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Simulation of Oscillatory Working Tool

The paper presents a study of the resistance forces in soils cutting, with emphasis on their dependence on working tool motion during the loading process and dynamic regimes. The periodic process of cutting of soil by a tool (blade) has described. Different intervals in the cycle of steady-state motion of the tool, and several interaction regimes were considered. The analysis has based on a non-linear approximation of the dependence of the soil resistance force on tool motion. Finally, the influence of frequency on the laws governing the interaction in the cyclic process was established.

Keywords: *cutting, soil, blade, vibrations, dynamics*

1. Introduction

In the soil cutting process, the forces on the working tool by blade type are variable and complicated, and they decrease the performance of earthmoving machines. The blade-tool interaction is correlated with generation of dynamic and cinematic phenomenon in which the dynamic has the most important role [5],[8].

This paper deals with the soil cutting process and setup a mathematical model of soil-blade interaction. It is significant to understand soil-blade interaction in establishing the performance, utilization and design of theses machines (e.g. dozers, frontal loader etc.).

2. Soil characterization

It is known that the soil is a complex medium, but for simplicity, it can suppose a combination of many particles of different shape, dimension and origin, fluids with different viscosity and binding agent. Among all components appear cohesive forces, dry or lubricated friction forces, reciprocal actions and reactions.

In general, upon loading process, the soils undergo elastic and plastic deformations. The soil acquires distorted positions corresponding to the cyclic motion of the vibration, as can be seen in Figure 1.

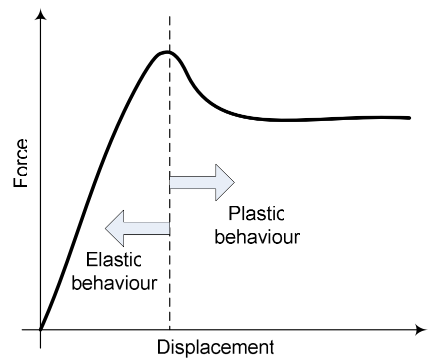

Figure 1. Resistance force of the medium on cutting process.

All available models for soils are based on a few basic models: Hooke (linear pure elasticity), Newton (linear pure viscosity), P-E Bathelt, Maxweel, Voigt, etc. In this study was used the hypothesis that, at beginning of the blade penetration process, the soil undergoes an elastic deformation succeeded by the wedge fall out and by the apparition of an irreversible plastic deformation. Also, for to simplify the mathematic model for the soil, the author adopted a model obtaining by serial connecting a Hooke model with a simple Bathelt model and paralel connecting with a viscous device, such as Figure 2.

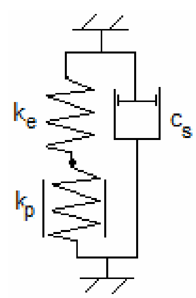

Figure 2. Model of soil.

F_s is the force exerted by the soil against the oscillatory blade and represents the elastic-plastic behaviour of soil. This force has various expressions in different stages of the blade motion, defined by Eq.(1).

$$F_s = \begin{cases} 0, \text{ for } \dot{x} < 0 \\ \dfrac{k_e k_p}{k_e + k_p} x + c_s \dot{x}, \text{ for } \dot{x} > 0 \\ k_e (x - \delta) + c_s (\dot{x} - \dot{\delta}), \text{ for elastic recovery} \end{cases} , \quad (1)$$

where δ represents the soil plastic deformation.

The parameters which are described the soil behaviour have the next values: k_e=17000 N/m, c_s=50 Ns/m and k_p=50000 N/m.

3. Hypotheses for study of dynamics of the tool-soil interaction

In this paragraph, the author presents some hypothesis, which makes more facile the settlement of analytical model for study of the efficiency of applying vibrations on blade, in process of cutting soil [2].

a) Assumptions of medium behaviour

The *first assumption* is that the medium is homogenous and the physical properties are supposed to be constant during of the earthmoving actions.

The *second assumption* is refer to continuity of medium (the tasks has the same into entire volume).

The *third assumption* is isotropic behaviour of the medium, which supposed that the reaction of the medium under external actions does not depend on the orientation of application

b) Assumptions of soil-tool interaction process

The mainly hypothesis regarding the tool-soil interaction are:

- the working tool has a longitudinal shape;
- the depth of material ahead of the penetrating tool is considered to be infinite;
- the speed of the penetration process is constant;
- the slope of the tool on working process is kept at a constant value.

4. Dynamics of the oscillatory cutting soil

The model of blade-soil interaction is represented by single degree of freedom system that correspond to the working tool. The base machine has excluded from the model, but the traction force provided its direct influence on the process.

In this case, the oscillator has connected directly to the tool frame and when the tool vibrates, this responds at a frequency value equal to that of the oscillatory forced function. It has supposed that a machine is moving with a constant velocity *v*, relative to the ground, and the soil forces F_r and F_s act at the tool tip. Driving force of the oscillatory mechanism has the expression $F_0 \sin \omega t$ and act directly on the working tool characterized by mass *m*.

The model of oscillatory system is depicted in the Figure 3.

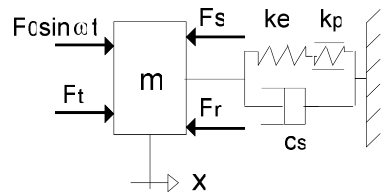

Figure 3. Dynamic model of oscillatory tool-soil contact.

The differential equation of tool motion can be written as follows [1].[3]

$$m\ddot{x} = F_t - F_r + F_0 \sin \omega t \cdot sgn(\dot{x}) - F_s \,, \tag{2}$$

where: m is the tool mass; x – the blade displacement; $\dot{x}$ - the blade velocity; ω - driving force frequency; F_0 - driving force (1000-1500 daN); F_t - traction force; F_r - resistance force acting in loading process of the blade; F_s – elastic-plastic force of the soil.

The author supposes that traction force developed by earthmoving machine remains constant during displacement, F_t=3000 daN.

Mihailescu et al. [3] was developed a theoretical model (see Figure 4) for prediction of the resistance force acting on the blade, F_r , which can be formulate as follows

$$F_r = R_t + W_1 + W_2 + W_3 \;, \tag{3}$$

where R_t denote soil cutting resistance; W_1, W_2, W_3 - the resistance forces created by the soil movements on the blade (in travel, downward and upward direction).

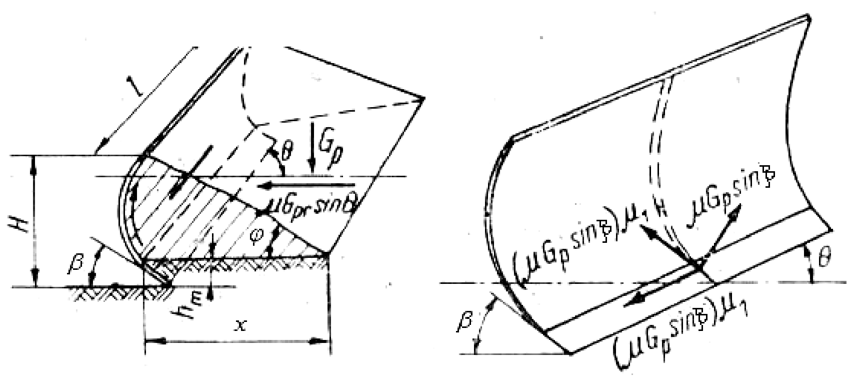

Figure 4. The resistance forces at soil-tool interaction.

In this paper, the analytical model was settement for study of the efficiency of the vibrated blade in the cutting process and thus it makes supposision that the blade have perpendicular direction in respect with machine displacement, so $\theta=0$. In this case, the relation (3) becomes:

$$F_r = k_t b h_m + G_{pr}\mu \sin\beta + (\mu G_{pr} \sin\beta)\mu_1 \cos\beta . \tag{4}$$

For this study, the constructive parameters of the blade was: H=0.270 m, l=1.6 m, m=200 kg and $\beta=55^0$. The average height of cutting wedge was supposed to be constant and equal with h_m=0.150 m.

Results: F_r=1260 daN.

The oscillatory displacement function can be represented as

$$x(t) = vt + x(\omega t), \tag{5}$$

where: v is the constant velocity of machine motion; $x(\omega t)$ is the periodic function with $T = 2\pi / \omega$.

The oscillating component of relative displacement to the ground is

$$x(\omega t) = A \sin \omega t , \tag{6}$$

with

$$A = \frac{F_0}{m\omega^2} . \tag{7}$$

When the vibrating equipment works, the machine moves at constant velocity v, and at the same time, the oscillator transmits the vibrations on the tool, which acquire a sinusoidal additional displacement. Under the action of the driving force $F_0 \sin\omega t$, the response of the tool related to the ground is

$$x(t) = vt + A \sin \omega t . \tag{8}$$

The instantaneous velocity of the tool relative to the soil $v(t)$ is composed by two terms: a constant component v and a dynamic component $\omega A \cos \omega t$, hereby:

$$\dot{x}(t) = v(t) = v + \omega A \cos \omega t \tag{9}$$

The penetration of working tool into the material is possible if it is achievement the next condition

$$F_0 + F_t \geq F_r + F_s \tag{10}$$

If

$$F_r + F_s = F_{blade} \tag{11}$$

results

$$F_0 + F_t \geq F_{blade} . \tag{12}$$

It can be evaluated the dynamic cutting velocity function of vibratory parameters and soil properties when the traction force is known. From the diagram depicted in Figure 5 results that in the same time with increasing of the ratio between the machine traction force and the soil cutting resistance the material do not breaking away from the blade ($v>0$).

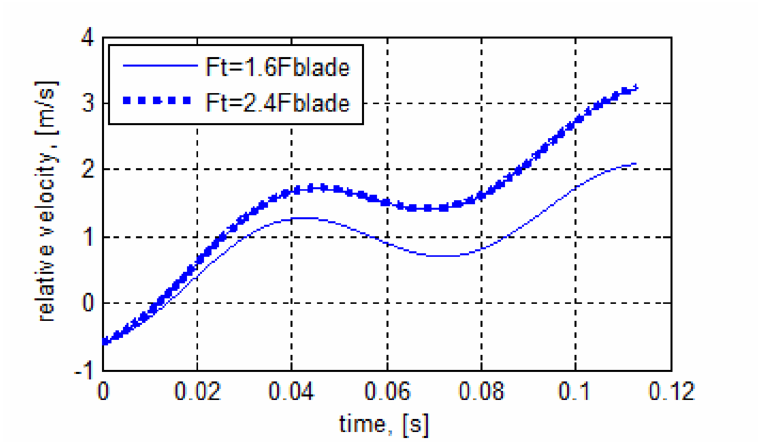

Figure 5. Diagram of dynamic cutting velocity of soil.

For the soil static cutting it is enough that $F_t = F_{blade}$, but in the dynamic cutting case it is necessary that $F_t > F_{blade}$. At the working by driving force amplitude, it was perceived two different cases:

- $F_t > F_{blade}$ - that means tool penetration with cutting edge break off;
- $F_t < F_{blade}$ - that means tool penetration without cutting edge break off.

In the next, the authors has simulated the dynamics blade supposing that machine velocity remains constant (v=1.57 m/s) and $v < A\omega$. In this case, angular velocity is governing by the law presented in figure 6.

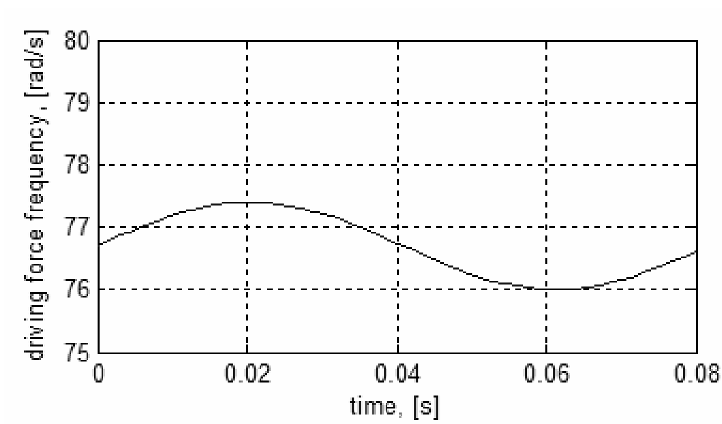

Figure 6. Representation of $\omega - t$.

Figure 7 show the behavior of the vibrating tool with steady state operating. It can observed that working cycle is recurrent.

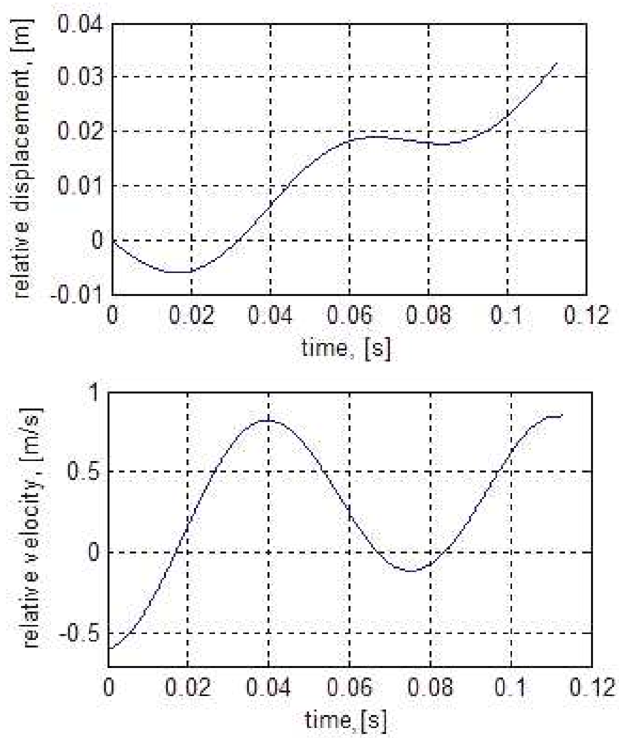

Figure 7. Relative displacement and velocity versus time.

The differential equations of the model are solved by using numerical methods [4], [7] that are implemented in MATLAB 7 software.

5. Conclusions

Based on the analysis of the results obtained in this study, it can be formulating the next partial concluding remarks. Hereby

- the traction force for dynamic cutting depends by the driving force F_0, vibration pulsation ω, mass *m*, travel velocity of machine *v*, resistance force F_{blade} at cutting operation;

- it is necessary that cutting relative velocity must have minimum value. For a given cutting velocity value, the diminishing of the relative velocity can be obtained through increasing of vibration velocity magnitude $A\omega$.

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