PERIODIC DRAFT TILLAGE FORCES IN SOIL WORKING PROCESSES OF AGRICULTURAL EQUIPMENT

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ABSTRACT

The article presents results of the mathematical modelling of the tensile strength for equipment for opening and compartmentalizing watering furrows. This agricultural machine develops a less common traction force, with two components, one of which with oscillates behavior. The mathematical model given in the paper provides calculation formulas for the static component and for the dynamic component. Model constants are used to calibrate the model using existing experimental data for this type of machine. The paper it is specified the dynamics problems of agricultural machines in which such models are needed.

Keywords: *draft force, mathematical model, agricultural equipment*

INTRODUCTION

The tensile strength of an agricultural machine is the main component for estimating the traction power required to operate it. Knowing this is important for choosing a tractor, for estimating working speed and fuel consumption, for estimating productivity, and for improving and even optimizing the working regime.

Theoretical modelling of the tensile strength is possible through engineering intuition and assumptions that are made about a car in the design and design stage. When the machine is already made and tested, these models can be calibrated using available model constants and experimental data. Finally, theoretical-empirical formulas are obtained that can be used for the purposes listed above, for various types of soils, working regimes, and even different power sources to which the equipment can be coupled, of course taking into account the quality requirements of soil processing.

In the literature, we do not know an approach to the problem of mathematical modelling of the draft soil tillage force, for the equipment such as the one that is the subject of our research.

MATERIAL AND METHOD

The subject (material) of this research is the equipment of open and compartmentalized irrigation canals (EOCIC), [1]. The EOCIC equipment was tested for the choice of a mathematical model of the tensile strength, and we used experimental data to calibrate the model. The main component of the tensile strength is generated by the interaction with the ground of the working member called lister or double mouldboard.

The blade that gives the final shape of the irrigation channel generates a secondary component that has values below 20% of the maximum value of the lister resistance force. In addition to the two components I wrote about above, there is also a component given by the friction with the ground of the driving wheel of the blade drive mechanism and the friction component of the ground rolling of the working depth limiting wheels.

We have neglected these forces or we will include them in the friction component of the lister resistance force, as we do not study the equilibrium of the structure in relation to the distribution of the load forces in this research. The main parameters of the model, notations, and units of measurement are listed in table 1.

Table 1. *Parameters of the interaction process between soil and the EOCIC: notations, significance, and units of measure.*

Notation	Name	Unit
m	EOCIC mass	kg
m_p	Pallet with actuating mechanism mass	kg
R_l	Draft force generated by the lister	N
R_b	Draft force generated by the blade	N
R_T	The total draft force	N
v	Working speed	m/s
b	Lister working width	m
a	Lister working depth	m
k	Coefficient that characterizes specific soil deformation resistance	MPa
ε	Coefficient which depends on the shape of the active surface of the body and the soil properties	kg/m^3
f	Coefficient analogous to friction coefficient	-
G	EOCIC weight	N
g	Gravitational acceleration	m/s^2
ρ	Soil mass density	kg/m^3
c_r	EOCIC mass distribution coefficient on the lister	-
B_d	The length of the small base of the blade	m
B_b	The length of the large base of the blade	m

Notation	Name	Unit
H_d	The height of the projection of the blade on the normal plane at the direction of travel	m
L	Average length of open channel	m
φ	Frequency of the draft soil tillage force function generated by the blade	Hz

The method of designing the model by choosing suitable models is the one described in [2]. Taking into account the specified method, a Goriacikin type formula is proposed for the tensile strength generated by the lister, [3-14]:

$$R_l(a,b,v) = f \cdot c_r \cdot m + k \cdot a \cdot b + \varepsilon \cdot a \cdot b \cdot v^2 \quad (1)$$

The resistance force generated by the blade is an approximately time-periodic component of the total resistance force. The hypothesis which we use for modelling this component considers the amplitude is given by a Goriacikin type product with coefficients similar to the force R_l, reduced accordingly taking into account that the soil that the pallet encounters in the open channel is partially disaggregated, so easier.

The area of the contact surface of the pallet with the ground is the area of the intersection surfaces between the lister open channel section and the surface of the blade projected on the normal plane at the forward direction, A_p. If the section of the channel opened by the lister is larger than the area of the projection of the blade on the plane normal to the forward direction, then function A_p is zero.

$$A_p(a,b) = \begin{cases} \frac{(B_d + B_b)H_d}{2} - ab, if \frac{(B_d + B_b)H_d}{2} - ab \geq 0 \\ 0, if \frac{(B_d + B_b)H_d}{2} - ab < 0 \end{cases} \quad (2)$$

By hypothesis, in the absence of an exact kinematic study and taking into account the random character of the soil parameters, more pronounced the harder and less humid the soil, the periodic component is modelled as a triangular signal approximated by Fourier series corresponding with the frequency given by the report between the length of the channel and working speed:

$$\varphi = \frac{v}{L} \quad (3)$$

In these conditions (hypotheses) the force generated by the action of the blade receives the expression:

$$R_b(a,b,v,t) = f \cdot g \cdot m_p + \left(k_1 + \varepsilon_1 v^2\right) A_p(a,b) \Theta(v,t) \, . \quad (4)$$

where the function Θ (t) is a Fourier, [13, 14], series approximation for the ideal working rate of the palette:

$$\Theta(v,t) = 0.5 - \frac{1}{\pi}\sum_{j=1}^{\infty}\left\{(-1)^j \frac{\sin\left[j\cdot\frac{2\pi v}{L}\cdot\left(t+0.53\frac{L}{v}\right)\right]}{j}\right\} \quad (5)$$

For the numerical calculation, in formula (5) the amount was limited to 50 terms. It is considered a constant working speed, v, and then the space covered by the aggregate will be:

$$s(v,t) = v \cdot t \quad (6)$$

Function (6) is used to control the tensile strength in relation to space travelled.

RESULTS

The mathematical model (1) - (6) of the resistance forces developed in the working process by EOCIC, allows the mathematical modelling of the experimental results and, in case the model will be validated, its extension also in other environmental conditions. Next, for a deeper understanding, some graphical representations of the model behavior are given for the following values of the modelling parameters: m= 110 kg, m_p= 5 kg, g= 9.81 ms^{-2}, c_r= 0.4, ρ= 1100 kgm^{-3}, k= 70000 Pa, ε= 2000 kgm^{-3}, B_d= 0.2 m, B_b= 0.4 m, H_d= 0.1 m, L= 2.8 m, v= 0.85 ms^{-1} (3.06 km per hour).

With the numerical data above and those specified in part for each of the graphical representations in Figures 1-5, the variation in time and space of the total tensile strength and its components is still represented. The time and space (separately) dependence of the total draft tillage force of EOCIC, is represented graphically in fig. 1 and 2.

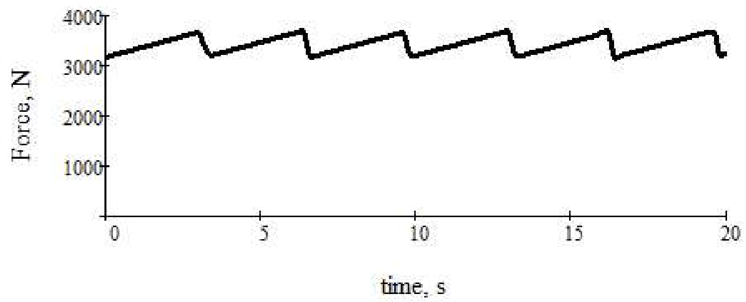

Fig. 1. *Time variation of the total tensile strength of EOCIC.*

For the working speed and the length of the channel, specified above, a frequency of the draft tillage force generated by the blade is obtained, with the value 0.304 Hz, respectively the period with the value 3.294 s. The six complete cycles in 20 s are observed (figure 1 and 4) or in approximately 17 m travelled in work.

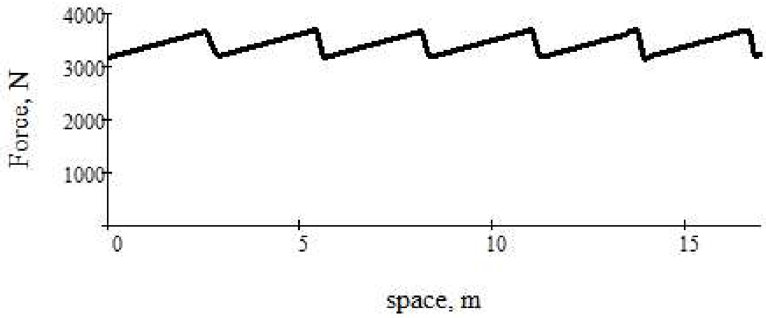

Fig. 2. *Space dependence of the total draft tillage force generated by EOCIC in the working process.*

Figure 3 graphically represents the variation of the draft soil tillage force generated by the blade, in relation to the space travelled by the aggregate. Figure 4 compares the variation of the total tensile strength and its components, in relation to time.

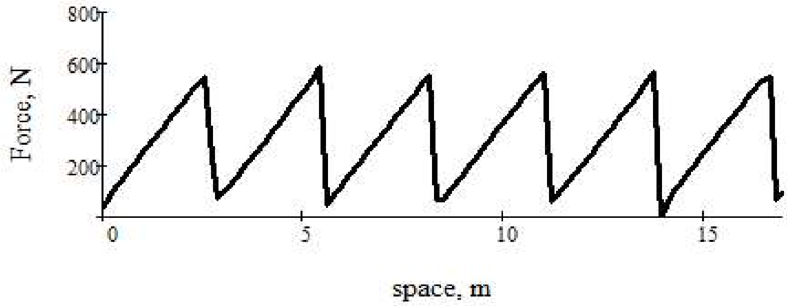

Fig. 3. *Space dependence of the draft soil tillage force generates by the EOCIC blade, in the working process.*

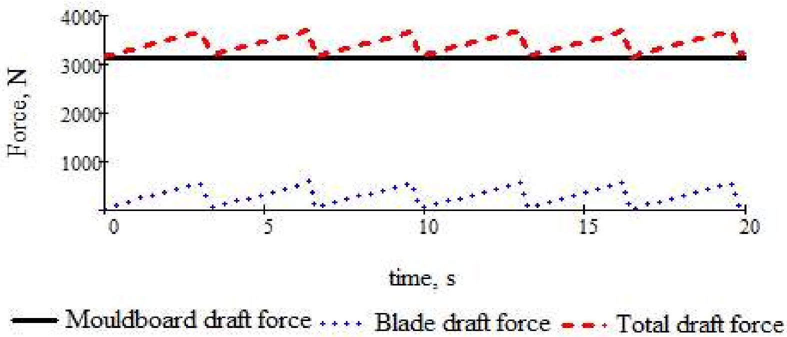

Fig. 4. *Comparative time dependence of the total draft soil tillage force and its components.*

Figure 5 shows graphically the dependence of the total draft soil tillage force, as a function of the working depth and working speed, for four values of the working width of the lister.

The draft soil tillage formulas which are given in the model (1) - (6), give, for various choices of the working regime, values included in the experimentally determined membership intervals: 1500 - 5000 N for the total tensile strength and 0 - 800 N for the tensile strength generated by the blade, [1]. For example, under the conditions specified by the above parameters, for a = 0.1 m, b = 0.4 m and working speed 1 ms^{-1}, it is obtained at time t = 0 s, R_T = 2684 N, and at time t = 2.7 s (when a maximum of the resistance to the blade is reached), R_T = 3601 N. If the working depth is doubled, a = 0.2, R_T = 5167 N is obtained.

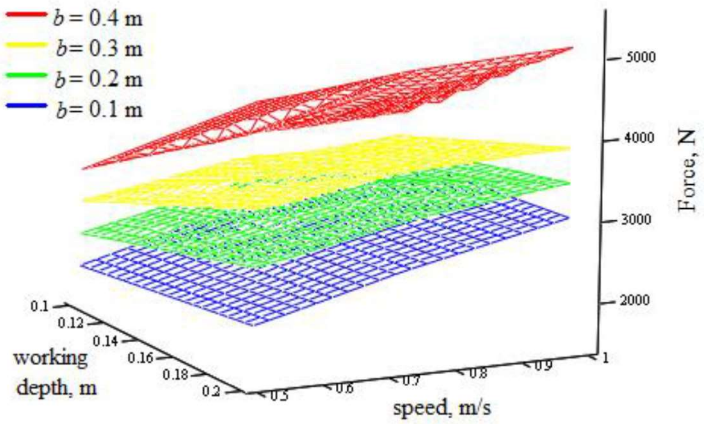

Fig. 5. *Depth and speed working dependence of the total draft soil tillage force of EOCIC, for four values of the working width of the lister.*

COMMENTS

In formula (4), normally the dependence on the length of the channel of the tensile strength force generated by the blade should be introduced. The correction can be made with a coefficient obtained by relativization at a reference length. Having no experimental data available for different values of the length of the open irrigation canal, we did not introduce this correction.

In all the formulas of the mathematical model of the tensile strength (1) - (6) we used the hypothesis that the working speed of the aggregate is constant.

The modelling of the draft soil tillage force generated by the blade made according to (4) and (5) is elementary. The reasons for this statement are: the random nature of the working process of the blade and the mode of operation with precise control of the blade. To perform a more in-depth analysis, the analysis of the blade drive mechanism must be used. The analysis of the mechanism is not simple and requires accurate information about its components. Given the random nature of soil behavior (composition, breakage, deformation, etc.) and the lack of a minimum of the necessary information about soil behavior in the EOCIC work process, the approach to a description at this level of depth is questionable. Therefore, modelling at a higher level of depth remains for the future.

The intensity of the draft soil tillage force depends very much on the soil moisture, which appears in the model only by the soil characteristics, f, ρ, k, and ε.

CONCLUSIONS

The draft soil tillage force generated by the EOCIC equipment in operation can be modelled mathematically in many ways. In our investigation, the modelling is done with the help of relations (1) - (4). The built model has a series of constants or model parameters that allow its calibration to the experimental data known for the equipment.

The model parameters used to represent both the influence of the environmental conditions in the process and the calibration parameters specific to the model, with the role of making the model respect certain relationships between the components of the draft soil tillage force and to respect the oscillating dynamics of the process.

From a practical point of view (for the design of the load-bearing structure and the calculation of the power source), it is sufficient to estimate the maximum value of the tensile strength. In this case, it is not necessary to model the variation in time of the resistance force generated by the blade. However, if we approach problems of aggregate dynamics (variation of the draft soil tillage force, oscillating effects on the quality of the work, resonant work regimes) a model of the type offered in this paper, is necessary. However, the fineness aspects (even the oscillating characteristics) can have (depending on the qualities of the soil) effects difficult to anticipate due to the random nature of many of the soil properties. However, these problems require a large volume of experimental work and a high statistical level of data processing.

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