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Process of Compaction of Plastic Materials under Influence of Vibrations

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Abstract—**The usage of the vibration allows the successful execution of different technological operations with the reduced energy expenses including the compaction and transportation of liquid-plastic substances. On the bases of a bio-mechanical modeling there is studied the possibilities of penetration of dangerous vibration into the body of operator.**

On the bases of the conducted researches there are showed the mistakes made during the modeling of the dynamics of nonlinear electromagnetic vibrator and building of an amplitude-frequency feature that take place in some articles and there are also showed their overcoming ways.

Keywords:—**vibration, amplitude, frequency, compaction, modeling and simulation.**

I. INTRODUCTION

Usage of vibrations in technique gives possibility to carry out variety of technologic operations that were previously considered as impossible. In spite the fact that there are many articles about vibration in the scientific literature, when one faces with the vibration he encounters such processes that are not practically described in the literature. Vibration on its nature is very complex phenomena connected with many casual events.

Many results obtained by means of existing mathematical models are very far from the reality since the technologic operations realized by means of vibration are very complex [2]-[4]. Practically, accuracy of theoretical description of vibration processes is impossible. In the course of study of transportation and compaction of plastic materials were revealed processes which aren't described in the scientific literature. The carrying out technologic processes significantly depends on vibration parameters.

II. SYSTEM DESCRIPTION

In spite of that there are many articles about practical usage of vibrations in the literature, still for realization of many technologic operations with optimal parameters the complex theoretical and practical investigations are to be carried out yet [1], [5]-[7].

For the observation of the separation and mixing processes the plastic bottle was filled up with the wet sand and placed on a vibrator plate. The plastic bottle, in the compaction proportion, first began moving to the direction of acting vibration then the motion of the bottle was stopped. After, the bottle with compacted materials began moving inversely of acting vibration with increasing speed. It should be noted that the glass bottle filled up with wet sand and other subjects continued moving with constant speed to the direction of acting vibration [5]. The above mentioned process was performed by the following vibration parameters (frequency 55-40Hz and amplitudes 0.4-0.9 mm).

It should be noted that the reason of backward movement of the plastic bottle is not the high elasticity of working surface of the vibrator and its own resonance oscillations. As it is known, the elasticity of the vibrator plate would cause the movements of subjects from the center towards the periphery i.e. from the big amplitudes towards the low amplitudes.

The process of the sand compacting, which occurred in the transparent plastic bottle installed on the vibratory plate, begins in the lower layers (directly at the vibration source) and gradually penetrates towards upper layer i.e. the process of vibration compacting is a function of time.

The further experimental investigations showed that the reason of the inverse displacement of the plastic bottle is the additional elasticity of the bottle's bottom part. It was determined that vertical displacements of the gravity center of the bottle caused by vertical component of vibration amplitudes are decreased by the elasticity of bottle bottom part. So, by means of plasticity of bottom part of the bottle the cycling pressure from the vibrator plate is balanced. Additionally, the variable dependence of sliding velocity on the coefficient of friction is the reason of being of the plastic bottle in an antiphase condition i.e. in inverse movement.

The correctness of the above mentioned supposition is proved by placing of the elastic spring with a lateral surface on the vibrator. The spring also moves to inverse direction (Fig.1). On the base of investigation it was determined that the relationship of mass on rigidity $k=m/c$ influences on the direction and velocity of inverse displacement of the spring. For instance at the value of amplitudes 25-30 Hz and 0.3-1.2 mm when $k= 0.5$-0.9 the spring is moving backward, but when $k< 0.5$ the spring stops. When $k>1.2$ the spring moves to the vibration direction (Fig.2).

Determination of the depth of compaction in plastic materials connected with penetration of vibration components through materials has a great practical meaning. The above mentioned problem is very difficult and depends on mechanical characteristics of compacting materials, the geometric form, vibration frequency, the value of vibration amplitudes, duration of acted vibration and etc. On the

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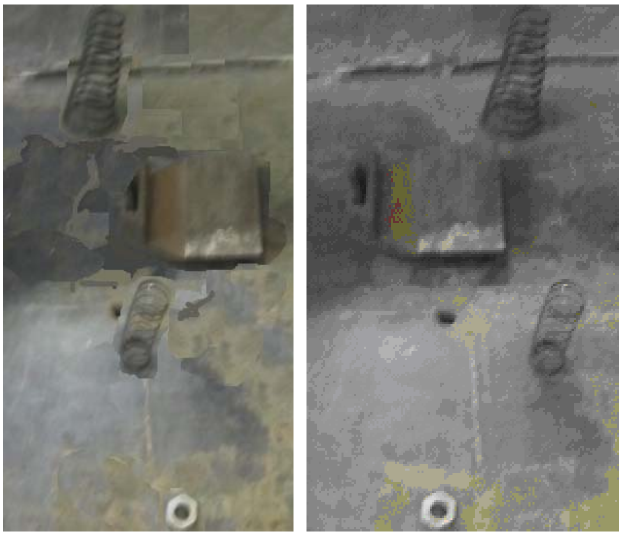
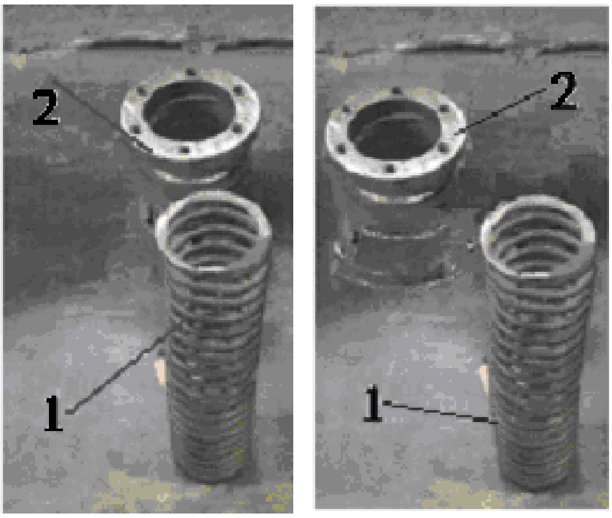
aforesaid assumption, in the scientific literature it is very problematic to find one or another suitable method allowing obtaining necessary parameters.



a b

Fig.1: Photographs (a) at the starting.
(b) After vibration displacement k=0.7



a b

Fig.2: Photographs at the starting (a) and
after displacement (b) 1) k=1; 2) k=1,9

At the experimental investigations the method determining dissipation of energy by means of decreasing free mechanical amplitudes was used for determination of the depth of compaction [1], [5]. In spite of the fact that the nature of the depth of damping of amplitudes in materials differs from the nature of damping of free fluctuations even so there is possibility to define the factor of damping in the depth of the material [5], [7], [8]. In spite of the fact that the factor of the damping of the penetrating amplitudes depends on physical and mechanical characteristics of the material the obtained results may be used for the approximate determination of penetrating vibration in other plastic materials. It is possible to define penetration of vibration through the depth of the material by simple calculation. The experience shows that for many tasks the approximate determination of the depth of the compaction and creation of mathematical models, describing dynamic processes in the depth of the material is enough [9]. For carrying out of road covering operations it is very important to know the depth of compaction of the ground.

It is very important to know the transformation processes at compaction of loose and liquid-plastic materials on the vertical plane. The processes of coating of the layer on the wall differ from the analogous processes on the horizontal plane. When the angle between acting vibration and gravity forces is a right angle (90^0), the compaction and interaction of separate grains on the vertical plane occur very unusually. The materials which are to be compacted on the vertical plane must have the adhesiveness. Otherwise, after removal of the vibratory head the compacting materials will be thrown off the wall. It is clear that, after removal the vibratory head, the compacted loose materials without stickiness will not stay on the vertical plane.

The liquid concrete is represented as a plastic material with four phase structure - cement, inert gravel, and water and air bubbles. The liquid coating layer on the vertical plane without farther compaction contains a big amount of air bubbles reducing the hardness of the covering layer as well as the contact area between surfaces of wall and the covered layer that causes preliminary destruction of the covering layer. Mechanism of this processes is the following: since concrete is very good adsorbent of moisture and water so in winter frosty days the soaked up and accumulated water in air bubbles turns into ice and it begins expansion while the concrete begins reducing in size as a result of which the obtained stress destroys the structure of the concrete.

To avoid this process, air bubbles must be reduced. In principle, it will not be novelty to use vibration for displacement of air bubbles from the covering layer as it is in building industry for compaction of concrete construction products.

It should be noted that if intensive vibration is necessary for realization of technologic operation the vibrating instrument must be well insulated to protect the operator from dangerous vibration for a long period. Unfortunately the insulating devises and methods protecting operators from acting of dangerous vibration are not effective in many cases. Moreover the modern polishing and cutting tools are balanced on the high level though they become sources of generating dangerous vibrations at technologic operations. The source of vibration in such cases, at the processes of operation, is unevenness of surfaces or changeable pressure on the device by operator. It must be noted that process of penetrating of dangerous vibration to the body and tiredness of the operator occurs more sharply when heavy vibrating subjects are held by the operator in his hands [4], [10].

III. SIMULATION RESEARCHES

At the given stage the goal of our investigation was to define the level of vibration delivery to the operator from vibration devices, but not to determine the depth of vibration penetration in a human body and corresponding reactions from separate organs. So differential equations were simplified.

$$m_1 \frac{d^2 x_1}{dt^2} + f_1\left(\frac{dx_1}{dt} - \frac{dx_2}{dt}\right) + C_1 x_1 + C_2 (x_1 - x_2) = P(t);$$
$$m_2 \frac{d^2 x_2}{dt^2} + f_2\left(\frac{dx_2}{dt} - \frac{dx_1}{dt}\right) + C_2 (x_2 - x_1) = 0; \qquad (1)$$

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where m_1, m_2 - masses of the vibrator and the operator, C_1, C_2, C_3 - elasticity (rigidity) of concrete, vibrator and hand (wrist) of the operator, x_1 is vibrator oscillation amplitude, x_2 is amplitude of the operator wrist, f_1, f_2 - coefficients of damping of the vibrator and operator, P(t) is driving force.

The carried out investigations show that it is very desirable and necessary if the operator is free from the long-lasting close contact with the vibratory devices [5], [9]. It is less dangerous when the operator presses the vibratory device only by fingers (Fig. 3) than carrying out technological operations by holding it in his hands (Fig. 4). So, it is reasonable to create special adjustments by means of which the operator becomes free from holding the vibratory devices in his hands.

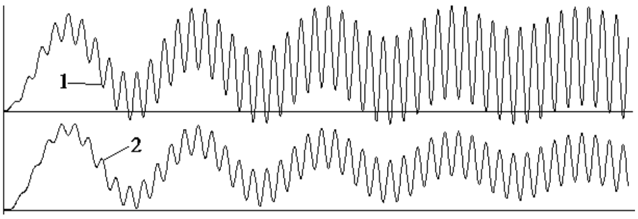

Fig.3. Oscillations: vibrator 1, wrist 2. The vibratory device is pressed by operator's fingers

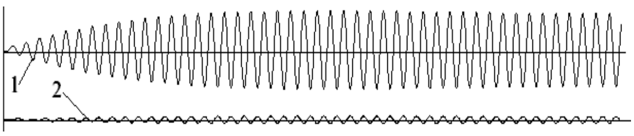

Fig.4. Oscillations: vibrator 1, wrist 2. The vibrator is pressed by operator hands.

At studying of dynamics of electromagnetic vibrators by means of mathematical simulation some problematic processes were observed and corrected [11]. The differential equations describing dynamics of the electromagnetic vibrators are as follow:

$$\frac{d^2x}{dt^2} + 2h\frac{dx}{dt} + \omega_0^2 x = a\phi^2, \qquad (2)$$

$$\frac{d\phi}{dt} = b\sin\omega t - c(\delta - x)\phi, \qquad (3)$$

where x - amplitude of the oscillations, ϕ - magnetic flow, 2h - resistance on viscous model, ω - circular frequency of the mechanical system, c - factor of the magnetic resistance with provision for air clearance δ, t - time, a - factor of driving force, b - factor of alternating current.

The researchers considered, simulating dynamics of electromagnetic vibrators by differential equation (3) at the negative periods of sin(ωt), the coefficient b as zero.

$$b = \left| \frac{0 \; when \sin(\omega t) < 0}{b \; when \sin(\omega t) > 0} \right.$$

Obtained in such way, half-cycle rectified current causes proportional accumulation of magnetic flow (Fig. 4b). Stability of the process in similar situations may be reached only artificially by means of correction of induction resistance.

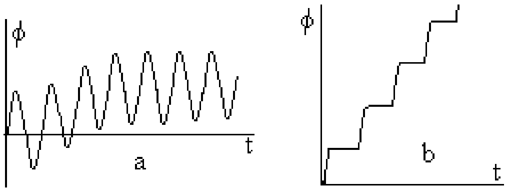

Fig .4 (a) Real dependence ϕ with t;
(b) - at periodically zeroed b in equation (3).

The semiconductor diode is included in electric circuit consecutively for the reason of half-cycle rectifying of alternative current, otherwise magnetic attractions and oscillation frequency will be doubled.

Naturally, such approach brings to the inadmissible mistakes. Since electric current and magnet flow are shifted on a phase of 90^0 angles together with the voltage so in the moment of zeroed voltage the electric current and magnetic flow have no zero meanings. To avoid above mentioned mistakes at the negative periods of sin(ωt) the equation (3) is to be changed by the equation describing disappearance of magnetic flow or ϕ must be equaled to zero [11].

Certainly, for accurate link-up of separate components of equations the following is to be taken into account: the shifts of the phases between electric voltage and magnetic flow and changes of the given phases before and after the resonance regimes [7], [11].

Taking into account that shift angles of direct current and magnet flow are shifted in equal value with electric voltage the above mentioned problem may be solved simply. Instead of periodic zeroed electric voltage in equation (3) the magnetic flow accordingly to negative meanings of sin(ωt) was zeroed in equation (2).

At the study of nonlinear resonances by means of mathematical simulation for smoothly link-up of separate areas obtained by solving of equations (2) and (3) the shifts of direct current, magnetic flow and electric voltage must be taken into account.

To estimate the dynamic features and stability of one or another system it is very important to have an amplitude-frequency feature (AFF). For obtaining AFF by mathematical simulation the frequency of driving force must be changed constantly and discretely at the period of modeling. As the discrete change of frequency of the driving force causes sharp shifts of angles between alternating current, magnetic flow and electric voltage; the obtained oscillation amplitudes gives 2-4 cycling increase or decrease (Fig. 5(a) depending on shift of phases is positive or negative. In Fig. 5 are given oscillations of magnet flows and mechanical system x by discrete change of sin(ωt).

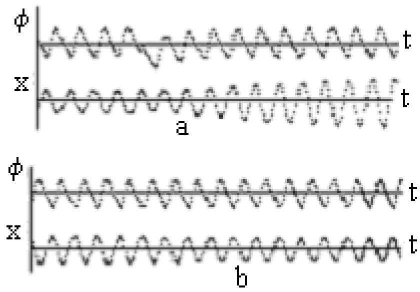

Fig. 5(a) Non stabile amplitudes without correction
(b) Stable amplitudes with correction of shift

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The correction of angle of the shift of the border condition may be solved in a simple way. By means of comparison the conditions $\omega_0 t=\varphi_0$ before and after $\omega_1 t=\varphi_1$ change of driving frequency ω follows to define new meaning t_1 from equation $\omega_1 t_1=\varphi_1$ by replacing φ_1 on φ_o so that to carry out condition $t_1=\varphi_o/\omega_1$. That is to say that on a new value of argument ω the angle of the shift φ_o is stayed unchangeable [7], [11]. By means of given condition at the mathematical simulations the obtained oscillations amplitudes are continued absolutely smoothly after discrete changing of driving force Fig. 5(b).

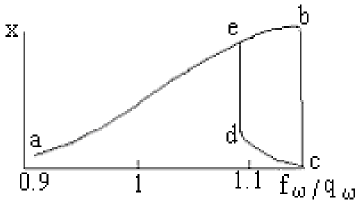

Fig. 6 Built up nonlinear soft characteristic AFF with correction of shift.

In Fig. 6 AFF is given which is built by means of aforesaid correction. Areas of curves "eb" and "cd" are characterized for nonlinear oscillations.

In Fig. 7 is shown distorted nonlinear AFF obtained without correction.

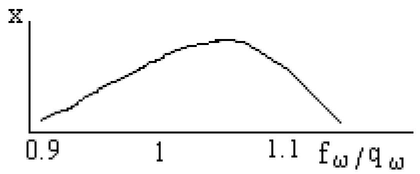

Fig. 7 AFF with distorted soft characteristic

It should be noted that without correction of angles shifts it is impossible to obtain "eb" and "cd" curves.

IV. CONCLUSION

For successful compaction and removing of air bubbles from plastic materials the various oscillation frequencies and amplitudes are needed. Amplitudes 0.5-0.9 mm on frequencies of 20-30 Hz are successful for compaction of plastic materials and are less dangerous for operators which are subjected to long-continued vibrations.

It is very reasonable to create special adjustments that make free operators from holding the vibratory devices in hands. Even the modern polishing and cutting tools being balanced on a high level by unevenness of surfaces becomes sources the generating dangerous vibrations at the performing of technologic operations.

For imitation of rectifying of half-cycle alternating electric current it is inadmissible the electrical voltage was zeroed periodically in equation describing driving force. To obtain AFF of nonlinear systems by mathematical simulation the shift of the angle phase between electric voltage and magnetic flow should be corrected at discrete changes of driving force i.e. must be defined coefficient of time t_1 so that equal shifts of phases existed before and after discrete change of ω.

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