УДК69.00.25
DOI: https://doi.org/10.32347/tb.2024-41.0404

Володимир Слюсар
Phd student,
Assistant at the Department of Machinery and Equipment for Technological Processes,
Kyiv National University of Construction and Architecture,
31 Air Forces Avenue, Kyiv, 03037, Ukraine
ORCID: https://orcid.org/0000-0003-4332-3144
E-mail: sliusar.vs@knuba.edu.ua

METHODOLOGY FOR EXPERIMENTAL RESEARCH ON THE DISTRIBUTION OF ENERGY IN THE ELEMENTS OF THE «VIBRATION MACHINE – COMPACTING CONCRETE MIXTURE» SYSTEM

Abstract. *The paper presents a methodology for experimental research on the distribution of energy in the elements of a vibration machine for compacting concrete mixtures. The development of this methodology is based on a thorough analysis of existing research methods and the determination of energies in mechanical systems and media. Within the general system of the "vibration machine – compacting concrete mixture," the following subsystems were identified: bearings of the vibration exciter, supports, vibration dampers, reactive and active masses, including the form mass and the compacting concrete mixture. Specific research methods for energy dissipation were determined for each of the mentioned subsystems, preceding relevant modeling. Energy dissipation depends on many factors: the composition and structure of the material, cyclic deformation and stresses arising from the medium's exposure, the type and parameters of the load, the duration of cyclic deformation, and more. The evaluation criterion for energy dissipation in media is the energy absorption coefficient, which expresses the ratio of energy used to perform the technological process of compaction to the potential energy. The ratio of these energies is considered an independent material characteristic, determined experimentally, taking into account actual technological and operational factors. It was found that the following main methods are used to evaluate energy parameters: phase, damping oscillations, hysteresis loops, energy, and resonance methods. The paper substantiates the methodology for experimental research of parameters and energy indicators of concrete mixture compaction processes. Two models—discrete and continuous—were used in the simulation of these processes.*

Keywords: *research methods, energy dissipation, experiment, concrete mixture, vibration machine, vibration parameters, amplitude, stress frequency, deformation.*

1. Introduction. Modern requirements of the construction industry involve the use of machines and technologies that minimize energy consumption while achieving high-quality technological processes [1]. Among the various processes employed, significant roles are played by transportation, crushing, sorting, mixing, and compacting with the application of vibration [2]. The operation of any machine involving vibration, performing a material processing task, can be represented as an energy flow: the energy source, the machine drive, converts one type of energy into another (usually electrical to mechanical) and delivers it to the working unit. The drive includes an energy converter, a transmission, and a motion transformer. Thus, any technological process requires energy expenditure. In the general system "vibration machine – processing medium," corresponding subsystems exist: bearings of the vibration exciter, supports, vibration dampers, reactive and active masses, including the form mass and the processing medium. Each of these subsystems absorbs part of the energy, making the task of minimizing energy consumption across all subsystems while ensuring high-quality technological process execution highly relevant.

2. Analysis of literature data and problem statement. In the current state, several different approaches are used to study energy, which differ from each other in approaches to definition and the accepted type of mathematical model reflecting the behavior of a vibrational system [1]. Thus, the phase method is based on determining the phase shift angle between the external harmonic force[1] acting on the vibrational system and the movement of this system caused by it, or the deformation of the material, on which the force acts during oscillations. At the same time, this method is integral and it is not effective to separate into subsystems. The method of attenuating oscillations[1] consists in recording vibrograms of free attenuation oscillations of the system, according to which the logarithmic decrement of oscillations can be determined, which is related to the energy absorption coefficient by a certain ratio [1]. This method has the same drawback as the phase method and, moreover, it is rational for use in systems with low values of energy dissipation in the system. The energy method is based on the direct measurement of the flow rate of electrical or mechanical power of the vibration exciter to maintain constant oscillations of the system under study[1-3]. At the same time, in the balance of the entire power of the pathogen measured, only part of the power is spent directly on maintaining the vibrations of the system under study, and the rest of the power is spent on overcoming resistances in the pathogen itself and dissipated throughout the system of the vibration system. The resonance method is based on the construction of the amplitude-frequency characteristic of the vibration system in the resonance zone and the determination of the values of the relative energy dissipation coefficients[4]. The method of dynamic hysteresis loop consists in simultaneously registering stress and strain and graphically reproducing the relationship between stress and corresponding strain in the form of an experimental hysteresis loop[1], the area of which characterizes the dissipation of energy in the material. This method allows you to determine the energy directly for the process of vibration treatment, which is used in the work to determine the energies for compaction of the concrete mixture. The considered methods and their application in experiments indicate a significant discrepancy in the obtained values of parameters and characteristics that determine the scattering of energies and explain their relativity. The known calculated ratios for determining dissipative forces (vibration attenuation method, phase angle method, etc.) are based on the proposal of the laws of change of these forces (resistance proportional to the first power of the oscillation velocity). Since there is still no generally accepted model of a vibrating medium, it is advisable to use methods that allow you to directly determine resistance forces. Significant studies performed in the works [5-7] outlined the importance of the influence of the processing medium on the dynamics of the machine[8-10]. Therefore, the solution of the problem in determining the reality of the energy value is to substantiate a method that adequately reflects the real process and makes it possible to determine all the components of the energy absorbed by each subsystem of the general system "vibration machine - processing medium".

3. Purpose and objectives of the study. The purpose of the study is to select a research methodology and determine the distribution of energy in the elements of the system "vibration machine - compaction concrete mixture". To achieve the goal of the study, the following tasks are defined:

- substantiation and selection of the method of energy research in the elements of the system "vibration machine - compaction concrete mixture";
- development of a methodology and program for conducting an experimental study of energy in the elements of the system "vibration machine - compaction concrete mixture".

4. Justification and selection of the method for studying energy in the elements of the system "vibration machine - compaction concrete mixture".

4.1. With general approaches and prerequisites for determining energy research methods. Energy dissipation depends on many factors: the composition and structure of the material, cyclic deformation and stresses that occur when acting on the medium, the type and parameters of the load, the duration of the cyclic deformation and other properties and characteristics. The parameters that determine the fraction of energy per resistance and found by different methods are in the following ratios[1]:

$$\gamma = \frac{\delta}{\pi} = \frac{\psi}{2\pi} = \frac{bT}{2\pi m} = \frac{T}{\pi\tau} \qquad (1)$$

where: γ – is the coefficient of resistance; $\psi = \Delta w / w$ – energy absorption coefficient for one period in a unit volume of material; Δw – dissipated energy; w – is the energy supplied to the material; m is the oscillating mass; τ – is the relaxation time of the system with a decrease in the amplitude of oscillations by a factor of e.

In the general system "vibration machine – compaction concrete mixture", the corresponding subsystems were defined: oscillator bearings, supports, oscillation limiters, reactive and active masses, including mold mass, compaction concrete mixture. The following prerequisites and assumptions are accepted for each of these subsystems[3].

1. It is believed that the working body, which consists of masses: the oscillation exciter and the frame, as well as the shape, are systems with discrete parameters, in which the energy dissipation, both in the idle mode of oscillations and when loaded with a concrete mixture, does not change, but the difference in friction in the bearings is taken into account by the mass of the concrete mixture added in the compaction mode.
2. Compaction concrete mix is a system with distributed parameters.
3. Dependencies (1) will be used in the appropriate stages of the scattering study

4.2. Simulation of the vibration process of compaction of concrete mixture. The problem of modeling the vibration process of compaction of a concrete mixture is formulated as follows. We have a vibration platform with parameters: amplitude of oscillations, $\boldsymbol{X_0}$ and frequency of oscillations $\boldsymbol{\omega}$; mass $\boldsymbol{m}$ of particles of the mixture, having a density $\boldsymbol{\rho}$ and an average size $\boldsymbol{r}$, has an average velocity $\boldsymbol{v}$ relative to the vibrating working body; friction force $\boldsymbol{F_{tp}}$, which occurs between particles during oscillations, is proportional to the square of linear size. It is necessary to determine the value of a certain set of parameters of the vibration system, which provide the highest value of the compaction coefficient of the concrete mixture with limited values of specific labor $\overline{A}$ and specific power $\overline{P}$, which are determined by the formulas[1]:

$$\overline{A} = \frac{1}{2} x_0^2 \omega^2; \quad \overline{P} = \frac{1}{A\pi} x_0^2 \omega^3 \tag{2}$$

It is these formulas that take into account the degree of energy dissipation, which are provided for determination experimentally using the phase method and the method of dynamic hysteresis loop. In this case, it is decided that the initial parameter is the compaction coefficient:

$$K_y = \frac{\rho - \rho_0}{\rho} 100\% = \rho_c \tag{3}$$

Then the functional dependence to achieve the goal for solving the task is in the form of:

$$\rho_c = f\left(m_c, r, x_0\omega, F_{TP}, t, g, \overline{A}, \overline{P}\right). \tag{4}$$

Using the dimensionality method [2] , we get:

$$\rho_c = f\left(\frac{F_{TP}}{m x_o \omega^2}; \frac{v}{x_0 \omega}; \omega\, t; \frac{x_0 \omega^2}{g}; x_c^2 \omega_c^2; x_c \omega_c^3\right) \tag{5}$$

Here $\mathrm{F_{тр}} / \mathrm{m_c x_0 \omega^2}$ and $\nu / \alpha\omega$ the resistance of forces and velocities is characterized, respectively; other parameters are limiting.

So

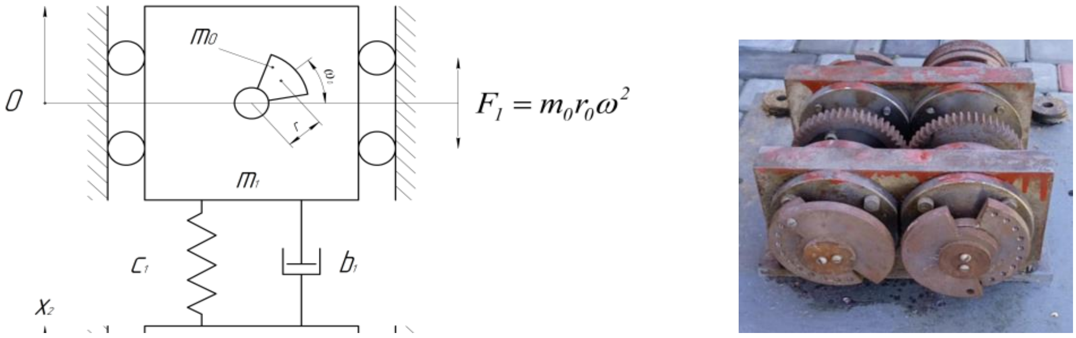
$$F_c = \frac{F_{TP}}{m x_0 \omega^2} = \frac{\mu\, r^2}{k \rho r^2 x_0 \omega^3} = \frac{\mu_1}{\rho r \omega v}, \quad \mu_1 = \frac{\mu}{k}, \quad k = \frac{4}{3}\pi, \tag{6}$$

that is, the ratio of the frictional force (μ is the proportionality coefficient) to the force acting on a particle of mass $\boldsymbol{M}$ is inversely proportional to the density of the concrete mixture $\boldsymbol{\rho}$, the amplitude of the excitation rate $\boldsymbol{v}$ of the particle size $\boldsymbol{R}$ and the frequency $\boldsymbol{\omega}$.

The defined method of modeling the vibration process of compaction of the concrete mixture makes it possible not only to estimate the energy for compaction, but also to determine the parameters of the vibration action, which provide the highest value of the compaction coefficient of the concrete mixture.

4.3. Simulation of the energy dissipation process in the bearing units of the exciter and in the vibration resistances of the vibration installation.

The design scheme of the vibration unit for compaction of the concrete mixture is a single-mass system (Fig. 1, a), and a centrifugal vibration exciter (Fig. 1, b), which is installed on the ground.



a *b*

Fig.1.Calculation scheme:
a - of the installation; b - the causative agent of oscillations

Four pairs of imbalances are fixed on two shafts of the vibration unit, rotating towards each other. In each pair, one imbalance is rigidly fixed on the shaft, and the second can be turned and fixed in relation to the first with the help of springs and a pin. This makes it possible to adjust the amplitude of vibration vibrations of the vibration unit within 0.1 to 1.0 mm. which allows you to adjust the frequency of forced oscillations from 0 to 6000 oscillations per minute. A feature of the drive is the presence of a reversible switch in the control circuit, which makes it possible to perform sharp braking of the engine and observe the behavior of the unit under study in the mode of free oscillations. The mold for the concrete mixture consists of a bottom and detachable sides, which allows you to change the geometric dimensions of the mold without changing its weight. The maximum size of the molded samples is 0.25x0.25x0.40 m. When determining the proportion of energy dissipation in the bearing units of the vibration unit, the energy method is used with the assumption that in the mode without technological load and in the mode of operation with a load, the resistance in the bearing units is the same. This assumption is due to the fact that the mass of the concrete mixture is much less than the active mass of the working body, taking into account the mass of the vibration pathogen and the mass of the mold. According to the design of supports and oscillation limiters, springs are selected that connect the masses to each other (Fig. 1,a) and rubber elements that implement vibration isolation of the installation from the foundation. Energy dissipation in elastic elements is supposed to be determined by the coefficient ***b*** by the method of attenuating oscillations [1]:

$$b = \frac{2\delta}{T} M_c , \tag{7}$$

where: δ - is the decrement of oscillations; T- is the period of oscillations; M_c – is the total mass of the vibration installation: M_c= $m_{р.о}$ + $m_{ф}$ + $m_{б.с.}$; $m_{р.о}$- is the active mass of the working body taking into account the mass of the oscillator exciter; $m_{ф}$- mass of the form; $m_{б.с}$- is the mass of the concrete mixture.

Determination of the geometric dimensions of supports and oscillation limiters is carried out by the static loading method. For this purpose, the length of the supports is measured in the direction of the action of the weight in an undeformed state (without load), and then the static draft of the spring is measured under the action of the weight force of the vibration system, i.e.:

$$x_{cm} = M_c g / c , \tag{8}$$

where: ***c*** - is the total rigidity of the supports;

From (8) we find the total rigidity of the supports:

$$c = M_c \frac{g}{x_{ст}} . \tag{9}$$

5. Development of a methodology and program for conducting an experimental study of energy in the elements of the system "vibration machine - compaction concrete mixture". To conduct experimental studies, an installation was designed, which consists of an oscillation exciter, two frames - active and reactive, a form with variable dimensions, supports connecting the frames to each other and supports connecting the reactive frame to the foundation. and the second can be turned and fixed in relation to the first by means of springs and a pin. This makes it possible to adjust the amplitude of vibration of the vibration platform within 0.1 - 1 mm. The drive of the vibration unit is a DC motor, which allows you to carry out the basic regulation of the frequency of forced oscillations from zero to 6000 oscillations per minute. A feature of the drive is the presence of a reversible switch in the control circuit, which makes it possible to perform sharp braking of the engine and observe the behavior of the system under study in the mode of free oscillations. The mold consists of a bottom and detachable sides, which allows you to change the geometric dimensions of the mold without changing its weight. The maximum size of molded samples is 0.3x0.3x0.5m. The experiments also used a one-piece mold measuring 0.3x0.3x0.4 m.

Table 1 Composition of concrete mixtures

Composition No.	Structure	V/c	Tightening
1	1:3:0	0,33	80+100
2	1:1,4:2,6	0,35	100+120
3	1:1,82:3,38	0,41	30+60

Table 2 Measured parameters of the system elements under study

<table>
<tr><td colspan="8">Concrete mix</td><td colspan="2">Parameters</td></tr>
<tr><td rowspan="2">Composition of the mixture Hardness</td><td rowspan="2">Density</td><td rowspan="2">Table</td><td rowspan="2">Height</td><td colspan="2">Dynamic pressure</td><td colspan="2">Amplitudes of oscillations at the limits</td><td rowspan="3">Static pressure</td><td rowspan="3">Amplitude of oscillations</td></tr>
<tr><td>At the bottom of the mold</td><td>In the mixture layer</td><td>At the bottom of the mold</td><td>Back to top borders</td></tr>
<tr><td>F, sec</td><td>$\rho, \frac{кg}{м^3}$</td><td>m, кg</td><td>$h, м$</td><td>$P_1, \frac{H}{м^2}$</td><td>$P_2, \frac{H}{м^2}$</td><td>$X_1, м$</td><td>$X_2, м$</td></tr>
<tr><td colspan="8">Vibration Installation</td><td rowspan="4">$\rho_{ст} \frac{H}{м^2}$</td><td rowspan="4">$X_{пр}, H$</td></tr>
<tr><td colspan="4">No mixture load</td><td colspan="4">Loaded with the mixture</td></tr>
<tr><td>Mass</td><td>Amplitude of oscillations</td><td>Oscillation frequency</td><td>Oscillation power</td><td>Amplitude of oscillations</td><td>Oscillation frequency</td><td colspan="2">Oscillation power</td></tr>
<tr><td>M_0, kg</td><td>$X_0, м$</td><td>f_0, hz</td><td>P_0, kW</td><td>$X_{0з}, м$</td><td>f, hz</td><td colspan="2">$P_{вз}$, kW</td></tr>
</table>

The methodology of experimental research provides for the following sequence:

- fixation of the initial parameters of the parameters of the unloaded vibration installation were recorded and recorded in the corresponding graphs (Table 1);
- composition of selected concrete mixtures (Table 1);

- installation of sensors, loading the mold with concrete mixture according to the experiment scheme;
- synchronous registration from all devices and sensors for each series of experiments (Table 2);
- numerical values of parameters based on the results of experiments (Table 3).

Experiments were carried out on concrete mixtures with a hardness of 30-120 seconds. (Table 3), which include almost all compounds used in the formation of products on vibrating platforms [32].

Table 3.Calculated parameters of the system under study

Concrete mix							
Distributed parameters					Discrete parameters		
Dynamic modulus of elasticity	Speed of propagation of oscillations	Absorption rate	Odds price Resistance	Stiffness coefficient	Mass characterizing inertial mass component	Decrement of oscillations	Coefficient of inelastic resistance
$E, \frac{H}{м^2}$	$C, \frac{м}{\sec}$	ψ	γ	$K, \frac{H}{м}$	$m_{ин}, кg$	δ	γ
Vibration Installation							
Natural frequency of oscillations			Decrement of oscillations		Coefficient of inelastic resistance		
$\omega_0, \frac{1}{\sec}$			δ_0		γ_0		

The methodology provides for research in a constant mode of oscillations and in the mode of fading oscillations. The limits of parameter variation are given in Table 4.

Table 4. Limits of change in the parameters of the system under study.

A series of experiments	System parameters		
	Permanent	Displacement	Limits of variation
1	$M_0, X_0, f_0,$ $m, ж$	ρ, h	$\rho = 1,6 + 2,4 \cdot 10^3 кg / м^3$ $h = 0,1 + 0,6 м$ in steps $0.1 м$
2	$M_0, X_0, \rho,$ $m, ж$	f, h	$f = 0 + 75$ Hz *through* 10 Hz $h = 0,1 + 0,6 м$ in steps $0,1 м$
3	$X_0, \rho,$ $h, ж$	$f, \frac{m}{M_0}$	$f = 0.75$ Hz througt 10 Hz $\frac{m}{M_0} = 0,2 + 1,0$ with an interval 0,2
4	$M_0, f_0 \cdot \rho_7$ $m, ж, h.$	X_0	$X_0 = 0,3 + 0,8 мм$ with an interval $0,1 мм$
5	$M_0, f_0, X_0,$ m, ρ, h	W	$ж = 30 + 100$ sec with an interval ~ 20 sec
6	$M_0, X_0,$ $m, \rho.$	h, f, P_{cm}	$h = 0,1 + 0,5 м$ *in increments* $0,1 м$ $f = 10 + 50 Hz$ through 10 Hz $P_{CT} = (10 + 100) \cdot 10^2 н / м^2$ through $25 \cdot 10 \ldots н / м^2$

6. Discussion of research results. The method of experimental study of energy distribution in the elements of a vibrating machine for compaction of concrete mixtures, which is proposed in the paper (dependencies 2,7-9) is based on the provisions of the classical theory of mechanical oscillations and the theory of continuous media. An experimental research setup has been developed, consisting of an oscillator exciter, two frames - active and reactive, a form with variable dimensions, supports connecting the frames to each other and supports connecting the reactive frame to the foundation will fully ensure the achieved goal of the work. methods of energy distribution research, which is envisaged in further research. The proposed technique can also be used in research on other technological processes, for example, vibration screens, conveyors.

7. Conclusions:

1. The evaluative criterion of the energy dissipation process is the energy absorption coefficient, which expresses the ratio of energy spent on the performance of the compaction process to potential energy. The ratio of these energies is considered as an independent characteristic of the material, which is determined experimentally, taking into account real technological and operational factors.
2. The analysis of existing methods for determining the dissipation of energy in media and materials according to various laws of change in energy indicators depending on changes in the properties of energy indicators and loads is carried out.
3. It was found that the following main methods are used to assess energy indicators: hysteresis loops, phase, attenuation oscillations, energy and resonance. based on the use of the hysteresis loop.
4. The developed method of experimental research in the elements of the system "vibration machine – compaction concrete mixture" makes it possible not only to estimate the energy for compaction, but also to determine the parameters of vibration action, which provide the highest value of the compaction coefficient of the concrete mixture.

References

1. Nazarenko I.I. Applied Problems of the Theory of Vibration Systems. Textbook (2nd edition).- Kyiv: Slovo Publishing House, 2010. – 440 p. (in Russian).
2. Serdyuk L.I. Fundamentals of the Theory of Dimensions, Theory of Similarity and Mathematical Modeling. Tutorial. Poltava: PNTU.2002.-98 p.
3. V.S. Slyusar. Methods of Experimental Study of Energy Distribution in the Elements of the System "Vibration Machine – Compacted Concrete Mixture", V International Scientific and Practical Conference "Energy-Saving Machines and Technologies", Kyiv, 2024, pp. 22-25
4. Bernyk I.M. Energy of Cavitation Processing of the Technological Environment. – 2015. – Volume 1 (47). - P.123–129.
5. Ivan Nazarenko,Viktor Gaidaichuk, Oleg Dedov, Oleksandr Diachenko. Determination of stresses and strains in the shaping structure under spatial load. EasternEuropeanJournalofEnterprise Technologies. 2018. Vol 6, No 7 (96). P. 13–18. https://doi.org/10.15587/1729-4061.2018.147195
6. Nesterenko M.P. Molchanov, V.M. Savyk, M.M. Nesterenko // Vibration platform for forming large-size-drein forced concrete products. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 2019, No 5. – P. 284 – 288.https://doi.org/10.29202/nvngu/2019-5/8
7. Nazarenko, I., Svidersky, A., Kostenyuk, A., Kyzminec, N., Slipetskyi, V. Determination of the Workflowof Energy-Saving Vibration Unitwith Polyphase Spectrum of Vibrations/ Eastern-European Journal of Enterprise Technologies this linkis disabled, 2020, 1(7-103), стр. 43–49
8. Delembovsky, M., Klymenko, M., & Korniychuk, B. (2020). Research based on fuzzy logic of the model for detecting failures of vibration pads. Collection of scientific papers ΛΌГОΣ, 111-112. https://doi.org/10.36074/25.12.2020.v1.38
9. Fundamentals of the theory of interaction of working bodies of construction machines with stress-strain medium. Nazarenko I.I., Smirnov V.M., Fomin A.V., Sviderskyi A.T., Kosteniuk O.O., Dedov O.P., Zukhba A.G.; edited by I.I. Nazarenko: monograph. Kyiv: MP Lesya, 2010. 216 p.
10. Nesterenko M.M. Methods of calculation of percussion-vibration installations for the manufacture of products from light concrete for energy-efficient reconstruction of buildings in Ukraine / M.M. Nesterenko, T.M. Nesterenko, N.M. Magas // Scientific Bulletin of Construction. – T. 88. – № 2. – 2017. – C. 178 – 182.