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Relation between terrain and operating conditions of forest skidders

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ABSTRACT: A model of the probability of operating conditions describes running of the examined unit in form of connected probabilities of occurrence of monitored operating factors can be stochastically dependent or independent. Operating factors will be divided, in order to the opportunity of the monitoring, on the quantification of the probability model of the forest skidder, into two parts: terrain conditions (micro and macrorelief of the terrain) and operating conditions (a line of operation, a load, a distance). In this paper opportunities are sought of the relationship between terrain conditions and operating conditions in the defined signification. A field of the application is in a monitoring of operating conditions, planning and organisation of the experiment, in this field.

Keywords: probability model; traction force; engine power; tyre characteristics

A probability model of operating conditions describes the operation of an examined machine in the form of conjugated occurrence probabilities of particular operation factors. Operation factors can be either stochastic dependent or independent.

While quantifying the probability model of a skidder operation, the operation factors are due to the examination of possibilities divided (Mikleš et al. 2010) into two categories: terrain conditions (terrain micro-and macroprofile), operating conditions in a narrower sense (operation period, load, distance).

A probability model of operating conditions is to be deduced from the following discussion. Let the operation factors $x_1, x_2, \dots, x_n$ describing operating conditions be random/arbitrary functions of the argument l and the operation of the machine be the simultaneous realisation of these factors. Then the effect that "the machine is situated" (works) in the j^{th} operating conditions is equivalent to the effect when the operating conditions are equivalent to the effect when the operation factors $x_1, x_2, \dots, x_n$ are from n-dimensional space D_j. The worded relation can be in the form of probability written as follows: P (operating conditions are in the state j) = $P\,\{(x_1, x_2, \dots, x_n) \subset D_j\} = \iint \dots \int f(x_1, x_2, \dots, x_n)\, dx_1, dx_2 \dots, dx_n (D_j)$

In this expression $f(x_1, x_2, \dots, x_n)$ means the conjugated probability density of the random vector $(x_{1,} x_2 \dots, x_n)$.

Becoming acquainted with the description of the probability model of operating conditions of the actual operation (whether in the form of the complete description of the law of probability distributions, or only in the form of its several characteristics), the term "hypothetical unit of operation duration" can be quantified as an alternative of operating conditions of the actual operation for frame durability adjustment and demonstration purposes.

Let us define a hypothetical unit of the machine operation duration represented by the "matrix" (1):

$$I_b \sim \begin{vmatrix} v_1 & v_2 & \dots & v_j & \dots & v_q \\ x_{11} & x_{12} & \dots & x_{1j} & \dots & x_{1q} \\ x_{21} & x_{22} & \dots & x_{2j} & \dots & x_{x_{2q}} \\ x_{i1} & x_{i2} & \dots & x_{ij} & \dots & x_{iq} \\ x_{n1} & x_{n2} & \dots & x_{nj} & \dots & x_{nq} \end{vmatrix} \qquad (1)$$

is such a sample (made on the basis of the knowledge of appropriate description of the law of their distribution) of the operation factors $(x_{1j}, x_{2j} \dots, x_{nj})$ and with them corresponding occurrence probabilities v_j, $j = 1, 2 \dots, q$, that with its utilisation the counted adjustment of technical life $L_{vyp} = \lambda \times l_b$ will with the probability approaching one either equal to the technical life of the actual operation under the operating conditions, or for the durability demonstration the extent of damage after the examination duration $L_{sk} = \lambda \times l_b$ with the probability approaching one will equal to the extent of damage of the actual operation under the operating conditions and during the same operation period.

MATERIAL AND METHODS

Terrain macroprofile. The terrain macroprofile, particularly represented by its grade, has an influence primarily on the level (it is the "source" of load, mainly its quasi-static central part) of engine, transmissions and undercarriage load, i.e. the load of those parts of the machine that are the sources of energy and that transmit energy from the source to the contact place of the machine with the ground (Bauer, Sedlák 2000; Grečenko 2003; Prikner, Grečenko 2007; Wong 2010)

The influence of the grade on the outer performance of the machine, its traction performance (Eq. 2):

$$PH = FH \times v/3.6 \quad (2)$$

can be conveniently pursued through its tractive characteristic.

Under the tractive characteristic (Grečenko 1978, 1980; Mikleš, Holík 2005) it is understood the plotted relation (observed or computed) between the traction performance *PH* (kW), operation speed v (km·h^{-1}), hourly fuel consumption *MP* (kg·h^{-1}), specific full consumption mH (g·kW^{-1}·h^{-1}) and slip *d* of the tractive force *FH* (kN) for all speed gears $i = 1, 2, ..., n$, i.e. a group of relations: *PH*; *v*; *MP*; *mH*; $\delta = f(FH)$.

The tractive force *FH* designates the component of the resulting tractive power F in the direction of the tractor movement (in the case of the movement on a plain – a horizontal component, in the case of downhill drive – a component parallel with the slope grade).

The complete computed tractive characteristic can be constructed if the following characteristics are known: (*i*) the course of slip in relation to the tractive power *FH*, (*ii*) speed characteristic of the engine with regulator, i.e. the relation: Per, Mekr, $m_{epr} = f(n)$ $P_j = \sup\{Per(n)\}$ (Grečenko 1978), (*iii*) complex transmissions for particular speed gears, effective radius r_h (m) of driving wheels, tractor gravity G (kN), mechanical efficiency m_t, rolling coefficient f and aggregate structure represented by the angle of the resulting tractive force inclination from the direction of the tractor movement (angle α).

In the tractive characteristic it is possible to follow the influence of slope grade and ground type on tractive qualities of a tractor (Kristek1977; Calek, Schwanghart 1998; Bauer, Sedlák 2000).

It can be stated that: (*i*) in a number of works, the coefficient of tyre adhesion utilisation has been proved not to change a lot in a wide range of tyre radial load, (*ii*) if the course of the relation $\delta = f(\mu)$ or $\mu = f(\delta)$ of a particular tractor on a plain is known and this relation is presumed not to change substantially with the change of the driving axial load, the course of tractor skidding during the slope movement can be relatively precisely determined, (*iii*) theoretical solutions and practical experiments proved the tension qualities of a tractor on a slope (in the direction of slope grade as well as of contour line) to be determined on the basis of the knowledge of its tension characteristics on a plain with sufficient accuracy, (*iv*) tractor traction performance on the slope declines ca 2 to 6% per one slope grade.

Based on the above-mentioned facts, the tractive characteristics of the skidder LKT 81 moving in the direction of the slope grade were computed for standardized conditions. Chosen results of the calculation are in Fig. 1 and Table 1.

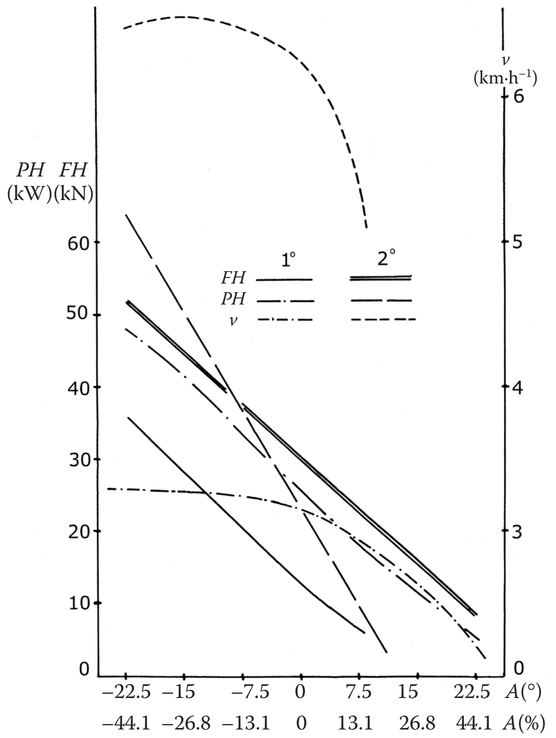

Fig. 1. Dependence of the traction performance *PH*; tractive power on the hook *FH* and speed *v* on the angle of ground climb (LKT 81, Ss 2, T = 30°, downhill drive)

Table 1. Maximal values of traction performance and responding values of tractive power on the hook and speed depending on the angle of ground climb and the type of ground (LKT 81, downhill drive, angle of power in the rope T = 30°)

A (°)	A (%)	PH max (kW)	v for PH max (km·h^{-1})	FH for PH max (kN)
Ss[1] 2 – compact topsoil (Grečenko 1978)				
i_1 = 150				
22.5	41.4	5.03	2.18	8.21
15.0	26.8	11.36	2.65	15.42
7.5	13.1	18.11	2.91	22.42
0	0	25.69	3.19	29.01
–7.5	–13.1	33.22	3.24	36.88
–15.0	–26.8	40.71	3.27	44.74
–22.5	–41.4	47.99	3.29	52.46
i_2 = 81.77				
22.5	41.4	IEP	–	–
15.0	26.8	IEP	–	–
7.5	13.1	9.63	5.25	6.60
0	0	22.45	6.35	12.73
–7.5	–13.1	36.65	6.46	20.42
–15.0	–26.8	50.93	6.57	28.28
–22.5	–41.4	64.95	6.49	96.00
Ss[3] 3 – concrete, asphalt (Grečenko 1978)				
i_1 = 150				
30.0	57.6	7.02	2.69	9.39
22.5	41.4	13.18	3.24	14.63
15.0	26.8	20.50	3.29	22.41
7.5	13.1	28.54	3.53	29.09
0	0	36.92	3.59	36.99
i_2= 81.77				
30.0	57.6	IEP	–	–
22.5	41.4	IEP	–	–
15.0	26.8	8.06	5.41	5.36
7.5	13.1	21.43	6.27	12.30
0	0	36.73	6.75	19.59
i_3 = 49.72				
30.0	57.6	IEP	–	–
22.5	41.4	IEP	–	–
15.0	26.8	IEP	–	–
7.5	13.1	11.19	9.30	4.33
0	0	35.58	11.22	11.41

A – angle of ground climb, *PH* max – maximal engine traction performance for particular speed gear *v* and *PH* max, or *FH* for *PH* max. – running speed, or tractive power on the rope for *PH* max, Ss^{1-3}– standard surface, i_{1-3} – speed gear, IEP – insufficient engine power

Terrain microprofile. Deriving from the facts that: (*i*) from the point of the relation between terrain and vehicle the microprofile is defined as a group of ground roughnesses that cause vibrations, (*ii*) from the deformation aspect the tyre that is of the lowest stiffness is that tyre which is simultaneously at the same time the member of the part where the largest amount of mechanical energy of terrain vibrations is being changed into thermal energy, the influence of the terrain microprofile can be examined as the relation of power losses in a tyre to the dimensions of ground roughness.

RESULTS

A particular machine – LKT 81 skidder is going to be examined (Andert 1983). First, some necessary tyre characteristics will be inspected.

Since no load characteristics of the tyres of LKT 81 have been measured so far, their parameters will be determined from available catalogue data. Thus, we will utilise the measured geometric characteristics of the 16,9/14-30 tyre of Czech production and catalogue values of the same type of tyre manufactured by the DUNLOP firms that are listed in Table 2.

Table 2. Chosen parameters of the 16.9/14-30 tyre

Manufacturer	Pressure (MPa)	*D* (m)	R_s (m)	*B* (m)	*T* (N)	H_b (m)
Barum	0.196	1.4753	0.6742	0.416	20,643	0.326
Dunlop	0.196133	1.4732	0.6604	0.4292	24,222	0.325

D – maximal tyre diameter, R_s – static tyre radius (st static load), *B* – tyre width, *T* – tyre load (load capacity), H_b – tyre height (spacing between the rim and the outer perimeter)

In the the text the following symbols are used:

- D – maximal tyre diameter (m),
- R_s – static tyre radius (radius at static load) (m),
- B – tyre width (m),
- T – tyre load (N),
- h_o – maximal vibration amplitude (m),
- H_b – tyre height (spacing between the rim and the outer perimeter) (m),
- ω_0 – angular frequency (rads^{-1}),
- c – radial tyre stiffness (N·m^{-1}),
- k – coefficient of tyre damping (N·sm^{-1}),
- K – radial stiffness of the system (N·m^{-1}),
- Ss[1] – standard surface.

These values were computed: $c = 0.3697·10^5$ (N·m^{-1}), $K = 5.2155·10^4$ (N·m^{-1}), $\omega_0 = 13.2547$ (rads^{-1}), $k = 3.936·10^3$ (N·sm^{-1})

The next step after the examination of the tyre characteristics is to determine the power "lost" in the tyre during the movement on terrain roughnesses. For harmonic mass movement on the elastic face for forces oscillation of frequency v_0 the relation for the deformation h (compression) is Eq. (3):

Table 3. Values of absorbed power in one (N_1) and four ($N_Σ$) tyres depending on the height of unevenness (h_0)

	h_0 (m)		
	0.03	0.05	0.0762
N_1 (kW)	0.311	0.864	2.006
$N_Σ$ (kW)	1.244	3.455	8.025

$$h = (t) = h_0 \sin\omega_0 t \quad (3)$$

Damping force T_{tl} for viscous damping is given by Eq. (4):

$$T_{tl} = k dh/dt = h_0 \omega_0 \cos\omega_0 t \quad (4)$$

Work per period L_p and power N is to be expressed by Eq. (5–7):

$$L_p = \int_0^T T_{tl}\, dh = \int_0^T k\omega_o^2 h_o^2 \cos^2 \omega_o t dt \quad (5)$$

$$N_1 = L_p/T = \frac{1}{T}\int_0^T k\omega_o^2 h_o^2 \cos^2 \omega_o t dt \quad (6)$$

where:

$T = 2\pi/\omega_0$

After integration:

$$N_1 = k\omega_o^2 h_o^2/2 = K\omega_o h_o^2/2 \quad (7)$$

The results of the calculation for values h_0 = 3; 5; 7.62 (cm) are written in Table 3. The value h_0 = 7.62 (cm) corresponds with the state when the wheel rebounds from the ground. For four tyres the total lost power is derived from Eq. (8):

$$N_ε = 4N_1 \quad (8)$$

From Table 3 the following conclusions were drawn: (*i*) the absolute value of lost power is small in comparison with tractor power, (*ii*) although relative differences in the values of lost power during movement through various roughnessses are significant, their importance is smaller in comparison with the machine engine power, and thus, also their difference is negligible in that case since there will be no possibility for it to come out.

On the basis of the above facts it can be stated, at least at first sight, that the influence of terrain of microprofile on machine power losses is of little importance, practically negligible.

DISCUSSION

The submitted results do not naturally have the universal validity, or the scope of their validity is restricted. Applicability of the results is restricted at least from three points of view: definitional, statistical, and from the viewpoint of practical realization of required experiments in operation.

A probabilistic model of operating conditions results from the possibilities of description of the processes [levels of processes] and conditions in which they are taking place. Therefore we understand the definitional restriction of the results: the processes depend on the type of machine, conditions of technology, and place of operation; among the conditions, it is necessary to include also the size of the machine (Mikleš, Holík 2010). Statistical restriction is understood as the 'reliability' (accuracy) of results, depending primarily on the amount (number) of results.

Restriction from the viewpoint of practical possibility of realization of required experiments in operation is connected with the necessity to reduce the number of input operation factors in a probabilistic model (Wong 2010).

In assessment of the possibilities of data transmission about the terrain microprofile, it is necessary to investigate the time constancy [variability] of information. In the course of time the microprofile of forest roads is exposed to the action of various natural, as well as technical influences [traffic of mobile machines] (Grečenko 1978).

From the practical point of view, it is possible to consider 'operational' and 'terrain' conditions in the defined sense as stochastic independent conditions.

CONCLUSIONS

The complex description of a probabilistic model of working conditions is so much complicated that it is not possible to realise globally. The size of the experiment therein seem could be technical unbearable.

Based on the consideration of power loss at repression of macro and micro terrain and following the literature data, from those that depicted the influence of various factors on labour productivity of forest pullers it may be stated:

– definitive hold on operating conditions has section of action,
– micro and macro road surface bumps are factors that only little affect operating conditions,
– from the practical point of view it is possible to consider working and terrain conditions as stochastic independent parameters,
– terrain conditions do not affect operating conditions of the machine, but as a part of working conditions they influence the machine and its parts replaying.

The main task remains research on a dependence between particular working factors, and/or their groups, especially research on reciprocal dependences between working and terrain conditions.

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