Skidder Traction Factors

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ABSTRACT

The paper deals with establishing the relationship between the traction factor and different parameters, such as the coefficient of rolling resistance, slip, some kinds of skidder efficiency, as well as other characteristics, and their change in correlation the tractive force and power. The analysis was made skidding different forms of wood: whole trees, tree length, long logs, logs and assortments. The traction factor is an exploitation parameter, the so-called net traction factor. It shows which part of the adhesive loading of a tractor can be used as draught. The general advice may be to perform skidding with minimum resistance but with maximum traction factor value.

Key Words: *Traction Factor, Wood Skidding, Skidder.*

INTRODUCTION

Extraction of wood from the forest by sliding or skidding with one-end-dragging on the ground is used worldwide. In Yugoslavia, Central Europe and USA, rubber-tyred skidders prevail on the logging scene.

The problem of wood extraction has been the least investigated in view of technical exploitation parameters influencing the energy efficiency and economical value of logging as the most expensive phase of forest exploitation. It is primarily associated with some factors that have resulted from the choice and preparation of the tractor for work and with those that are being changed in the course of their usage.

More than other parameters, the line pull resistance has been investigated. It takes place during dragging of wood over the ground (horse skidding, winching), one-end-suspended wood skidding (adapted farm tractors, cable skidders, choker skidders, grapple skidders, clam bunk skidders, etc.), or at forwarding (farm tractors equipped with trailers or semi- trailers, feller-bunchers, forwarders, feller-forwarders and other multi-function machines).

In order to define the characteristics of skidding, different dimensionless numbers are used. Thus, the friction factor at ground wood skidding is defined by $\mu_g = F_H/Q$; the resistance factor at wood skidding with one-end suspended is defined by $\mu_s = F_H/Q_2 = F_H/(Q-F_V) = F_H/(Q-Q_1)$; skidding factor, by $k_s = F_H/Q$; transport draught factor, by $k_t = F_H/Q_{tot}$; gross skidding factor, by $k_{gs} = F_R/Q$, etc. [1] [4] [5] [7] [8] [15] [16] [17] [21]. The list of the physical nomenclature quantities is to be found at the end of the article. For the ratio of the same physical values, the term "factor" has been used; for the ratio of different values, the term "coefficient" has been used .

A forest tractor is a mobile or self-propelled specially designed forestry machine for harvesting, transporting, processing, planting and site preparation for growing timber and wood fibre [25]. The paper goes into detail with the research on one type of cable skidder, the so-called choker skidder, which has within its equipment a one-drum or double-drum winch, a log arch and log-bumper with wheel protection plate, front dozer blade, etc.

In order to evaluate the viability of the cable skidder at wood skidding, an analysis of different technological and technical parameters is used. Technological parameters are, among others, distance, characteristics of the dragged load, skidding speed, tilting angle, output etc. Technical factors are the horizontal and vertical components of the line pull, the factor of loading efficiency, skidding factor, traction factor for semi-suspended wood skidding, net and gross traction factors, utilization of the horizontal component of line pull, etc. Based on theoretical considerations there are seven different technical factors of wood skidding, five of which are dimensionless: skidding with the minimum resistance factor μ_s; the skidding factor κ_s and gross skidding factor κ_{gs} respectively, can be recommended, all by the maximum traction factor κ. For its major part, the paper deals with the traction factor for wood skidding and with its change depending on other exploitation parameters.

THEORETICAL APPROACH & REVIEW

For the purpose of a simple definition of the relation between the pull and adhesion of the driven (powered) wheels, the relation of the two forces has been introduced into the research on tractor performance [2]. Two relations are usually mentioned; the total required force of the driven wheels to overcome the motion resistance and the component of the tractive resistance parallel to the ground— the so-called gross traction factor, and alternatively, the component of the tractive resistance parallel to the ground, both in proportion to the dynamic adhesion of the tyre. The gross and net traction factors, defined in this way and subtracted, presents the factor of motion resistance.

The net traction factor expressed in this way presents the tractive force of the tractor at work, provided that in one-end-suspended skidding it contains in adhesion one part of the skidded load. This parameter is expressed by

$$k=\frac{F_H}{G_D}=\frac{F_p-F_f}{G_D} \tag{1}$$

The net traction factor is sometimes called draught equation [24], traction coefficient [2], coefficient of net traction [6], unit tractive force [12], drawbar pull/dynamic vehicle weight ratio [9], specific tractive force [12], tractive pull/dynamic load ratio values, coefficient of dynamic bond, etc.

The definition of traction in [2] emphasized the fact that the locomotion, trafficability and mobility of vehicle has been, in the course of development, named drawbar-pull and dynamic vehicle weight ratio, as the force at N (newton) by N of vehicle weight. This is only that part of the vehicle's weight considered that takes part in the creation of the tractive force while loading the axles, the so-called adhesive weight. In the case of investigating the cable skidder of the 4-WD type (all four powered wheels), total weight of the skidder and the whole vertical component of the tractive force are adhesion. The parameter κ, the so-called net traction factor can now be interpreted in terms of physiogeometrical characteristics of the given soil-vehicle systems [2]. Thus, for the first time, various values of the traction factor quoted in the technical literature in terms of unspecified soil nomenclature may now be reduced to a numerical relationship between these values and the physically measurable soil parameters. When attempting to improve the off-the-road vehicles such as skidders, one should first analyse how far to go within the existing trends in order to achieve this goal. A similar problem can be found in the decrease of the drag/lift ratio, which is the main objective in any type of locomotion. In automotive language, future progress primarily depends on the increase of the drawbar-pull/weight ratio or on an increase of the factor of traction. Traction factor has not changed for the past decades [2]. From 1924 to 1954, for conventional agricultural and industrial tractors, the factor of the traction has remained enclosed between the narrow limits of 0.75 and 0.95 in the considered soil. The question is, what is happening to the κ in forestry operations, especially in wood skidding?

As described above, the parameter of the traction factor contains the unit component of the skidder main line pull parallel to the ground over which the wood is dragged, per unit of the dynamic load of the axles, well defining the productivity of wood skidding that has a cyclic character [11]. Typical results have been produced from two surfaces [6], highlighting the substantial differences. They expressed graphically the gross coefficient of traction as the sum of the net coefficient of traction and the coefficient of rolling resistance ($\mu=\kappa+f$). That factor is of great importance in maximizing the productivity, optimizing the energy efficiency, and minimizing skidder operating costs.

The dependence of the traction factor on tractor efficiency is determined by introducing into the tractive efficiency a mathematical expression depending on the traction factor $\kappa = F_H/G_D$ (traction pull/dynamic axles load ratio values) and the factor of rolling resistance $f=F_f/G_D$ (motion resistance force/dynamic axles load ratio values for 4-WD tractor). Traction pull efficiency of the tractor's wheel is thus expressed by the traction factor as follows:

$$\eta_w=\frac{F_H}{F_f+F_H}(1-\delta)=\frac{F_H/G_D}{F_f/G_D+F_H/G_D}(1-\delta)= \tag{2}$$
$$=\frac{\kappa}{f+\kappa}(1-\delta)$$

wherefrom the traction factor is

$$\kappa=\frac{\eta_w \cdot f}{1-\delta-\eta_w} \tag{3}$$

Traction factor can be determined by considering the forces that act on the tractor's wheel at skidding, particularly for the driven and non-driven wheels.

Non-driven (unpowered) wheel:

$$F_p = G_w.e / r_d = G_w.f \quad or \qquad (4)$$

$$F_f = G_w.f \quad or \quad F_t = G_w.k$$

The parameter of the traction factor expressed in this way is, in its character, the same as the coefficient or factor of adhesion φ, where in case of f < φ (coefficient of rolling resistance smaller than coefficient of adhesion), rolling will occur. Such multiple meaning of this factor will also be found in studying the non-driven wheels and the torques that act upon them.

Driven (powered) wheel:

$$F_N = .e + F_t.r_d = M_w \qquad (5)$$

$$F_t = M_w / r_d - G_w.e / r_d = F_p - F_f. \qquad (6)$$

The first article of the equation's right side, M_w / r_d, is the drive force on the wheel's periphery, the so-called gross traction. The equation F_t=F_p-F_f is the so-called net traction, wherefromF_t φ . G_w and F_t κ . G_w respectively. The necessary drive force on the wheel periphery is:

$$F_p = G_w.\varphi + G_w.(\varphi + f), \qquad (7)$$

so that for $f \prec \varphi$, it follows that

$$F_p \leq \varphi.G_w.$$

Accordingly, observing the wheel, the net traction is expressed only by the horizontal component of the tractive force parallel to the ground over which the wood is dragged, as the ratio on the adhesive tractor load. It means not the total force on the wheel periphery, which also contains the force for overcoming the rolling resistance, where the rolling resistance force is the difference between the gross traction and net traction.

Many authors showed that the highest values of traction efficiency of a tractor are achieved at low percentages of slippage. Since the usefulness of the tractor depends on the traction factor, this fact is most interesting when dealing with the tractors that are used for wood skidding considering the use of energy due to slippage. The fact that compaction of soil is lower at such lower slippage is interesting to forestry.

The tractive pull/dynamic load ratio values [9] are defined from the rolling resistance test by the following equation:

Net rolling resistance RR_N *= Total recorded rolling resistance between the pulling vehicle and the test skidder* RR_T*- Tractive pull (parallel component with skidding ground)* P_T= $P . \sin\beta$.

These values of the traction factor at skidding are reported in the literature [9]as low; the highest have been established at a slip of 20 %, about 0.12 for dual-tyred skidder on wetland. It is very low compared to the reported values of up to 0.7 in agricultural production. The same paper quotes the definition of the dynamic load on skidder axles as the sum of skidder net weight and the vertical component of line pull, P_T=$P.\cos\beta$.

In parallel research on forestry and agricultural tyres [10], the coefficient of traction as a dimensionless value is used as the parameter for evaluation of tyre characteristics (the coefficient of traction is defined as the ratio of net traction and dynamic load on the tyre).

Investigating the variability sources in the traction data [24], horizontal force at the axle center (called net traction) in ratio with the dynamic load on the axle is used. The authors give the dependences of $\kappa = f(\delta)$ for different inflation pressures, different vertical loads, soil types, slip, etc. For expressing the dependences of the traction factor and slip, the authors use the following type of equation: $\kappa = a\ (1 - e^{-c\delta})$, where *a* and *c* are traction equation coefficients and e the base of the natural logarithm.

OBJECT STUDY & METHODS

Research was carried out on 4-WD choker skidder of permanent power "B" 48 kW and "A" 43 kW respectively, and a mass of 5620 kg (Kockum 821). In order to determine the forces between the tractor and pulling load for the purpose of determining the line pull components, as well as between the wheel and the ground for determination of the gross traction, universal measuring transducers were partly used beside the specially made ones. They were to meet the metrological and dynamic phenomena occurring during skidding. Since all quantities measured during skidding have incidental and temporary features, they were also measured (recorded) exactly in accordance with the time. The measuring equipment enabled measuring of the mechanical values by means of electricity. Fig. 1 is a schematic presentation of the measuring system.

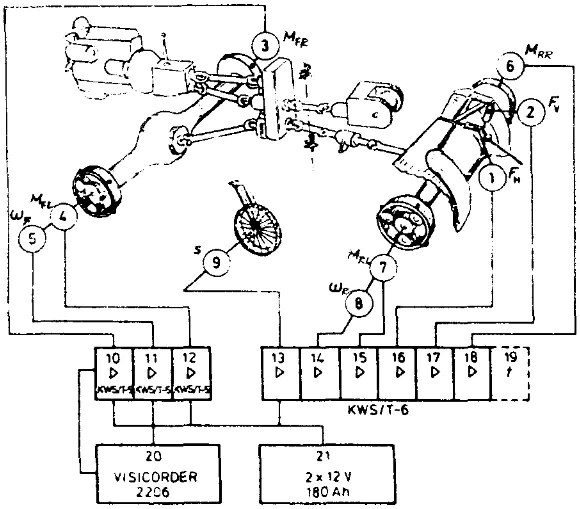

Fig. 1. Schematic review of the measuring accessories: 1- Force measuring transducers FH; 2 - Force measuring transducers FV; 3 - Torque measuring transducer MFR; 4 - Torque measuring transducers MFL; 5 - Angular velocity of the front axle wF; 6 - Torque measuring transducer MRR; 7 - Torque measuring transducer MRL; 8 - Angular velocity of the rear axle WR; 9 - Track measuring transducers; From 10 to 18 - Amplifiers; 19 - Time basis oscillator; 20 - Recorder; 21 - Electric power supply.

Investigations were carried out on wood skidding over a flat strip road. The hauled timber consisted of whole trees, tree-lengths, long logs, logs and mine spruce timber, with differently lifted ends (butt or top-end foremost). The investigation of soil characteristics and the soil conditions indicate that the soil of the skid trail on which the skidding was performed, was homogeneous. The grain size composition of the soil shows that it was loam coming near to dusty loam. The average soil moisture contents on a dry weight basis were 48 percent. The homogeneity of the soil was confirmed by penetrometric tests and the mean value of the marginal compaction force of 104 N [3].

All experiments were carried out at constant tyre inflation pressure (f/r - 1.2/1.4 bar; 16,9x30/14 PR).

RESULTS & DISCUSSION

In investigating wood skidding, special attention was paid to the influence of the choker line pull on the dynamic axle load and to the change of the traction factor. The net weight of the 4-WD cable skidder as a constant value was added to the changing value of the vertical load for the purpose of determining the adhesive load.

Fig. 2 and 3 show the regression equation of net traction and tractive power on the traction factor. The correlation between the net traction and traction factor is very strong. Straight line equation produces the coefficient of correlation $r = 0.9981$, and the second degree polynomial gives the correlation index $R = 0.9986$, which is normally low, since the traction factor is also, by definition, proportional to the tractive force, i.e. to its component which is parallel to the ground over which wood is dragged.

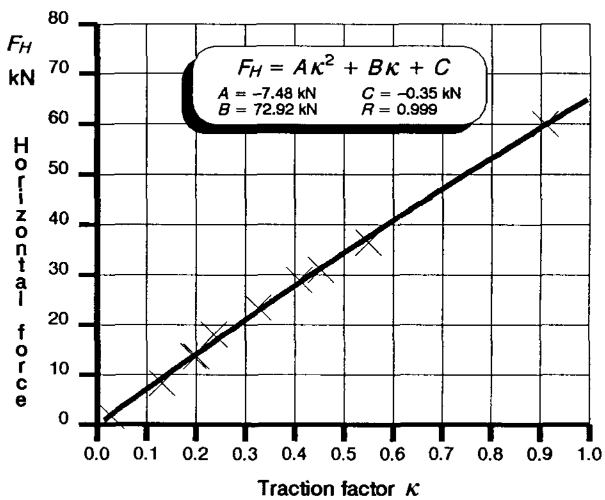

Fig. 2 Relationship between net traction and traction factor

A slightly better approximation by a second degree polynomial can be explain with impact of the vertical force of traction resistance on changing the adhesive load of tractor. Correlation index $R = 0.82$ was determined for the dependence between the tractive force and traction factor based on all test pairs (263), while the equalization was performed by means of the general type of curve $P_H = A \cdot \kappa^B + C$, with the obligatory condition that $C = 0$ (curve passing through the starting point of the coordinate system). By introducing the traction power, skidding speed was also considered, which contributed to data scattering, particularly at higher values of the traction factor, the highest being only 0.32. Fig. 2

shows four pairs of values for the traction factor higher than 0.32, referring to skidding of whole trees, which is not performed at regular exploitation, but for the purpose of skidding experiment at high slip percentage (over 40 %). For slippage up to 40 %, traction factor reached only about 0.3 values. The examination results obtained show that skidders are more convenient for stem and long logs skidding than for assortment skidding.

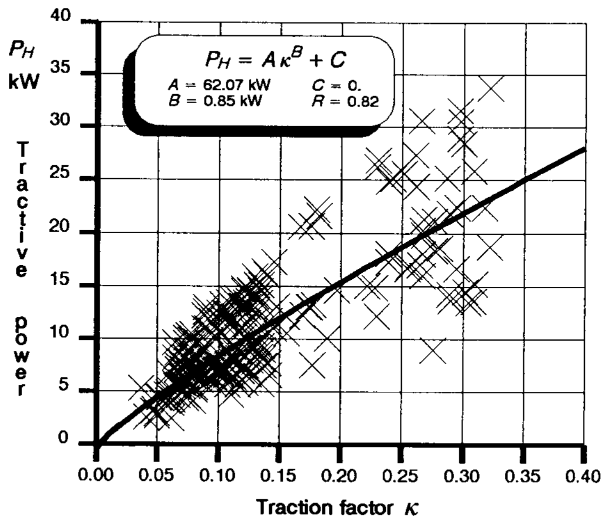

Fig. 3 Relationship between tractive power and traction factor

The small traction factor obtained during skidding can be explained by this tractor's large mass (the unit mass of the skidder is between 80 and 110 kg/kW).

Furthermore, the correlation between the net tractive power and the vertical choker line pull shows that it is impossible to influence the increase of the vertical component of the tractive force with small-sized assortment; consequently, the adhesion and the drawbar power cannot be influenced either.

The analysis of the relationship between the tractor's adhesive load and the line pull force shows that the unloaded skidder's unit weight of 100 kg/kW increases while skidding up to 140 kg/kW [22]. That means an increase of the axle load by about 28 % performed in an extreme case.

Fig. 4 shows the results of the regression analysis of the dependence between the traction factor and slip. Among others, slippage involves loss of skidding speed. The result shown in Fig. 4 refers to 84 data pairs with the established correlation index $R = 0.3294$. At the equation by regression curve of the type $\kappa = A \,.\, \delta^B$ marginal value of the traction factor for all data was established at 0.25. In addition, statistical calculation of all data was carried out. Separate groups belonging to one class were made by testing the pairs of the traction factor/slip for the skidding of trees, trunks, long longs, logs, mine timber, etc., and then equalized with the polynomial of the second degree.

All values (208) of the test, regardless of the class, were regressed with the curve type $\kappa = A\,[1 + (B/^{\delta})^{-1/2}]$. The asymptotic value of the traction factor of 0.195 was established with the correlation index $R = 0.394$. In both cases the steep rise of the curve shows that the soil has poor capability to take over the wheel forces. All established statistical links range between poor and medium [23].

The traction factor defined in this way is called the exploitation factor of adhesive weight [12]. According to this, the dependence of the traction factor upon slip can be used to evaluate the traction characteristics of a skidder, which has been reported by other authors [13] [14]. It has also been reported that 4-WD tractors with the same wheel diameters as those of, say, cable skidders, yield higher traction factors than the tractors with different wheel diameters such as the adapted agricultural tractors used in forestry. Another author [18] gives results of investigations on the traction factor for 4-WD tractors of the same wheel diameter; at a slip between 17 and 18 %, a traction factor of about 0.4 was achieved. The

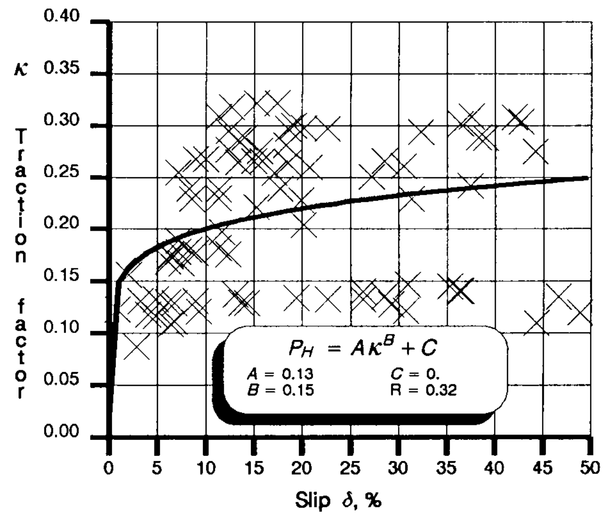

Fig. 4. Relationship between traction factor and slip

low traction factor of special forest tractors is explained by the formerly discussed fact that they have a big mass (big unit mass), and by the conditions of the soil during the experiment (work during wintertime). It is common knowledge [22] that the effective power of the driving engine is proportional to the tractor's mass. One kilogram of the skidder mass bears a considerably lower amount of the unit power of the driving engine, which does not necessarily mean that they are less perfect in their construction than, say, agricultural tractors, but indicates harder working conditions of the skidders.

The research on the traction factor and motion resistance was carried out by looking for the dependence factors of traction upon the coefficient of rolling resistance, Fig. 5. The regression curve refers to all data for all classes of the established skidding methods with 263 samples (whole trees, logs, industrial timber, etc.). The increase in the rolling resistance coefficient causes a decrease of the traction factor, which was established for each class separately [21]. This was logically concluded from the basic dependence of the gross and net traction factor ($\kappa = \mu - f$)

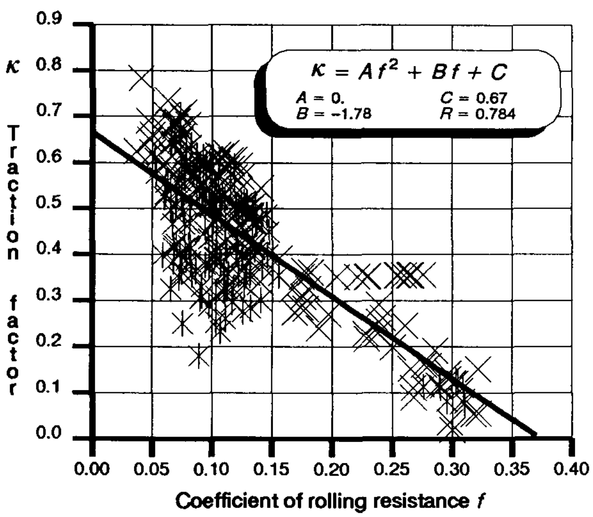

Fig. 5. Relationship between traction factor and coefficient of rolling resistance

There are different ways for determining the rolling resistance coefficient. Since the research was based on energy measurings of wheel torques, this parameter for this experiment was established from the dependence $f = 1 - \eta f$. Another approach is also possible, the determination being carried out by skidding experiments to establish the tractor's weight [9] $f = F_f / G$. The rolling resistance coefficient values established in this way need not be mixed, since they have been determined by different methods. Traction factor as a dependent variable was likewise investigated for the purpose of studying the dependence of different kind of efficiency's, Fig. 6, 7 and 8. The dependence of the efficiency of rolling resistance on the traction factor indicates an increase of the efficiency following the increase of the traction factor (Fig. 6), which implies the requirement to use

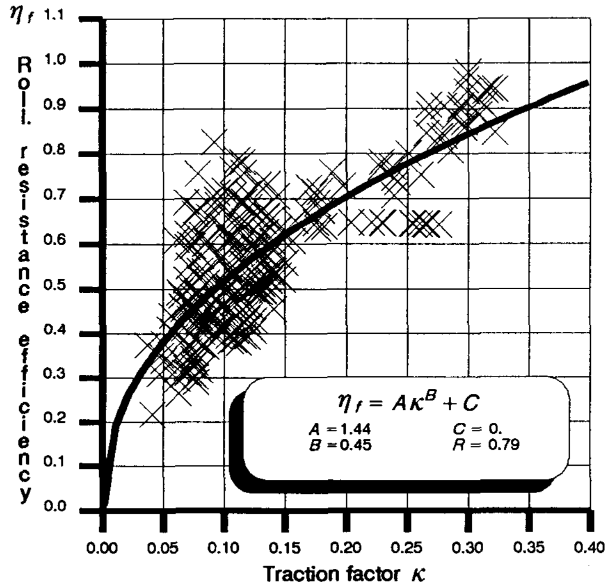

Fig. 6. Dependence of the efficiency of rolling resistance and traction factor

the highest possible traction factor in wood skidding too. The result refers to the sample of 263 pairs, the correlation index being established R = 0.7963. The dependence of slip efficiency ($\eta\delta = 1 - \delta$) on the traction factor indicates its decrease following the increase of the traction factor (Fig. 7). The same trend was seen by straight line equalization together with the fact that the correlation coefficient is significantly bigger than0.18, at an error probability 0.05 (number of pairs 264).

The complex parameter of wheel efficiency $\eta_w = \eta f . \eta\delta$ as the product of slippage efficiency and rolling resistance, depending on a stronger influence for the studied skidding, has shown an increase of the wheel efficiency following the increase traction factor (Fig. 8). An increase of the rolling resistance efficiency in relation to the decrease of the slip efficiency is obviously higher.

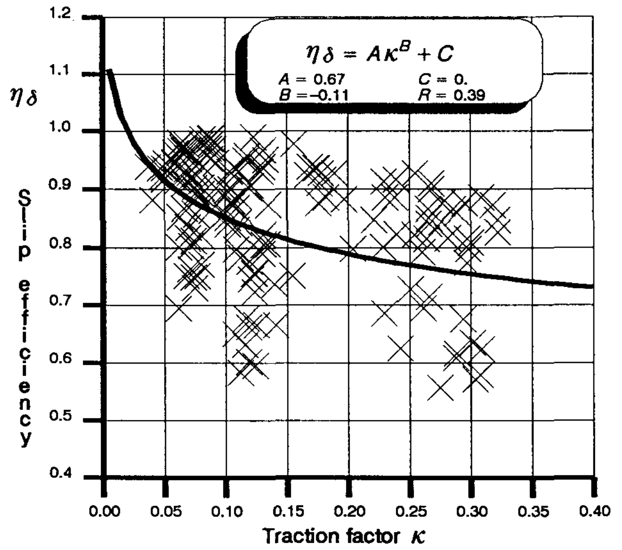

Fig. 7. Dependence of the slip efficiency and traction factor

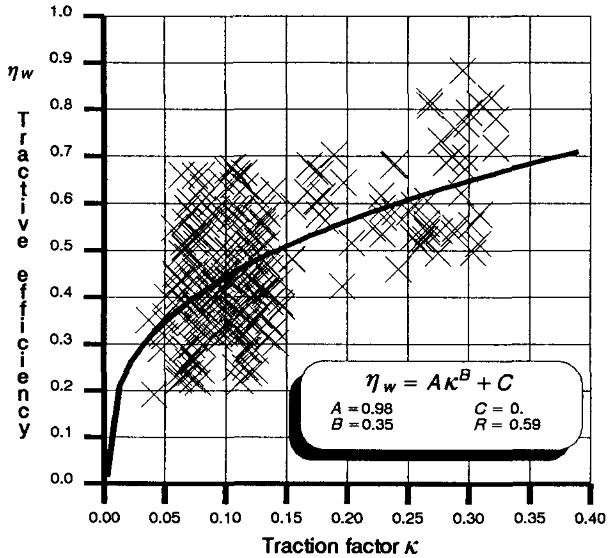

Fig. 8. Dependence of the wheel efficiency and traction factor

CONCLUSIONS

The established low values of traction factor in the operations of wood skidding indicate that the tractive power efficiency of the cable skidder tyres might be very low.

The examples of the established regressions show that the traction factor is an important exploitation parameter that well describes the phenomena of skidding by special forest tractors. Depending on other factors, the traction factor can serve for certain efficiencies of working methods by certain skidder types and categories, on the grounds of certain characteristics and given forms and properties of wood to be skidded.

The traction factor also contains the choker line pull force and adhesive load as a feature of the tractor and its load, as well as of the reception of the load by the tractor; therefore it well describes both the properties of the tractor and resistances during wood skidding.

Under real conditions of wood skidding, butt end foremost means an increase of the adhesive load due to bigger vertical component of line pull, and thereby a decrease of the line pull, i.e. its horizontal component, which is proportional to the traction factor. This indicates that the real traction factor during wood skidding is the result of two influences; a smaller or bigger line pull, and a bigger or smaller vertical load and its contribution to creation of the resulting adhesive load. Which of the two influences in the observed case will prevail, will create a bigger or smaller realized traction factor. The examples of such opposite actions on the individual parameters are frequent in the field of wood skidding. At marginal slip achieved in all tests up to 40 %, a traction factor of 0.32 was established. This indicates that cable skidding is more suitable for the skidding of stems and long logs rather than of assortments or small-size wood.

The small established traction factors of skidders can be explained by their big mass, i.e. its unit mass per 1 kW of the driving motor power. An increase of the rolling resistance coefficient is proportional to the decrease of the traction factor.

Generally, according to the investigation of several parameters, wood skidding at minimum traction resistance and maximum traction factor can be recommended, as it will result in a higher efficiency of the energy use.

NOMENCLATURE

κ	Traction factor, F_H/G_d
μ	Gross factor of traction, M_w/r_d
Q	Gross skidding load weight
Q_1	Part of wood vertical load transfer on skidder
Q_2	Part of wood vertical load transfer on ground
$Q_{tot.}$	Load and transport device weight
G_w	Part of weight on wheel $G_w=F_N$, (equal to normal soil reaction on the wheel)
$G_{adh.}$	Adhesive weight of tractor, $G_{adh.} = G_{tractor} + F_V$
G_D	Dynamic weight on 4-WD skidder axles (changeable F_H and F_V)
F_s	Resistance at wood skidding
F_H	Horizontal component of drawbar-pull
F_V	Vertical component of drawbar-pull
F_R	Choker main line pull (resultant force), $(F_j^2 + F_V^2)^{1/2}$
F_f	Rolling resistance force
F_N	Normal soil reaction $F_N = G_w$
F_p	Peripheral force of tractor wheel, $F_p = F_H + F_f$
F_T	Tangential force ($F_T = F_H$)
M_w	Torque of driven wheel
P_H	Horizontal acting power
φ	Coefficient of longitudinal friction between the wheel and soil
μ_g	Friction factor of ground wood skidding
μ_s	Friction factor of wood skidding with one-end suspended
κ_s	Skidding factor
κ_t	Transport draught factor
κ_{gs}	Gross skidding factor
f	Coefficient of rolling resistance
δ	Slip
ηw	Wheel efficiency, $\eta_w = \eta_f . = \eta_d$
ηf	Efficiency of rolling resistance, $\eta_f = 1\text{-}f$
$\eta\delta$	Slip efficiency, $v\delta = 1\text{-}\delta$
r_d	Dynamic radius of tyre
e	Ground reaction distance of F_N
β	Angle of the choker line pull with the

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