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Loading Processes Dynamics Modelling Taking into Account the Bucket-Soil Interaction

The author propose three dynamic models specialized for the vibrations and resistive forces analysis that appear at the loading process with different construction equipment like frontal loaders and excavators.The models used putting into evidence the components of digging: penetration, cutting, and loading.The conclusions of this study consist by evidentiate the dynamic overloads that appear on the working state and that induced the self-oscillations into the equipment structure.

1. Introduction

The present work investigations on vibrations and forces encountered during earthmoving processes by cyclic (but non-rotary) excavation machines. The objective is to integrate the formulation for cutting and penetrating forces to those for excavation. Common practices for characterising an unfrozen medium and the associated tool actions are discussed, followed by a general overview of various models describing earthmoving tasks of penetration, cutting, and loading, as illustrated in Figure 1.

Figure 1. The phases of digging

Although penetration and cutting are distinct actions, it has been note that resistive forces observed while cutting are of the same nature as those encountered during penetration. Moreover, in practice a penetrating device may be used as a measure of the cutting resistance.

These models presented in this paper do not taking into account the base machine weight and its influences on the vibrations propagation.

It is introduced the following simplified hypothesis

- the movement of the working tool into soil is maded with constant value of velocity;
- the detached furrows have the same dimensions of the stripe;
- by the pont of view of the physical and mechanical properties, the soil is considered homogeneous; also it is considered an elastic medium with k_{soil} stiffness.

2. The dynamic model for the penetration (cutting) process

In Figure 2 is presented an rheological model for the dynamical process analysis of the working tools penetration into soil.

The strength force on working tool during the dynamic action of the penetration phase for the soil is giving by the following expresion

$$W_{penetration} = (x' - x)k_{soil}, \tag{1}$$

and the constitutive equation of the model is

$$\begin{cases} x = ct., \dot{x} = 0 \quad for \quad (x' - x)k_{soil} < \sigma, \\ m(x)\ddot{x} + (x' - x)k_{sol} - \sigma \cdot sgn\,\dot{x} = 0 \quad for \quad (x' - x)k_{soil} \geq \sigma, \end{cases} \tag{2}$$

where σ denote the friction forces between the bucket walls and the soil, *m* denote the furrow mass which is floating, *x′* denote the displacement of the working tool in the soil, *x* is the displacement of the furrow which strip off the bags.

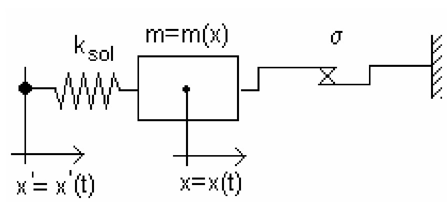

Figure 2. Rheological model for the penetration dynamical process analysis into soil.

In Figure 3 is representated the movement of the furrow, and in Figure 4 the behaviour of the resistive forces of the bucket at the penetration(cutting) phase.

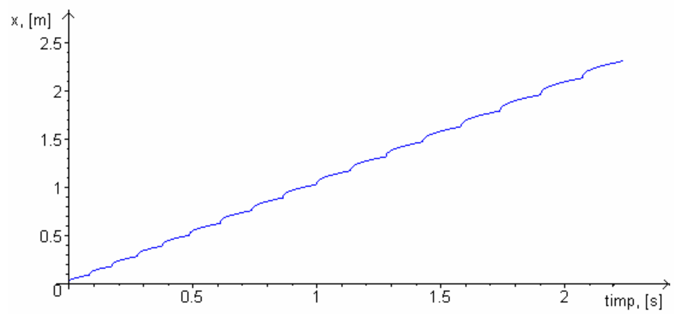

Figure 3. Movement of the furrow at the penetration (cutting) phase

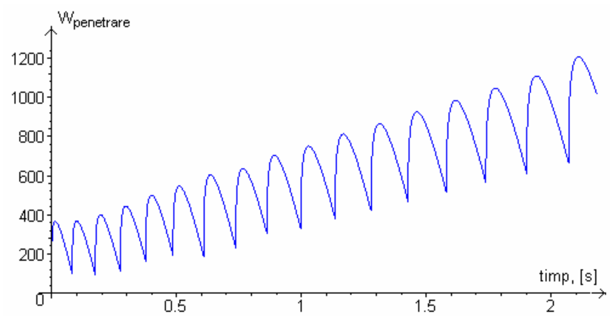

Figure 4. Behaviour the resistance forces of the bucket at the penetration phase.

Analysing the figure 4 it is remarked that this resistive force introduce the self-oscillations to the working tool, then, which are transmitted at the equipment structure and on the entire machine. In this situation, it is necessary to know the natural frequency of the resistive force oscillations, which appears in the penetration phase for avoiding the resonance phenomenon.

This fact means that it is necessary to analyse the frequencies composition of the resistance force signal. Taking into the account the properties of the surroundings, of the working tool, and the penetration speed, it is necessary to make an optimization study of these parameters, thus that the specifical dynamic effects of this phasis to be minimal.

3. The dynamic model for the bucket loading phase

Another proposed dynamic model for the promonence of the self-oscillations transmitted in the system by the bucket-material interaction, during the bucket loading phase, it's presented in Figure 5.

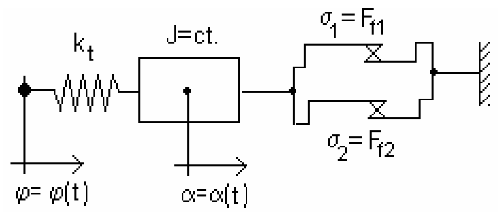

Figure 5. The rheologic model for loading phase analysis

For writing this model, the following simplified hypothesis are used

- the bucket loading is maded with constant angular velocity, that was allowed by the driving system of the liniar hydraulic engine
- during the bucket loading phase, the material is not lost and the mass of the dislocated soil have constant value, and constant *J* moment of inertia vis-a-vis of the joint point.

The resistive force at the bucket loading phase $W_{rotation}$ is estimated with following relation

$$W_{rotation} = (\varphi - \alpha)k_t \ , \tag{3}$$

and the constitutive equations of the model are

$$\begin{cases} \varphi(t) = \omega t, \ \ \dot{\alpha} = 0 \quad pentru \ (\varphi - \alpha)k_t < max(\sigma_1, \sigma_2), \\ J_{c+p}\ddot{\alpha} + (\varphi - \alpha)k_t - [max(\sigma_1, \sigma_2)] \cdot sgn\dot{\alpha} = 0 \quad pentru \ (\varphi - \alpha)k_t \geq max(\sigma_1, \sigma_2), \end{cases} \tag{4.}$$

where φ is the angular displacement of the bucket; α - is the angular displacement of the center mass of the dislocated prism; k_t - denote the stiffness of the soil; J_{c+p} - is the moment of inertia of the loaded bucket; ω - denote the angular velocity of the loading bucket.

There are situations when the bucket loading it was realized only using of the advancement moving of the bucket in the material, without acting of the cilinders of the equipment driving system. In this situation, it's important to analyse the penetration (cutting) at the bucket in the soil, taking into account the specific parameters of the base machine, respectively, by the traction force developed on the displacement driving system.

In the time of the working tool penetration in the soil, the resistance forces growing up, and the machine power reserve remain at the constant value.

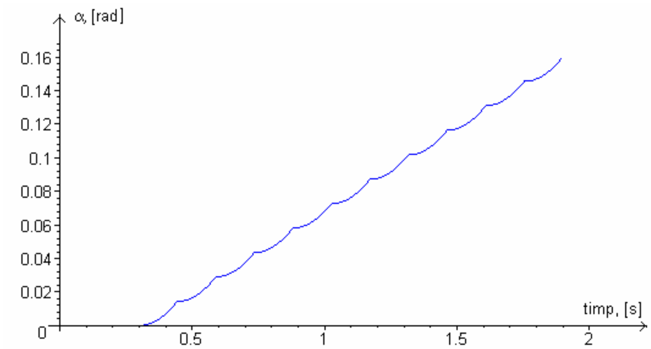

Figure 6. The behaviour of the angular displacement of the prism at the bucket loading phase

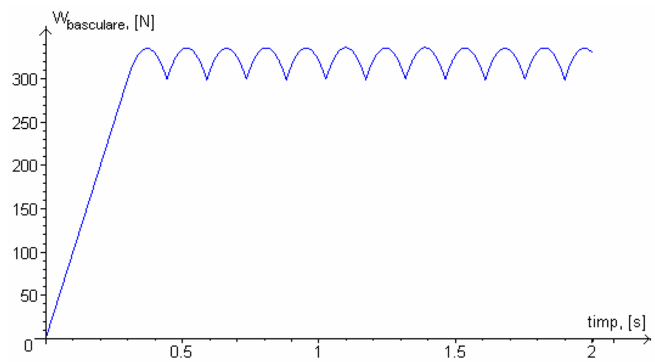

Figure 7. The behaviour of the resistive force at the loading phase

In Figure 8 it is presented the dynamic model for the simple load process of the frontal loader's bucket, with consideration of the floating traction force and implied with the floating speed at the penetration (cutting) phase.

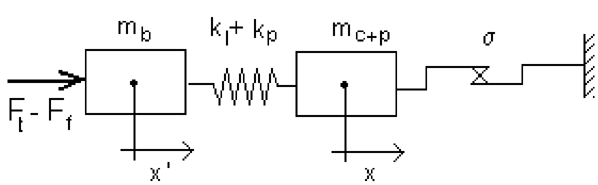

Figure 8. The rheologic complex model for the penetration (cutting) phase with frontal loader's bucket.

The differential moving equations for the dynamic model, presented in the Figure 8, are

$$m_b \ddot{x}' + \left(k_l + k_p\right)\left(x' - x\right) = F_t = \frac{P_m}{\dot{x}'}\eta_t ;$$
$$m_{c+p} \ddot{x} - \left(k_p + k_l\right)\left(x' - x\right) - \sigma \cdot sgn\,\dot{x} = 0, \quad (5)$$

where m_b is the base machine mass; m_{c+p} - the bucket loaded mass; x_b, x', x - the displacement of the base machine, of the bucket and the dislocated prism; k_l - the working equipment stiffness; k_p - the dislocated prism stiffness; σ - the resultant friction forces among the bucket-material and the material-material interactions; P_m - the power of the machine.

4. Conclusions

The force and vibrations required to insert a tool into a medium is of major interest for the design and automation of earthmoving machinery.

A better understanding of the earthmoving phenomenon may lead to propositions for control strategies. Therefore, the goal is to express mathematically the value of the resistive force a medium exhibits to a tool during a general excavation task in terms of the parameters of the medium, the tool, and the tool motion.

The dynamic models proposed in this paper, putting in prominence the pendulous character for the resistive forces that acts on the bucket, during the digging phase. These researches constitute a begining of the large, complex and complete analysis of the bucket - material interactions, that are consequences of the exhaustive studies at this domain.

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