tested wheel. On the way of that transmission a strain gauge for force measurements is placed. The wheel turning angle is recorded by an optical sensor which gives pulses initiating the writing of the measured forces on the HD of the computer. To get the movement of the hydraulic piston, the outer hydraulic circuit is used. Torque control as well as lifting and lowering of the tested wheel is enabled by the valves of hydraulic distributors, that also make possible sensitivity regulation (Figure 1, 2). Values of the force in the driving chain are recorded by Daq 112B, data acquisition PC card, produce of IOtech Incorporation firm. A notebook is used as a PC and measured values are written every 1.5° of the wheel turning angle. The computer program is used to set the following quantities: number and sort of active channels, frequency, card amplification, mode of record initiation, measuring characteristics of each channel. The first photo-optical pulse gives start to data recording. Force is measured until it reaches the maximum value. The end of session is forced manually. Results of measurements are saved as text format and can be imported to any calculation program for further processing (Figure 3).

Figure 1. Diagrammatic view of the wheel tester: 1– tractor, 2 – static frame, 3 – tractor upper link, 4 – hydraulic cylinder providing torque, 5 – hydraulic cylinder for lifting the moveable frame, 6 – piston rod, 7 – strain gauge, 8 – measured wheel, 9 - chain transmission, 10 – beam for weights, 11– stabilizing rod, 12 – weights, 13 – tractor lower link, 14 – pull rod stabilizing the static frame, 15 – hydraulic control

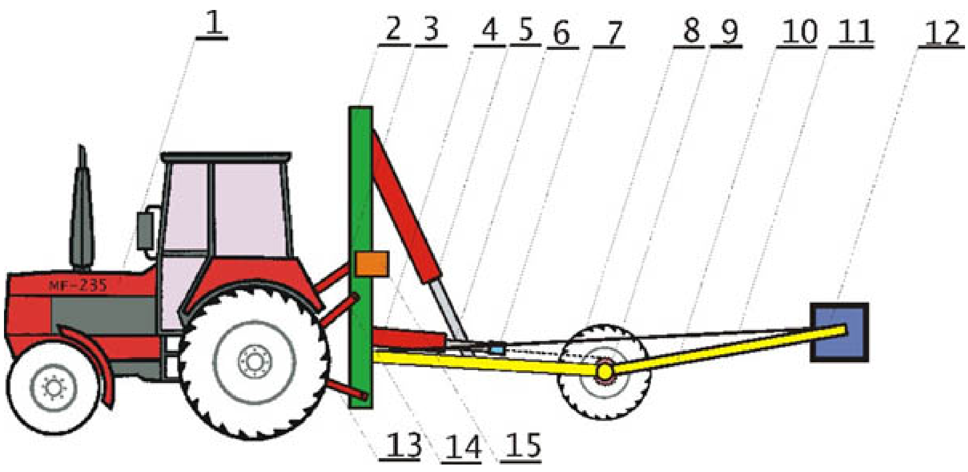
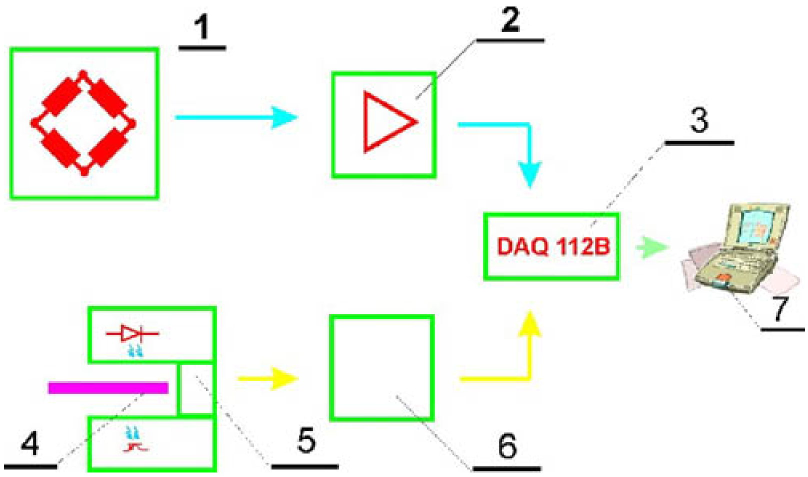


Figure 2. General view of the wheel tester

Figure 3. Block diagram of the measuring systems: 1- strain gauge measuring forces acting in the driving chain, 2- analogue amplifier, 3 – PC data acquisition card, 4 – diaphragm, 5 – photo-optical sensor of the diaphragm movement, 6 – system generating pulses controlling the data recording, 7 – computer (Notebook)



Research was carried out in Niepołomice forest district, on fresh mixed coniferous forest stand. The soil to the depth of about 0.3 m can be classified as loose, non-skeleton sand (sand – 94%, silt 2%, silt and clay – 4%, clay fraction – about 3%).

Description of the forest floor

1. Eastern direction of slope, inclination 12 degree
2. Stand:
    - Composition of species: pine 60%, oak 40%
    - Moderate crown closure 0.7 – 0.8; horizontal
    - Age class proportion – two generation
    - Life period: mature forest
    - Mean height: 26 m

3. Underwood: oak (singly)
4. Underbrush: alder buckthorn (singly)
5. Forest floor vegetation:

English name	Latin name	Sociability	Population size
bilberry	*Vaccinium myrtillus*	5	5
common haigrass	*Deschampsia flexuosa*	1	1
reed grass	*Calmagrostis epigeios*	1	1
blackberry	*Rubus plicatus*	1	+
hair wood-rush	*Luzula pilosa*	1	1
-	*Entodon Schreberi*	2	+

6. Organic matter

Litter	$0.5 – 1·10^{-2}$ m
Ol	$2·10^{-2}$ m
Of	$3·10^{-2}$ m
Oh	$5·10^{-2}$ m

7. Roots

down to $7\text{-}8·10^{-2}$ m turf (sod)
down to 0. 3 m a great amount

The wheel used for measurements was equipped with a radial tyre 6.5/80R13 inflated to 240 kPa. The vertical load amounting to 4.75 kN was selected according to the tyres catalogue data.

The initial characteristics of the experimental site, carried out on three blocks, involved measurements of soil density and moisture content using volumetric cylinders, shear stresses by means of shear vane [8] and penetration resistance, determined by cone penetrometer with electronic data logger [11]. The shearing torque as a function of the wheel turning angle was measured in 18 replicates on each block. In the created wheel ruts shear vane measurements were made again, to observe possible changes in soil strength.

As a result of the carried out experiment relation between wheel torque and wheel turning angle was obtained. Through further processing, values of torque were transformed into forces, considering in calculation dynamic wheel radius. Then forces divided by the wheel-surface contact area resulted in shear stresses, presented in dependence on horizontal soil deformation under wheel.

Based on the course of torques and forces dependent on wheel turning angle, it was possible to find the angle, at which the wheel circumferential force reached maximum value. Its division by the wheel vertical load gave the maximum value of the coefficient of adhesion.

For determining of angle at which 100% slip occurs, the length of the wheel-soil contact area was found. Division of the maximum slip by the value of that angle resulted in slip corresponding with 1° of turning angle. This procedure lead to determination of slip dependent on coefficient of adhesion, calculated as a ratio of the circumferential force and the applied vertical load.

The enclosed film illustrates some measurements taken in the research.

RESULTS

The moisture content on the experimental site during the time of measurements corresponds with favourable situation, as far as conditions for mechanised works are concerned. The variation of moisture content is rather high, though it does not depart very much from what is often encountered at in situ measurements. Concerning bulk density, it falls into lower range of values (Table 1).

Table 1. Measured soil physical parameters

Depth (m)	Bulk density ($Mg \cdot m^{-3}$)	Coefficient of variability in bulk density measurements (%)	Moisture content by weight (%)	Coefficient of variability in moisture measurements (%)
0.0 – 0.10	0.61	37.23	21.9	51.8
0.11– 0.20	1.17	12.72	5.9	50,1
0.21 – 0.30	1.28	9.75	3.3	44.1

Resistance to shear measured to the depth of 0.25m is a good indicator of the soil ability to withstand horizontal forces (Figure 4) and quite well corresponds with shear stresses determined on the wheel (Figure 6.) Here the values are generally lower, which results from the mode of measurement. The vertical and horizontal forces acting on the wheel contributed to increase of the shear resistance on each one of the measured layers (Figure 4).

Figure 4. Soil shear resistance measured by shear vane on control plots and in wheel ruts after loading by vertical and horizontal force

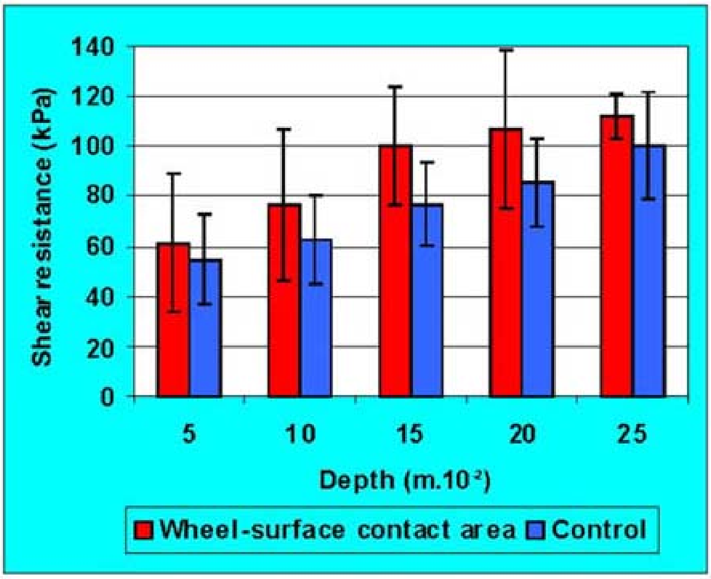
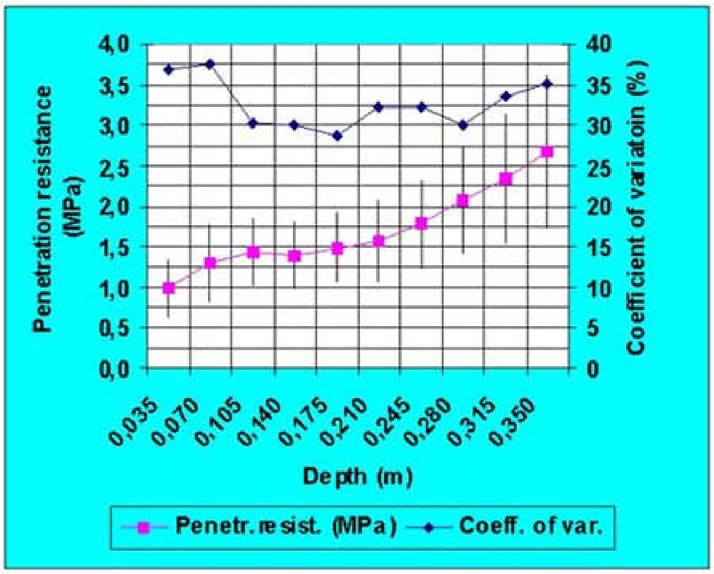


Figure 5. Average soil penetration resistance on the control sites



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Soil penetration resistance data can give some idea about soil load carrying ability. The results (Figure 5.) indicate that soil on the examined stand cannot be counted among the very susceptible to compaction. This happens in spite of very low bulk density of the first layer (Table 1). The bearing ability is considerably improved by sod. Coefficient of variation not exceeding 40% at the top layer testifies in favour of the penetration method in estimation soil characteristics, mainly with regard to soil compaction. This kind of measurement can be carried out in great number of replicates, taking into consideration the nonuniformity of the forest environment.

Specification of the measured parameters in dependence on the wheel turning angle is given in Table 2. Owing to the effect of the vegetation cover, the variation coefficient for shearing force (similarly for torque) at the start amounted to about 70%. It kept decreasing with higher values of the mentioned quantities, reaching 10% at the maximum wheel turning angle.

The wheel dynamic radius r_d was calculated from nominal radius, diminished by the tyre deflection. The latter was measured on the experimental site during the loading of the wheel by vertical and horizontal force.
Shearing stresses increased (Figure 7) until the wheel turned through an angle corresponding with the lug pitch. Continuation of the wheel movement had no more effect and the associated stresses were kept on the same level. Explanation can be looked for in low cohesion of the organic matter.

Table 2. Results of measurements and calculations

Wheel turning angle (^{o})	Torque (N·m)	Standard deviation (N·m)	Coefficient of variation (%)	Circumferential wheel force (N)	Coefficient of adhesion	Slip (%)
0.0	0	0	0	0	0.000	0
1.5	71	50	71	346	0.072	3
3.0	179	123	68	892	0.187	7
4.5	316	192	61	1576	0.330	10
6.0	441	234	53	2138	0.447	13
7.5	541	253	47	2537	0.531	17
9.0	615	259	42	2759	0.577	20
10.5	678	266	39	2944	0.616	23
12.0	729	244	33	3044	0.637	27
13.5	800	187	23	3161	0.662	30
15.0	856	134	16	3216	0.673	33
16.5	897	102	11	3290	0.689	37
18.0	911	97	11	3295	0.690	40
19.5	927	95	10	3351	0.701	43
21.0	934	92	10	3341	0.699	47
22.5	939	86	9	3352	0.699	50
24.0	941	89	9	3337	0.700	53
25.5	**944**	**90**	**10**	**3348**	**0.701**	**57**

Slip as a function of coefficient of adhesion (Figure 6) for given terrain (soil) conditions makes possible determination of slip for any kind of vehicle, equipped with proper pneumatic running gear (proper tyre on the driving wheels), when working under similar conditions as considered in the carried out research [2, 3].

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Figure 6. Shear stresses as a function of soil horizontal deformation under the wheel

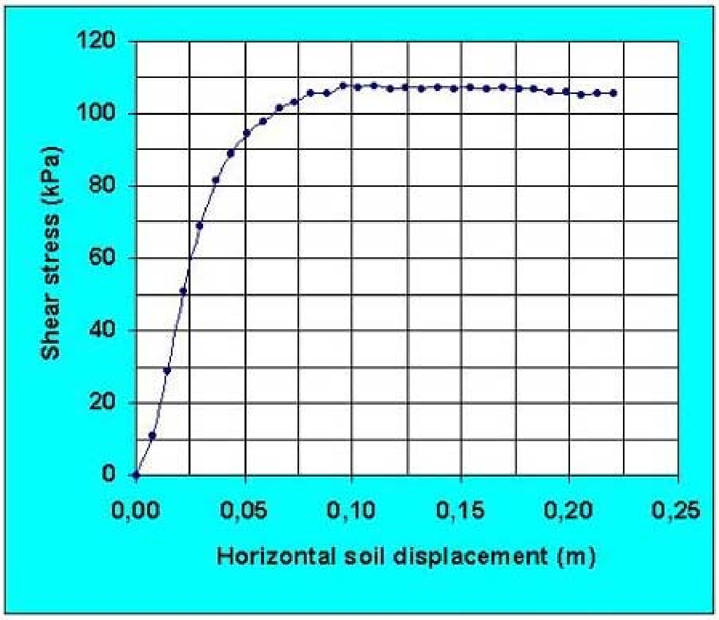
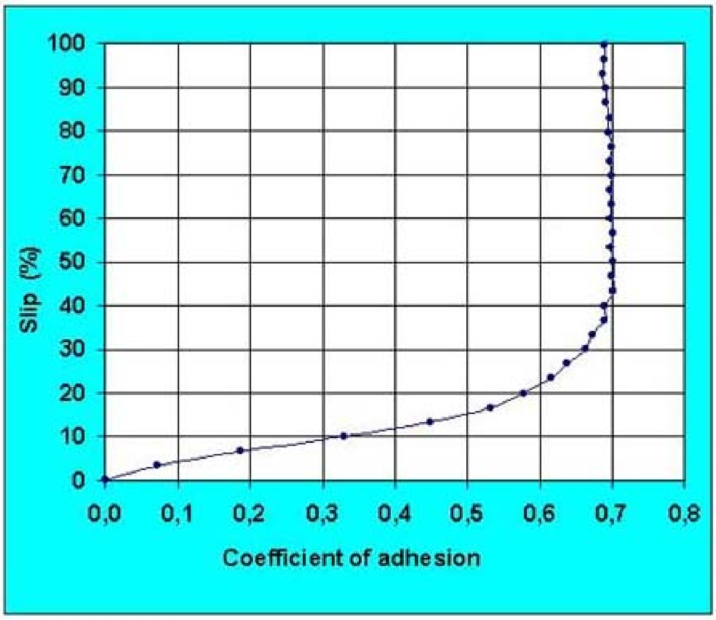


Figure 7. Slip in relation to coefficient of adhesion



SUMMARY AND CONCLUSIONS

The obtained results indicate that the maximum wheel driving force on the examined forest floor occurs when the wheel turns through an angle that corresponds with the wheel lug pitch. As opposed to some agricultural soil [2] this value does not decrease with further movement of the wheel. The carried out research resulted in the findings of the relation between slip and coefficient of adhesion that to some extent differs from those applied on agricultural soils.

The applied method for measuring wheel circumferential forces is free from influence of the rolling resistance, as the wheel does not make linear movement when it shears the soil.

Values of resistance to shear measured by the shear vane are lower than the corresponding results calculated for the wheel, owing to the fact that vertical loading influences the latter.

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