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EXPERIMENTAL STUDIES OF FORMING DESIGN AT DYNAMIC LOAD

Об'єктом досліджень є процес руху формоутворюючої конструкції вібраційної установки із просторовими коливаннями. Основним недоліком подібних вібросистем є відсутність даних про взаємовплив машин і середовищ. Розроблена та виготовлена експериментальна вібраційна установка. Установка обладнана двома асиметрично встановленими вібраційними збуджувачами коливань, які прикріплені безпосередньо до формоутворюючої поверхні. Запропоновано нову методику вимірювання руху формоутворюючої конструкції із розташуванням датчиків в зонах динамічного навантаження. В основу їхнього розташування покладено передумову визначення контактних сил взаємодії підсистем між собою. А також оцінку співвідношення часу дії та часу розповсюдження хвиль. Такий підхід є новим, оскільки враховує реальні співвідношення динамічних параметрів машини і середовища між собою і ступінь взаємовпливу. В ході дослідження використовувалися записи безперервної фіксації розподілення активних коливань формоутворюючої поверхні. Отримано принципово новий результат, який полягає в тому, що перехідний процес передбачено враховувати при визначені параметрів та місць розташування вібраторів. Завдяки цьому реалізуються форми власних коливань системи з більшими за значенням амплітудами коливань та відповідно нижчою частотою. У порівнянні з аналогічними відомими конструкціями віброустановок це дозволяє значно зменшити енергоємність приводів вібраційної машини. Застосування пневматичних збудників в реальних заводських умовах знижує рівень шуму та прискорює швидкодію процесу ущільнення бетонної суміші. Розроблені практичні рекомендації для раціонального конструктивного оформлення перерізів формоутворюючої конструкції. Визначені технологічні параметри коливань з новими значеннями вихідних числових значень амплітудно-частотного режиму збудника коливань. Для конструювання подібних формоутворюючих конструкцій визначені місця установки вібраторів. Отримані результати можуть бути використані у суміжних процесах, наприклад, в горнорудній промисловості, як активні поверхні для транспортування руди, для переміщення суспензій і розчинів в хімічній промисловості.

Ключові слова: *експериментальна модель, формоутворююча конструкція, просторове навантаження, напружено-деформований стан.*

1. Introduction

At the present stage of development of the construction industry there is an urgent problem of introducing such technologies and machines, which make it possible to ensure high quality of the finished product, a significant reduction in energy costs and increased productivity. Energy saving is an urgent task of research and development. Vibration machines and processes occupy an important place in the construction industry. With the help of vibration, the processes of grinding, sorting, transportation, mixing and compaction are carried out. As a rule, such machines are designed and created on the basis of design models that take into account the characteristics of the processing medium and the machine with discrete parameters. To date, there is a significant discrepancy between the existing physical and mathematical models that describe the movement of vibration machines and sealing media. This lack of generally accepted computational models adequately reflects the real picture of the movement of the machine and the movement of the processing material makes it difficult to develop an effective vibration technique. The behavior of metal structures of machines of this type under the action of dynamic loads was studied very little. Performing experimental studies of models is the basis for creating a new class of machines with minimizing energy costs.

2. The object of research and its technological audit

The object of research is the movement process of forming structures of a vibration unit with spatial oscillations. The main disadvantage of such vibration systems is the lack of data on the mutual influence of machines and media.

The vibration unit simultaneously performs the function of a mold for a concrete mix and consists of a welded box-section frame, which is installed on rubber elastic supports on a concrete foundation. Vibration unit is equipped with two, not symmetrical installed centrifugal generators of high-frequency oscillations. Two non-removable sides and one movable side are fixed on the frame. A geometric 3D model is created to study the vibration unit, on the basis of which the design finite element model is developed (Fig. 1).

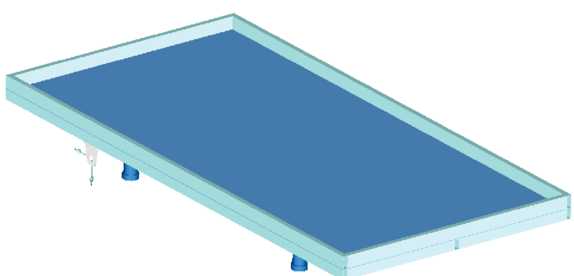

Fig. 1. Design 3D model of vibration unit for the formation and compaction of concrete mixtures

The preliminary calculations are performed to determine simple and more complex waveforms. The choice is the possibility of implementing modes of operation with higher levels of energy transfer to the processed medium.

The most interesting issue in the study of such structures is the determination of the laws of energy transfer from the forming surfaces to the processed medium. As well as the use of wave phenomena in the forming surfaces in the implementation of operating modes at the main oscillation frequencies.

3. The aim and objectives of research

The aim of research is experimentally determination of the amplitudes of oscillation forming the surface of the structure of the vibration unit.

To achieve this aim, the following objectives are defined:

1. To develop an experimental model of vibration unit with active forming surfaces.
2. To evaluate the basic frequencies and amplitudes of oscillation of forming surfaces.
3. To test the hypothesis of the presence of wave phenomena in the forming surfaces of the structure of the vibration unit.

4. Research of existing solutions of the problem

A number of works are devoted to the study of vibration units. Thus, in [1], an approach for modeling dynamic systems with distributed parameters is proposed. The given method of taking into account not only elastic, but also dissipative properties of the medium processed during oscillation. In [2], an analytical method is proposed for determining the influence of the processed medium on the dynamics of the «machine – medium» system. The analytical dependences for estimating the influence of the medium resistance at poly-frequency oscillations are obtained. In [3], studies of a shock vibration machine for molding concrete products are given. Studies are based on the determination of the reduced mass and the equivalent coefficient of resistance of a concrete mix. As a result, the dependences for the description of wave phenomena in the medium are obtained. However, the results of experimental determination of the dynamic parameters of the investigated units in the above works are absent. The authors of [4] consider a dynamic system capable of accumulating internal energy. Phenomena in complex nonlinear systems, as the authors note, are promising direction and require additional research. Experimental studies of the oscillatory system using measurements of accelerations are given in [5]. The study is based on a certain oscillation spectrum and the identification of natural oscillation frequencies. The method can be used to study more complex dynamic systems. Measurements of the dynamic characteristics of systems in order to identify defects in structural elements are described in [6, 7]. In these works, the technique of applying experimental studies of vibration and their processing is presented. It is proposed to improve the computational model based on the obtained dynamic characteristics. Such an approach can be used to verify the conformity of the mathematical and experimental models of the investigated complex dynamic systems [8, 9]. In [10], the method is applied to nonlinear active vibration control systems. As the authors note, the advantage of such an integral method is that there is no need to know the system parameters, such as mass, attenuation and stiffness coefficients, which are usually obtained by finite element methods. According to the measurement of oscillations, acceleration measurement sensors are usually used [11]. But at the same time there are alternative solutions. Thus, in [12], options for remote measurement of oscillations using laser and optical devices are considered. And the use of oscillation sensor based on an optical fiber is proposed in [13]. Of course, such data acquisition systems are highly accurate and sensitive. But their application is limited to high cost.

Thus, the results of literary analysis allow to conclude that acceleration measurement sensors are used to measure dynamic parameters. The use of strain gauge measurement

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methods is one of the modern and effective for fixing dynamic parameters. This is due to the ability to simultaneously record both numerical and qualitative characteristics, taking into account the phase shift.

5. Methods of research

To implement the research of vibration unit, the following sequence of research works is assumed:
- analysis of calculations of the structural elements of the machine in terms of accounting for all types of loads that are carried out in the machine design;
- development of a computer model of the object of research (general or some of the most loaded nodes, structural elements);
- carrying out additional modeling and calculations to determine the behavior of structural elements and the machine as a whole, while the various loads act simultaneously;
- development on a computer model of a matrix of control points of limiting values of integral characteristics of the structure state for further use in field tests;
- carrying out field tests by applying certain loads on its model;
- adjustments of the computer model until the comparison of the integral characteristics obtained by measuring at the control points during the experiment and in the simulation will differ among themselves within the limits of the permissible error. The computer model obtained in this way will be adequate to the real construction within the limits of adequacy – the points of the integral characteristics control.

In the case of modernization of the existing machine model for technological purposes, the computational model in such a complex will allow analyzing the technical level of the structure and predicting its reliability. And in combination with the performed experimental studies, assess the current technical condition, the appearance of possible failures, and the like.

On the basis of such studies, it is possible to assess the nature and magnitude of the change in the stress-strain state of elements and steel structures as a whole. This will make it possible to determine the quality of the fabrication of the structure and its compliance with the design data (performance of welds, bolted joints, structural integrity).

6. Research results

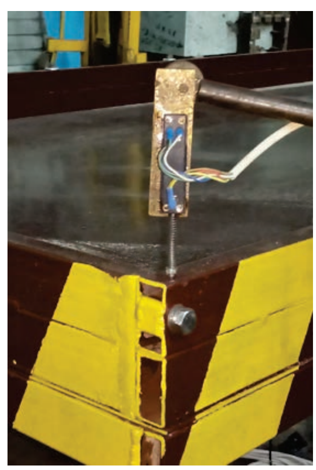
The experimental model of the vibration unit is developed on the basis of studies of the computational model [13]. Vibration experimental unit is made of metal. The design consists of a welded tubular frame with forming surfaces. The frame rests on rubber elastic supports. A general view of the vibration unit is shown in Fig. 2.

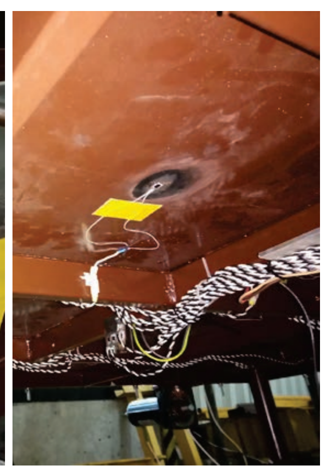
The vibration unit is equipped with two asymmetrically mounted vibration exciters (Fig. 3), which are attached to the frame with fasteners. To control the excitation frequency and the unbalance position in space, the vibration exciters are equipped with unbalance position sensors.

To determine the amplitude of oscillations, inductive type displacement sensors are used (Fig. 4, *a*). The condition of the forming surfaces is monitored using strain sensors (Fig. 4, *b*).

Fig. 2. General view of the vibration unit

Fig. 3. The vibration exciter with unbalance position sensor





a *b*

Fig. 4. Sensor: *a* – displacements; *b* – deformations

The oscillation amplitude of the investigated unit is determined on the basis of measurements of amplitudes at three points located along the structure. The control of the deformed state of the forming surfaces is carried out on the basis of data from 18 strain gauges. The layout of the measurement sensors is shown in Fig. 5.

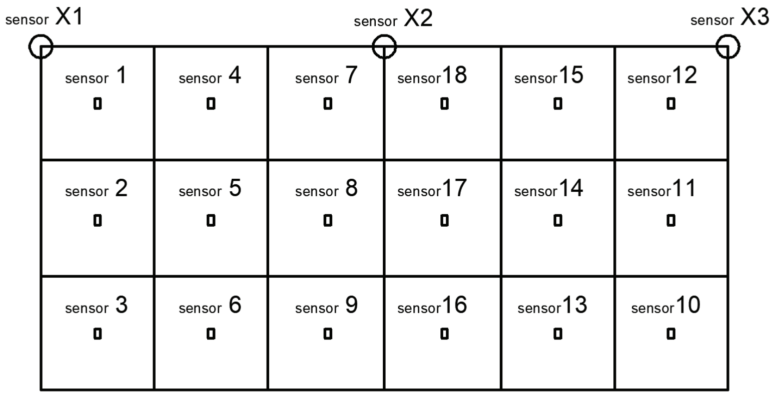


Fig. 5. Layout of measurement sensors

Data readings from sensors and their subsequent processing are carried out using the developed circuit based on a 32-bit controller with two independent analog-digital converters. Such a system provides the speed of sampling signals from 20 kHz sensors. Data processing is carried out using a PC. A general view of the experimental unit with the measurement system is shown in Fig. 6.

When conducting experimental studies, a number of oscillograms are obtained on various operating modes of the vibration unit. Typical oscillograms are shown in Fig. 7. As can be seen from the oscillogram in Fig. 6, there are transients, which are explained by a change in the oscillation frequency.

After processing the received oscillograms of vibration unit movements, the main oscillation frequencies are determined. Also, the waveforms that are carried out at these frequencies are analyzed. So, with an excitation frequency of 12.5 Hz, the forming surfaces perform vertical oscillations (Fig. 8). The movement of the unit occurs in the common mode, which indicates the realization of the oscillation form, when the whole structure moves progressively in the vertical direction. So, to determine the amplitude of oscillations, sensors of inductive type are used (Fig. 4, *a*). The condition of the forming surfaces is monitored using strain sensors (Fig. 4, *b*).

The motion of the vibration unit at an excitation frequency of 18.6 Hz and 24.3 Hz, in contrast to the previous one, indicates the realization of an oscillation form with anti-phase movement (Fig. 9, 10).

To assess the stress-strain state of forming structures, the data of strain sensors are analyzed. Based on the obtained results, the following can be noted. When implementing the operating mode at a frequency of 24.3 Hz, a complex stress-strain state arises in the forming surfaces.

This is evidenced by various forms and values of deformation in the corresponding parts of the surface. It should also be noted about the presence of wave phenomena (Fig. 11, 12), which occur in the forming surfaces.

Fig. 6. General view of the experimental unit

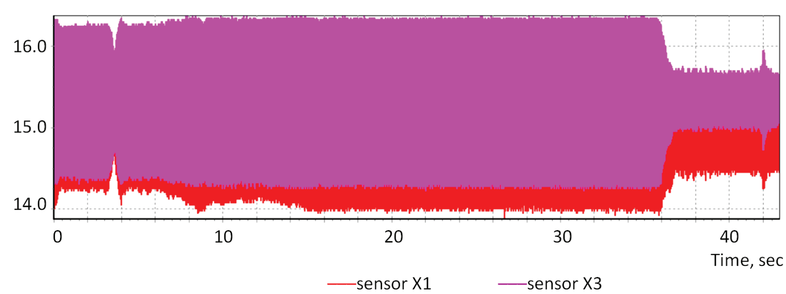


Fig. 7. Oscillogram of vibration unit movement

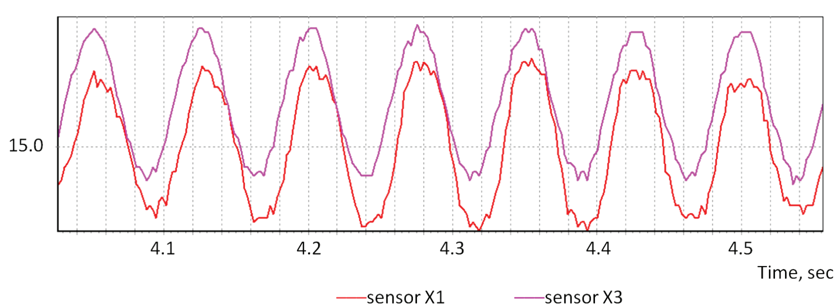


Fig. 8. Oscillogram of the vibration unit movement at an oscillation frequency of 12.5 Hz

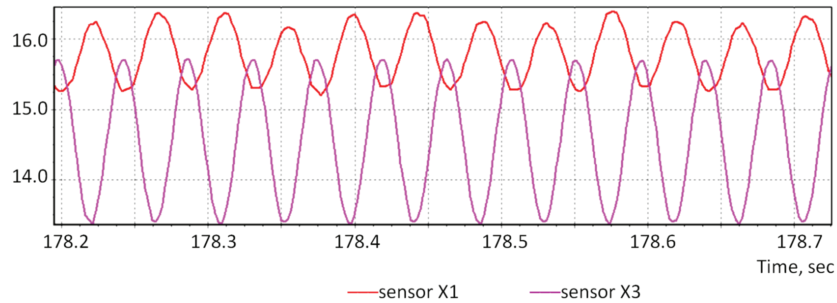


Fig. 9. Oscillogram of the vibration unit movement at an oscillation frequency of 18.6 Hz

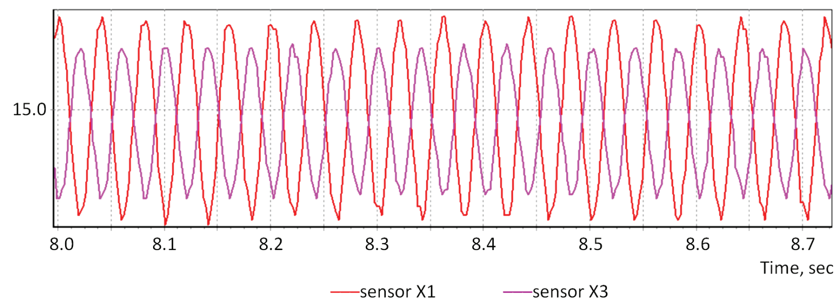


Fig. 10. Oscillogram of the vibration unit movement at an oscillation frequency of 24.3 Hz

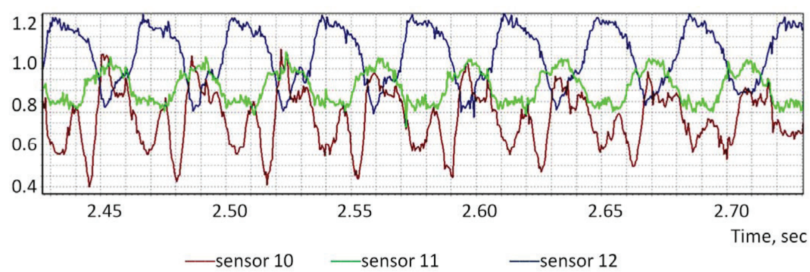


Fig. 11. Deformations of the forming surfaces at an oscillation frequency of 24.3 Hz (sensors 10, 11, 12 (Fig. 5))

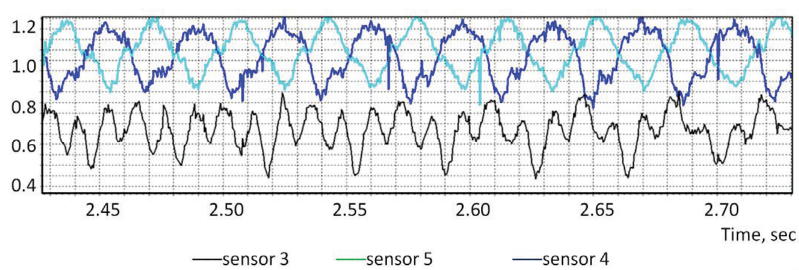


Fig. 12. Deformations of the forming surfaces at an oscillation frequency of 24.3 Hz (sensors 3, 4, 5 (Fig. 5))

Thus, the presence of poly-frequency (Fig. 11, 12, sensors 4, 12) and anti-phase character (Fig. 12, sensors 3, 5) of oscillograms indicates wave propagation both in the longitudinal and in the transverse directions of the structure.

7. SWOT analysis of research results

Strengths. Research results indicate the presence of complex oscillation forms of forming frame of vibration unit. Thus, the possibility of implementing modes of operation in the presence of wave phenomena in the forming surface is confirmed. This is a proof of research conducted by the authors in [14].

Weaknesses. This research has limitations, since unexplored modes of unit operation at higher vibration frequencies. As well as the necessary calculations of qualitative and quantitative indicators of changes in the stress-strain state of the forming surfaces. For objective analysis, several other methods should be applied, such as spectral or wavelet analysis. Such studies are planned by the authors for the future.

Opportunities. A promising direction for further research is the need to search for possible locations of the vibration exciter on the forming surfaces. The second direction of research is the use of parametric oscillations in such systems. In theoretical studies, this solution is effective. The problem is only in the absence of effective constructive and reliable solutions to implement such fluctuations. The possibilities of such research lie in the plane of the development of practical recommendations for the rational constructive design of sections of forming structures. As well as the development on the basis of certain technological parameters of oscillations of the latest structures similar to the investigated.

Threats. The rapid development of the construction industry of Ukraine in the direction of the use of frame-monolithic technology for the construction of buildings and structures displaces machines of this type from the market. But foreign experience shows that there is no need for such machines. The threat may be the lack of machines of this class on the Ukrainian market and the loss of production capacity, which can be applied to the object of research.

Among the threats to this area of research is the attempt of technologists to use auxiliary additives to reduce the need to use vibration methods. At the same time, additional studies of the life cycle of the structures created using this technology are required. Abroad there are similar solutions for other environments.

8. Conclusions

1. On the basis of preliminary calculations and modeling of frame bearing elements by beam finite elements, elastically deformed under the action of longitudinal force, bending moments in two planes and torque, an experimental model of vibration unit with active forming surfaces is developed. In the investigation of the system, principles are applied that ensured the model adequacy, as well as the possibility of further research – solving other types of problems.

2. The main oscillation frequencies are determined, which are realized at 12.50 Hz, 18.60 Hz and 24.30 Hz. At the same time, oscillation forms with complex movement of forming surfaces are realized.

3. The presence of wave phenomena in the forming surface is experimentally proved when implementing modes of operation at the main frequencies of oscillations. The amplitudes of oscillations of the unit in the range of 0.0006...0.0003 m are determined at excitation frequencies of 18.60 Hz and 24.30 Hz.

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