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Research paper

Cassette Vibration Installation Mathematical Modeling for Compacting Concrete Mix During the Formation Reinforced Concrete Products

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Abstract

Calculated scheme of the vibration unit with the spatial motion of the working body is proposed and a mathematical model of the vibration plant is created taking into account the resistance of the compacted mixture to the working body, which allows more precisely to design vibration machines for the production of reinforced concrete and concrete products, which is an extremely urgent task, especially in modern market conditions.

Keywords: *vibration installation, mathematic model, oscillations, concrete mix.*

1. Introduction

In the mathematic modeling and practical calculations of vibration compacting machines, it is necessary to take into account the influence of the concrete mixture on their dynamics, since overcoming the resistance in the compacted medium, consumes a significant part of the energy of the machine. With vibro-compaction, the working body and the environment are moving in accordance with their own laws. In this case, the energy of the movement of the working body is spent in the machine itself, in contact with and in the environment.

In the construction industry, besides the monolithic way of erection of buildings and buildings, the demand for reinforced concrete products for individual construction are demanded. When performing such types of work, small concrete and reinforced concrete products of high quality and a variety of configurations can be used, which can be manufactured both at ZBV and K factories, and directly on the construction site. For formation of such products it is possible to use vibroplaces of small carrying capacity with spatial movement of a working body, developed in PoltNTU.

In the scientific worked V.N. Shmigalsky, P.F. Ovchinnikova. A.A. Afanasyeva. V.Ya. Sivka, O.A. Savinova, B.V. Guseva, I.I. Nazarenko [4, 7, 9] and others noted that the process of compacting proceeds faster when selecting the frequency and amplitude of oscillations that correspond to the maximum intensity of vibration exposure and change in terms of vibration modes. In works P.F. Ovchinnikova, B.I. Zikova V.Ya. Sivka [9] has been proven that the nature of the frequency variation in the process of vibration compacting can be determined by the stress-strain state (VAT) in the product, depending on its dimensions, the method of formation and features of the concrete. However, the issue of creating vibroplanes, which will be able to implement the optimal VAT conditions, remains unresolved.

The obtained results help in solving the task of interaction of the working body of the machine with the environment. The solution is based on the creation of a mathematical model of the motion of the medium in the function of a stress-strain state. The modes of motion that correspond to the maximum energy transmitted from the working medium to the medium are determined. The dependencies between constructive and dynamic parameters of the vibroplane are established.

The purpose of this work is to create a mathematical model of vibration installation, taking into account the resistance of the compacting mixture to the working body, which will allow more precisely design vibration machines for the production of reinforced concrete and concrete products, which is an extremely important task, especially in today's market conditions.

1.1 Making calculation scheme of the vibration unit with spatial movement of the working body and the creation of its mathematical model, taking into account the resistance of the compacted mixture to the working body

Efficiency of the process of transferring energy from the working organ to the medium and, consequently, the quality of the compacting depends to a large extent on how far the machine's mode of operation corresponds to the mode of product fluctuations. To assess the effectiveness of this process, it is necessary to study the range of issues related to the transfer of energy from the working body to the environment. In this regard, a compacting machine and concrete mixture should be regarded as a single dynamic system. Characterizing the internal energy losses in the medium of the area of the hysteresis loop, we distinguish three ways of taking into account the resistance in the dynamics of vibration densities:

1. The energy method according to which the deformable material determines the value of the relative energy dissipation as the ratio of the area of the hinge loop to the elastic energy corresponding to the amplitude of the vibrational displacement.

2. The method of partitioning the components of the resistance, which separately considers the elastic, viscous and dry (coulomb) supports and take into account these components in the general equation of motion of the system. This method, unlike the previous, allows you to take into account the elastic and viscous properties of the medium.

3. Numerical method of taking into account the resistance of the medium is used in cases when it is necessary to accurately take into account the features of the loop of hysteresis and when it is difficult to represent it in an analytical form. Using this method, an experimental piecewise-linear model is used for analytical description of the compacting process, which distinguishes three stages of vibration compacting. Depending on the stage, the concrete mix is approximated: 1 - an elastic-plastic medium that retains deformation (the beginning of the compact); 2 - an elastic-plastic medium with strengthening and unloading of deformations; 3 - a medium that deforms linearly (the end of the vibration compacting process). In applying this method, the system of equations of motion of a working body, taking into account the resistance of the medium, consists of the equations of motion of the working body and the vibrations of the medium [7].

In studying the influence of the medium on the motion of working bodies of the vibrator, we propose to confine ourselves to studying the motion of the center of mass loading in accordance with the theorem on the motion of the center of mass of the system [7]. In this simulation, the medium is presented as a unit mass that is centered on the masses and interacts with the working body in the direction of three axes of coordinates with the help of elastic, viscous and plastic properties of the medium.

If we consider the environment rigidly attached to the working body, which is determined by the adhesion and cohesive forces, the fundamental characteristics of the "solid-liquid" mixture, in particular, the formation of a thixotropic elastic-viscous spatial grid of chain of grains of a solid phase of the medium that is in contact with hydrated films [12], then For the correspondence of the calculations with these experiments, it should be assumed that not all mass of the concrete present in the form of the concrete affects the system fluctuations, but only its part, or so-called connected mass. It is convenient to make use of the coefficient of the attached mass, which is the ratio of the weight of the tightly attached vibrating machine to the working body of the vibrating machine to the entire mass of the concrete mixture in the form, which causes the same decrease in the amplitudes of vibration displacements, as well as all the concrete mixture, which is in the form. It has been experimentally established that the coefficient of the adherent mass for concrete mixtures depends on their composition and reinforcement density and is within the limits of k = 0.15 ... 0.4. The composition of the mixture is less affected by the value of k than the reinforcement density. Therefore, for non-armored products take k = 0,15 ... 0,25, for the medium-armed - k = 0,25 ... 0,3 and for the reinforced ones - k = 0,3 ... 0,4.

I.I. Nazarenko, considering the main types of rheological models [4], notes that the most commonly used for taking into account the influence of a concrete mixture on the movement of working bodies is the Voigt model, which allows for the consideration of the elastic and viscous properties of the medium. The motion of a system with one degree of freedom in this case is described by the equation

$$m\ddot{x} + b\dot{x} + cx = F(t),$$

де m − respectively mass and acceleration of the system;

$b, c,$ − respectively coefficients of viscous resistance and elasticity;

$\dot{x}$ − speed;

x − movin.

For the compilation of the differential equations of motion of the system "working body - debalance - a mixture" (RO-D-C) we use the algorithm Nielsen [11,13], the feasibility of which for the mathematical modeling of vibration machines has been repeatedly confirmed in scientific works.

In order to simplify the mathematical apparatus and reduce computations in solving equations, a number of assumptions are adopted based on the experience accumulated in solving the problems of mathematical modeling of vibrating machines and do not violate the accuracy of the results obtained.

1) Taking into account to design features of vibration plant under study, namely, the method of connecting the moving part with the fixed one and the method of installing the vibration exciter, we conclude that this system has a "zero" (fixed) point and its motion can be regarded as spherical.

2) The presence of a concrete mixture in the form takes into account the method of the division of resistance, which it creates, introducing the mixture in the form of an elastic-viscous body (Figure 1).

3) A movable frame with a vibration axle (with a vibrator) attached to it and a shape will be considered equivalent to the mass of the solid body in which the geometric axis and the axis of material symmetry coincide.

4) Efforts arising from the deformation of the elastic elements of the supports in the working range, we assume proportional to the magnitude of the deformation.

Taking into account the adopted constructive decisions of the proposed vibration installation and taking into account the above assumptions, the calculation scheme of the installation will be presented as a mechanical system of PO-D-C (Figure 2).

Determination of the number of degrees of freedom of the material system is carried out in the following way, since the position of the working body in space with a spherical motion can be uniquely determined by three angles of rotation ψ, θ, φ, around the axes of coordinates, the motion of the vibration dampers with the same angles of rotation and additionally the angle of rotation around the axis of symmetry of the vibration unit α, The position of the mixture to be compacted will be determined by the angles of rotation $\psi_1, \theta_1, \varphi_1$ around the same coordinate axes as the working body, then the system RO-D-C will have seven degrees of freedom, and the system of Nielsen equations will consist of seven differential second-order equations in seven generalized coordinates, in which we will take corners of turns $\theta, \psi, \varphi, \theta_1 \psi, \varphi_1 \alpha$,

$$\begin{aligned}
&\frac{\partial \dot{T}}{\partial \dot{\theta}} - 2\frac{\partial T}{\partial \theta} = Q_\theta; \frac{\partial \dot{T}}{\partial \dot{\theta}_1} - 2\frac{\partial T}{\partial \theta_1} = Q_{\theta 1};\\
&\frac{\partial \dot{T}}{\partial \dot{\psi}} - 2\frac{\partial T}{\partial \psi} = Q_\psi; \frac{\partial \dot{T}}{\partial \dot{\psi}_1} - 2\frac{\partial T}{\partial \psi_1} = Q_{\psi 1};\\
&\frac{\partial \dot{T}}{\partial \dot{\varphi}} - 2\frac{\partial T}{\partial \varphi} = Q_\varphi; \frac{\partial \dot{T}}{\partial \dot{\varphi}_1} - 2\frac{\partial T}{\partial \varphi_1} = Q_{\varphi 1};\\
&\frac{\partial \dot{T}}{\partial \dot{\alpha}} - 2\frac{\partial T}{\partial \alpha} = Q_\alpha.
\end{aligned} \qquad (1)$$

where T – kinetic energy of the system RO – D– S;

$\dot{T}$ – the complete first derivative of time from kinetic energy;

$\theta, \psi, \varphi, \alpha, \theta_1, \psi_1, \varphi_1$ – generalized coordinates;

$\dot{\theta}, \dot{\psi}, \dot{\varphi}, \dot{\alpha}, \dot{\theta}_1, \dot{\psi}_1, \dot{\varphi}_1$ – generalized speeds;

$Q_\theta, Q_\psi, Q_\varphi, Q_\alpha, Q_{\theta 1}, Q_{\psi 1}, Q_{\varphi 1},$ – generalized forces.

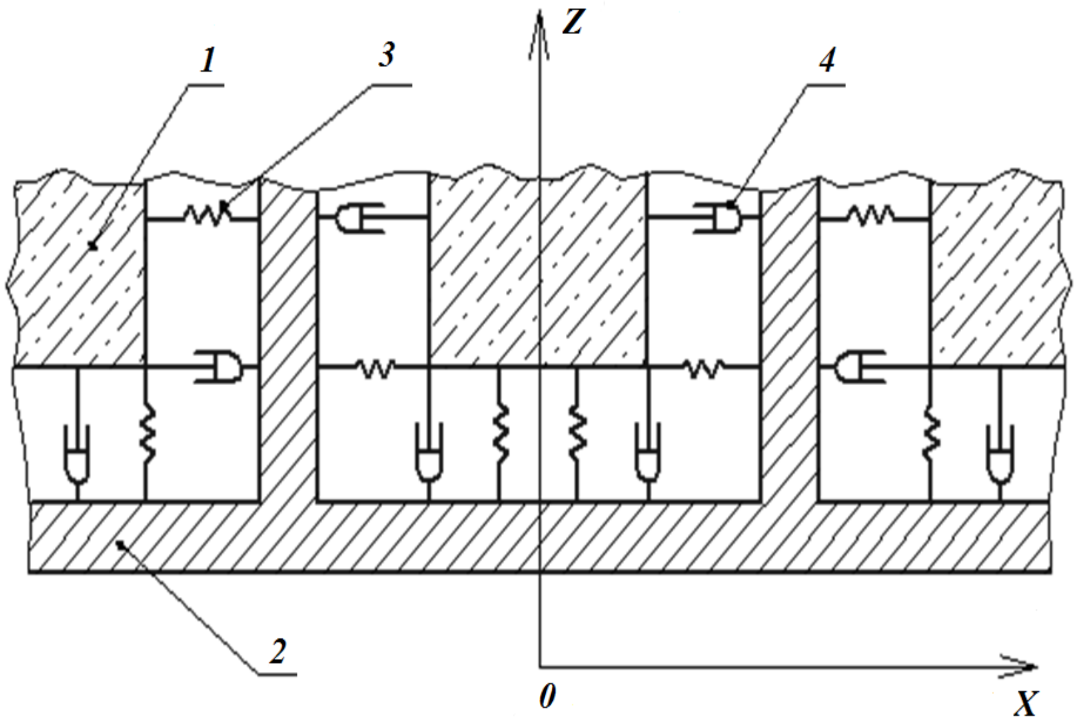

Fig. 1: Estimated diagram of the vibration unit in the plane of the KHZ taking into account the influence of the concrete mixture: 1 - concrete mixture; 2 - metal form; 3 - elastic bond; 4 - viscous knitting

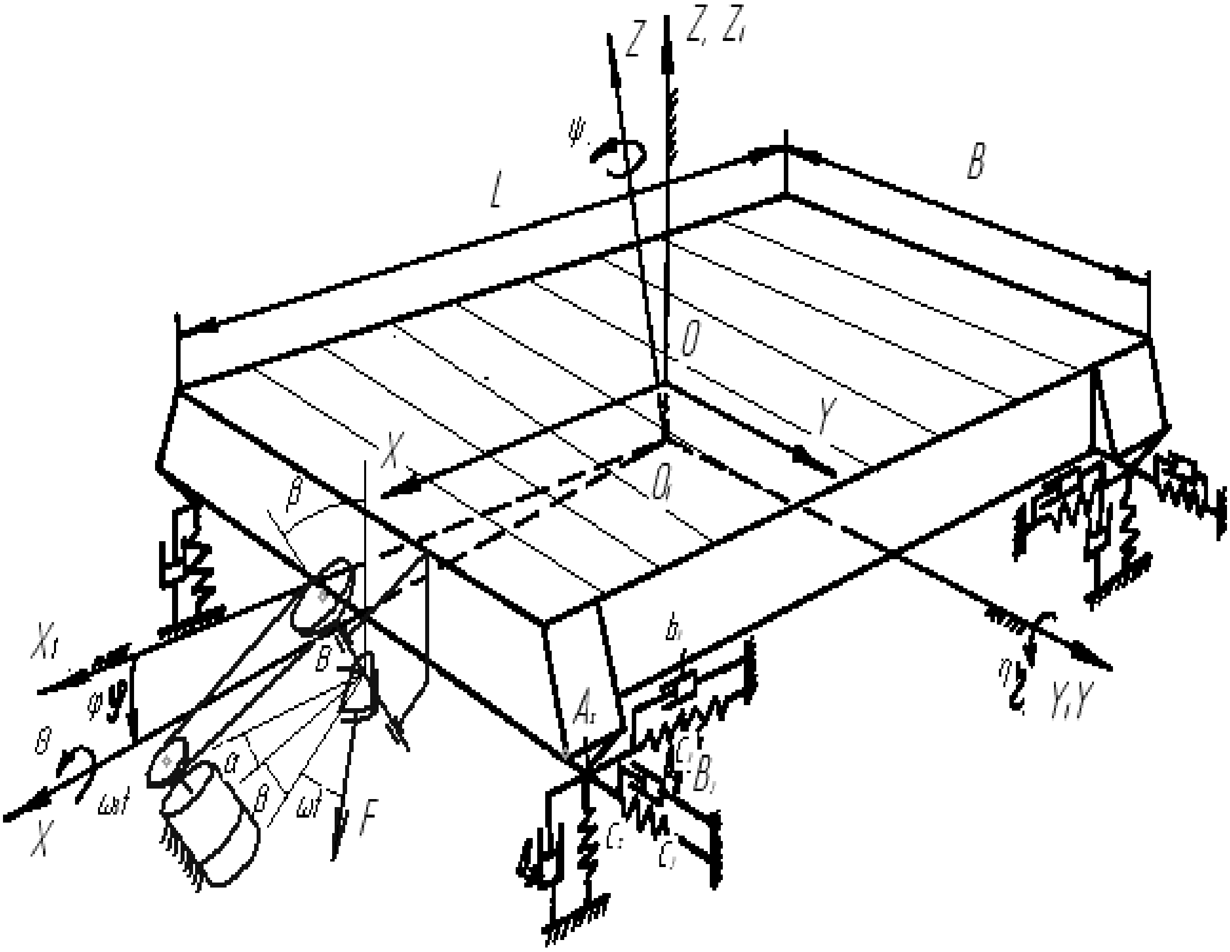

Fig. 2: Schematic diagram of the vibration unit with spatial motion of the working body

To determine the position of the bodies of the RO-D-system, we will adopt four rectangular coordinate systems: to establish

the position of the working body and the mixture — fixed $Q\xi\eta\varsigma$ and moving $Oxyz$ – rigidly connected with the working body, beginning at a zero point O (picture 1); to determine the position of the balance - the coordinate system $D\xi_1\eta_1\varsigma_1$ and $Dx_1y_1z_1$, which have a beginning in the center of mass unbalance. With this axis of the system $D\xi_1\eta_1\varsigma_1$ during the movement of the balance remain parallel axes $Q\xi\eta\varsigma$, and axis $Dx_1y_1z_1$ rigorously associated with imbalance. At the initial moment of time, the axes of each pair of coordinate systems coincide.
To move from a moving coordinate system to a fixed one, we take corners based on the principle of vibration taking into account the above assumptions. We shall write the kinetic energy of the system RO-D-S in the form

$$T = T_{RO} + T_D + T_S, \qquad (2)$$

where T – kinetic energy of the RO-D-system;
T_{RO} – kinetic energy of the RO-D-system
T_S – kinetic energy of the mixture, which is compacted with the help of a vibrating installation;
T_D – kinetic energy of the balance.
Determine the kinetic energy of the working body of the vibration installation. Based on the above assumption, the motion of the working body is regarded as spherical with respect to the zero point of O (Fig. 2). In this case, the expression of the kinetic energy of the working body is written in the form

$$T_{RO} = J\omega^2 = \frac{1}{2}(J_x\omega_x{}^2 + J_y\omega_y{}^2 + J_z\omega_z{}^2), \qquad (3)$$

where J – moment of inertia of the working body relative to the instantaneous axis of rotation;
ω – angular velocity of the working body in its rotation relative to the instantaneous axis;
J_x, J_y, J_z – moments of inertia of the working body relative to the corresponding axes;
$\omega_x, \omega_y, \omega_z$ – projections of the instantaneous angular velocity of the working body on the corresponding moving axis. For vibration axes, taking into account the above assumptions, we have

$$\omega_x = \dot{\theta},$$
$$\omega_y = \dot{\psi},$$
$$\omega_z = \dot{\varphi}$$
(4)

Given formula (4) expression (3) will look like

$$T_{RO} = \frac{1}{2}(J_x\dot{\theta}^2 + J_y\dot{\psi}^2 + J_z\dot{\varphi}^2).$$
(5)

Similarly, the kinetic energy of the mixture will be determined as

$$T_S = \frac{1}{2}(J_{xb}\dot{\theta}_1^2 + J_{yb}\dot{\psi}_1^2 + J_{zb}\dot{\varphi}_1^2), \qquad (6)$$

where J_x, J_y, J_z – the moments of inertia of the concrete mixture relative to the corresponding axes.
We will determine the kinetic energy of the balance by reasoning this way. We will write the expression of the kinetic energy of the balance according to the Kionig theorem in the form

$$T_D = \frac{1}{2}mv_D^2 + \frac{1}{2}J_D\omega_D^2 \qquad (7)$$

where m – mass of imbalance;
v_D – the absolute speed of the center of mass balance imbalance;
J_D – moment of inertia of the imbalance relative to the instantaneous axis of rotation;
ω_D — instantaneous angular velocity relative to instantaneous rotation axis.
Absolute velocity of point D - center of mass balance in its translational motion

$$v_D = (\dot{\xi}_D + \dot{\eta}_D + \dot{\varsigma}_D), \qquad (8)$$

Where $\dot{\xi}_D, \dot{\eta}_D, \dot{\varsigma}_D$ – projections of absolute velocity of the center of mass balance on the corresponding axis of a fixed coordinate system.
The absolute velocity of point D will be determined as the sum of the relative velocity of point D in its rotation around the axis and the speed of the point D', which is a projection of the center of mass balance on the axis and moves along with it.
Consideration of energy dissipation in elastic elements in the study of oscillations of an elastic system is due to complexity, since internal friction depends on a number of factors, the impact of which is complex and practically not subject to direct accounting. Among the many hypotheses describing dissipative forces, in recent times the Kelvin-Voigt hypothesis has become most widely used, according to which dissipative forces are proportional to the rates of deformation of elastic bonds. In this case, the normal stress is determined by the dependence

$$\sigma = E\varepsilon + \mu\dot{\varepsilon}, \qquad (9)$$

where E – modulus of elasticity;
ε – relative deformation;
μ – coefficient of internal resistance.
This hypothesis is relatively simple, but with sufficient accuracy characterizes the forces that arise during deformation of elastic bonds, and provides sufficient convergence with experimental data.
In fig. 3 shows a vibration cassette unit for the formation of reinforced concrete lintel.

Fig. 3: Industrial sample cassette installations with a working body

As a result of the experimental studies, the accepted design scheme of the mathematical model was confirmed, in which the moving frame together with the cassette form filled with concrete mix, in the process, performs spatial oscillations on which the normal impact on the concrete mix is superimposed by inserted vertical partitions in the form of plates which provide effective formation of concrete mixes.

Based on the experimental studies of the vibratory cassette installation in the operating mode, its basic parameters were refined to ensure the specified modes of vibratory impact on the seals environment during the formation of concrete and reinforced concrete products

During the factory tests, it was established that the vibration installation is efficient and easy to manufacture and operate, with its operation energy savings of up to 40 - 45% were achieved. The quality of the molded products complies with the requirements of the relevant regulatory documents, the noise level is 72 - 78 dBA. Vibration in the workplace of the operator of the vibration installation does not exceed the permissible norms. The discrepancy between the values of the actual vibration parameters, obtained directly during the formation of products, with the theoretical does not exceed 12%.

2. Results and Discussion

1. Analysis of the mentioned methods of taking into account the resistance in the practice of calculating the vibration separation machines contributes to the rational choice of the effective way to describe the dynamics of vibration compacting machines.

2. The proposed calculation scheme of the vibration unit with the spatial motion of the working body allows analytically to describe the process of compacting the concrete mixture during the formation of reinforced sleepers. The decision of the mathematical model will allow obtaining the amplitude of the oscillations (vibration acceleration) of the concrete mixture at any point of the form.

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