Розроблена розрахункова модель системи машина – середовище із врахуванням взаємовпливу робочого органу і ущільнюючої суміші. В основу покладено умову визначення контактних сил взаємодії підсистем між собою та 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.

Дослідження та визначення напружень і деформацій у часі підтвердили гіпотезу про суттєвий вплив на процес. Виявлено принципово новий результат, який полягає в тому, що перехідний процес передбачено враховувати при визначені параметрів та місць розташування вібраторів. Встановлені закони зміни напружень і деформацій при просторових коливаннях формоутворюючої поверхні. Реалізуються форми власних коливань системи з більшими за значенням амплітудами коливань та відповідно нижчою частотою. А це відкриває реальну можливість зменшити енергоємність приводів вібраційної машини. Отримані числові значення напружень та характер розподілу в формоутворюючій поверхні в залежності від кута миттєвого напрямку дії зовнішньої сили вібраторів засвідчили наявність згинальних і крутильних коливань. Зокрема, за умов прикладання двох сил збурення, точки прикладення яких зміщенні одна відносно одної на ½ довжини конструкції. Розташування точок прикладання симетрично на відстані ¼ довжини конструкції по обидва боки дозволили отримання синфазних та протифазних напрямків напружень і діючої зовнішньої дії.

В розрахунках вібраційних машин із використанням формоутворюючих поверхонь запропоновано враховувати вихідні числові значення амплітудно-частотного режиму збудника коливань. Розроблені практичні рекомендації для раціонального конструктивного оформлення перерізів формоутворюючої конструкції та визначені технологічні параметри. Для конструювання подібних формоутворюючих конструкцій, визначені місця установки вібраторів. Отримані результати можуть бути використані у суміжних процесах, наприклад, в горно рудній промисловості, як активні поверхні для транспортування руди, для переміщення суспензій і розчинів в хімічній промисловості

Ключові слова: розрахункова модель, формоутворююча конструкція, просторове навантаження, напружено-деформований стан, бетонна суміш

UDC 69.00.25
DOI: 10.15587/1729-4061.2018.147195

DETERMINATION OF STRESSES AND STRAINS IN THE SHAPING STRUCTURE UNDER SPATIAL LOAD

I. Nazarenko
Doctor of Technical Sciences, Professor, Head of Department*
E-mail: i_nazar@i.ua

V. Gaidaichuk
Doctor of Technical Sciences, Professor, Head of Department
Department of theoretical mechanics**
E-mail: viktor_gaydaychuk@bigmir.net

O. Dedov
PhD, Associate Professor*
E-mail: dedovvcbk@ukr.net

O. Diachenko
Postgraduate student*
E-mail: sanyadrg@gmail.com

*Department of machinery and equipment of technological processes**
**Kyiv National University of Construction and Architecture
Povitroflotskyi ave., 31, Kyiv, Ukraine, 03037

1. Introduction

At the present stage, the vibration equipment for the construction industry is based on the use of linear above resonance modes. Such modes are characterized by considerable energy consumption of technological processes. This is typical for concrete mix compaction processes, as well as processes such as grinding, sorting, mixing. Therefore, the problem of finding more effective design and technological solutions is relevant. With the development of the theory of oscillations of discrete-continuous systems, the idea of possible joint purposeful use of internal properties of a machine and the environment appeared. The implementation of the idea consists in the development of such computational models that take into account the mutual influence of the machine and the environment on the overall movement of the machine – environment system. The solution will accurately calculate and guarantee the minimum energy consumption and the necessary parameters. Rational design parameters require the determination of the magnitude and nature of stress and strain distribution in machine elements. This applies substantially to the working bodies of machines that directly transmit energy to the environment. Accounting of stresses reveals fundamentally new trends in the study and development of a new class of equipment. In this case, the necessary structural strength is to be provided.

2. Literature review and problem statement

The defining parameter, which essentially affects the nature of stress distribution in plane structures under vibration, is oscillation frequency. In [1], it was noted that the analysis of natural oscillations of plate structures is an important area of research due to the wide application in equipment. The influence of various ratios of sides and boundaries of thick and thin plates was considered. The influence of other materials in contact with plates was not taken into account. No stress studies were given. This confirms the necessity and relevance of the study of stresses and strains in the shaping surface. In [2], frequencies and shapes were determined by solving the problem with eigenvalues of the matrix equation of a system with a set of degrees of freedom. The Lagrange's equations of motion were applied. The influence of stiffening ribs on the vibration response was determined. Stresses and kinetic energies were added to the corresponding energies of the plate. The studies were performed for the analysis of vibrations of orthotropic plates without considering the properties of various other materials. This is also noted by the authors of the present paper [2], indicating that further research should take into account the properties of various other materials and more complex structures. The work [3] is close in terms of taking note of the influence of the material with other properties on the behavior of a beam. It presents the study of bending and torsional oscillations of beams on the foundation. Natural frequencies for the torsional mode exist independently, increase with increasing thickness ratio. As the rigidity of elastic elements and shear increase, the frequency parameter increases regardless of the vibration mode. Under spatial load, complex oscillations arise and division into torsional and bending oscillations is a kind of assumption. Such an assumption is valid in the framework of solving a certain research problem under certain conditions. In this case, there is no evidence of rational design taking into account the stress state of the plate. One of the directions for reducing the energy intensity of the working process is the use of parametric resonance [4] as a phenomenon of the resonant gain of the system's motion. Compared to usual resonance, it allows obtaining higher output power for the accumulation of vibration energy. This approach is rational for small and low-powered devices. Vibration machines in the construction industry are characterized by significant weight and variation of the properties of the processed medium. This creates considerable structural difficulties for the implementation of parametric resonance. The problem of designing vibration systems having their own necessary structure was considered in [5]. The proposed method completely depends on receptors and was applied to linear continuous systems, i.e. for the steady linear mode of oscillations. There are no studies of stresses and strains in other modes. The above works deal with research in the implementation of linear vibration. The study of nonlinear oscillations is given in [6]. It presents the theory of feedback for processing a nonlinear vibration system. The feature of the method is that it does not require a type and parameters of nonlinearity. But this condition is valid if the input and output degrees of freedom are beyond the nonlinearity itself. An important parameter for the determination of stresses and strains is the consideration of dissipative forces. The paper [7] presents studies on accounting for dissipation using a hysteresis loop. The hysteresis loop is given in the force – displacement coordinates. For a more general picture of the energy dissipation effect, use should be made of the stress and strain relationship. The confirmation consists in practical implementation with the fixing of the hysteresis loop. The paper [8] presents the results of discussion of the design and development of a test facility for assessing the beam characteristics under vibration load. The model reflects the application of force at one point, which narrows the range of use and makes it impossible to practically check spatial oscillations of the beam under a complex load. Much attention is paid to numerical research methods. Direct numerical simulation using finite elements [9] allowed homogenizing high frequencies for periodic media. It was found that in periodic media there are frequencies for which constant waves, periodic with period or double period arise. The modal and harmonic analysis of the vibration screen and vibration frame of the machine for industrial and mining enterprises under conditions of high-intensity loading was carried out [10]. In [11], the linear theory of viscoelasticity based on the Kelvin-Voigt model for dual-porosity materials was considered. In [12], on the basis of the modified couple stress theory, free oscillations of the orthotropic plate were considered and analyzed. Conclusions on the directed use of stresses as input information for rational design were not given. The influence of the scaling effect on the results of numerical calculations was noted, but there is no mention of such influence in case of large plate sizes. In [13], numerical simulation of vortex oscillations of a vertical tensioner in the conditions of sinusoidal vibration excitation was used. Similar approaches can be used when modeling the movement of the supports of the shaping surface. Oscillations of plane surfaces, as a means to create an auxiliary effect, in concrete mix compaction were called shaping in [14]. In the work, natural frequencies were determined and the impact on the process was estimated. The need for further studies of the stress state of plane surfaces was noted. In [15], a vibration cassette system with horizontally directed oscillations was investigated. Oscillations and stresses of the inserted vertical plates were not taken into account. They have a frame and special shape for mixture placing and do not use any elements to enhance the compaction effect. In [16], the interaction of the vibrating plate with concrete mixture was investigated. The plate was modeled as a solid body without account for stresses and strains. The analysis and evaluation of the studies of the stress-strain state of plane surfaces confirm the existence of the problem of stress and strain determination for use and further development of vibration equipment for the construction industry.

3. The aim and objectives of the study

The aim of the work is to determine stresses and strains in the shaping structure of the vibration unit, taking into account the impact on the efficiency of the compaction process and rational structural solutions.

To achieve the aim, the following objectives were identified:

– to develop and validate a computational model for taking into account the interaction between the working body and the compaction mixture;

– to select the scheme of the shaping structure of the vibration unit and implement studies and calculations;

– to develop practical recommendations for improving the efficiency of the concrete mix compaction process.

4. Method of developing a computational model for taking into account the interaction between the working body and the compaction mixture

When developing the computational model of the system, the condition of maximum approximation of the model to the real process was used. The basis for model validation was the estimation of the ratio of the time of vibration for the period to the time of wave propagation. The shaping structure was modeled by a distributed parameter system. Not only elastic, but also dissipative properties were taken into account. In contrast to [14], the environment processed during oscillation in the system motion equations is represented by the reaction [17]. The reaction consists of the sum of squares of two terms. Physically, they determine the degree of influence of the elastic-inertial (reactive) and dissipative (active) components of the forces of the environment on the movement of the system as a whole.

When creating a finite-element model, the values of the geometric parameters of specific elements of the investigated structure were selected from the drawings prepared in the AutoCAD system.

Verification calculations of the strength and stability of the structure were carried out by the finite element method. The finite element model of the structure was developed through approximating all structural elements by SOLID type finite elements, elastically deformed under the action of the longitudinal force, bending moments in two planes and torque.

5. Selection of the scheme of the shaping structure of the vibration unit and implementation of studies and calculations

In order to study and determine stresses and strains in accordance with the aim, it is necessary to compute bearing structures of the system in its most critical states. Therefore, the design of the vibration unit, which is a shaping surface for concrete mix compaction, is chosen for the research. The design consists of a welded box-section frame, mounted on rubber elastic supports and a metal sheet as a shaping surface. The load from auxiliary structural elements and concrete mix was included in the dynamic component of forces.

The computational scheme is based on finite element simulation. SOLID type finite elements were taken for simulation. Application of bulky finite elements allows obtaining the results of calculations containing the maximum amount of data on the stresses and strains in three-dimensional space. Thus, the created model has a total number of finite elements equal to 59856, the number of nodes is 100998. It is assumed that the frame of the structure is rigidly fixed on rubber supports, and materials of all elements are deformed only in the elastic stage.

The nature of the stress-strain state of the structure under the influence of external forces and gravity is illustrated in the color palette in Fig. 1, 2. The scale of displacement values corresponding to this palette is shown on the left in the form of a colored column. As it follows from Fig. 1, the maximum values of equivalent stresses of the shaping surface are 2.5 MPa. Higher stress values are concentrated in the zone of application and distribution of the driving force.

The frame structure accepts maximum stresses of 11.7 MPa (Fig. 2). The scope of such stress values is limited by the areas of contact between the frame and the supports and is local. In general, the frame of the structure is in a state of uniform stress distribution.

In order to study the behavior of the shaping surface under dynamic action, stress distribution in time is analyzed. In particular, Fig. 3. presents vibration records of stress variation of the shaping structure for individual elements located near the application of the dynamic external force. As can be seen from Fig. 3, the transient process was found at the beginning due to the transition of the system from the resting state to oscillatory motion. An increase in the stress amplitude at this stage is a consequence of the transition of the system through resonance modes at lower oscillation frequencies.

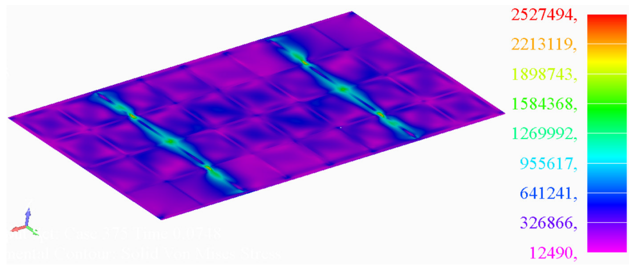

Fig. 1. Distribution of equivalent stresses (Solid Von Mises Stress) of the shaping surface (time 0.0748 s)

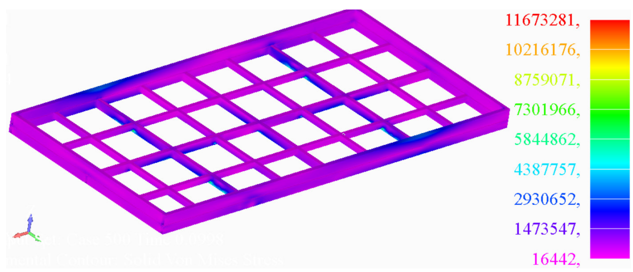

Fig. 2. Distribution of equivalent stresses (Solid Von Mises Stress) of the frame of the structure (time 0.0748 s)

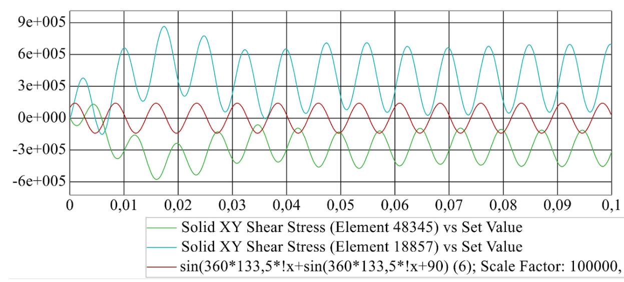

Fig. 3. Dependence of shear stresses (Solid XY Shear Stress) of the shaping surface (elements 48345 and 18857) and the vertical component of the driving force

In such conditions, modes of natural oscillations of the system with higher oscillation amplitudes and correspondingly lower frequencies are implemented. In the set operating mode, negative stresses arise in the element 18857. The variation nature of these stresses is periodic and antiphase compared with the applied spatial force. The stresses of the element 48345 have positive values and vary with a shift of $\pi/2$ relative to the applied force. This dependence is explained by the spatial arrangement of the elements relative to the point of application of the force and variation nature of this force load, as the force varies on two axes of space.

For the elements 48114 and 17290 of the structure, which are symmetrically located on the opposite side of the applied force, the nature of variation is shown in Fig. 4. Unlike the previous vibration records, one can see the lack of phase synchronism of stress variation with respect to the driving force. The essential difference can be explained by the phenomena of dissipation taking place in the structure and caused by the resistance of the medium.

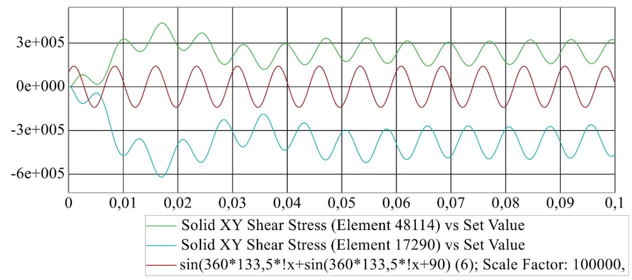

Fig. 4. Dependence of shear stresses (Solid XY Shear Stress) of the shaping surface (elements 48114 and 17290) and the vertical component of the driving force

It is quite obvious that variation of the stress-strain state of the studied system is rather complex. Such variation is associated with the implementation of complex spatial oscillations and multistage compaction process. An important criterion for evaluating the structure in terms of efficiency of the compaction process is shear stress. As in the presence of such stresses in the environment, there is an intense movement of particles and compaction.

For the analysis of shear stresses of the shaping surface, time intervals that correspond to 1/4 of the oscillation period of the driving force were selected. So, Fig. 5 shows stress distribution on the XY plane at a time of 0.0748 s, which is taken as a relative start. This is evidenced by the zones with maximum positive stress values in which force is applied. The whole surface is in a complex alternating stress-strain state.

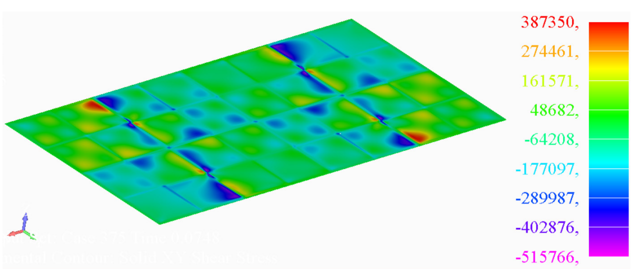

Fig. 5. Distribution of shear stresses (Solid XY Shear Stress) of the shaping surface (time 0.0748 s)

When the force is rotated by the angle of π/4, stress distribution changes (Fig. 6). The appearance of additional zones of maximum stresses indicates the transfer of the load in the horizontal direction and the presence of bending and torsional oscillations. In this case, the middle of the structure is in relative rest.

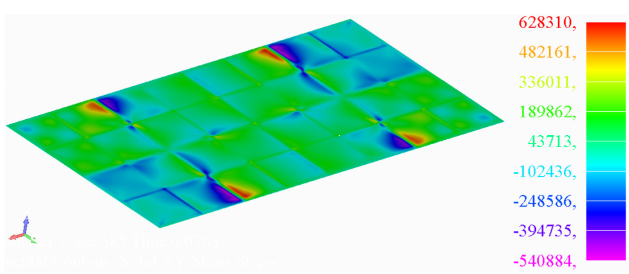

Fig. 6. Distribution of shear stresses (Solid XY Shear Stress) of the shaping surface (time 0.0768 s)

When the force returns to the angle of π/4, there is a disturbance of practically the entire shaping surface (Fig. 7). Strains and stresses have alternating nature, which indicates the presence of wave phenomena. The transmission of stresses occurs in the direction of the diagonal, connecting the points of application of external dynamic forces.

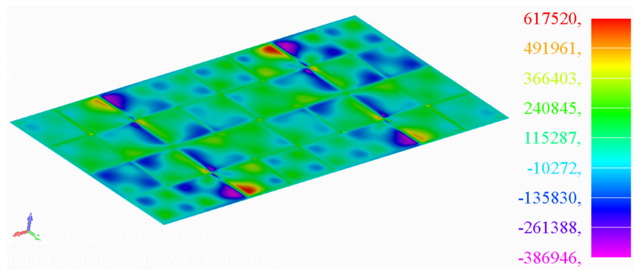

Fig. 7. Distribution of shear stresses (Solid XY Shear Stress) of the shaping surface (time 0.0786 s)

In the period of time 0.0806 s (3/4 π), the propagation of oscillations continues as evidenced by the change of stress distribution (Fig. 8). Strains and stresses have alternating nature as in the previous period, but stress distribution is more uniform and ordered. The presence of the zones in the corners of the shaping surface is worth noting. In these zones, stress variation proceeds less intensively, and most of the surface perceives positive stress values. At the same time, the number of surface areas with negative stress values is negligible.

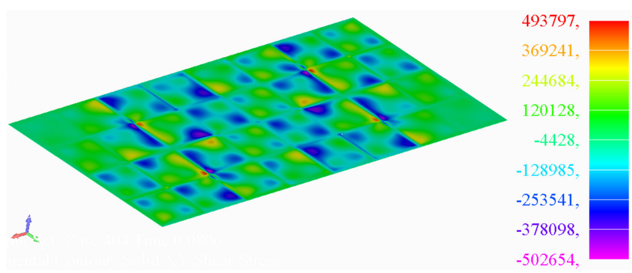

Fig. 8. Distribution of shear stresses (Solid XY Shear Stress) of the shaping surface (time 0.0806 s)

Comparing the results of the stress-strain state of the shaping structure, we can note the following. The application of high frequencies of the operating mode will produce a new effect during concrete mix compaction. Due to the application of the spatial driving force to the shaping structure, a complex stress-strain state of steel structures is created. But direct contact with the concrete mix helps to reduce the energy consumption of the compaction process.

6. Discussion of the results of the study of stresses and strains in the shaping structure under spatial load

The results of the studies (Fig. 1) show that the maximum values of equivalent stresses on the shaping surface are 2.5 MPa. Higher stress values are concentrated in the zone of application and distribution of the driving force. The frame structure accepts maximum stresses of 11.7 MPa (Fig. 2). The scope of such stress values is limited by the areas of contact between the frame and supports and is local. Vibration records of stress variation of the shaping surface

(Fig. 3) are given for individual elements located near the application of the dynamic external force. The transient process found is to be taken into account when determining the parameters and location of vibrators. In such conditions, modes of natural oscillations of the system with higher oscillation amplitudes and correspondingly lower frequencies are implemented. And this opens up a real opportunity to reduce the energy intensity of the drives of the vibration machine.

Stresses for structural elements, symmetrically located on the opposite side of the applied force, are investigated (Fig. 4). Unlike vibration records (Fig. 4), there is no cophased variation of stresses in relation to the driving force, which confirms the expediency of taking into account dissipative forces in the computational model. An important criterion for evaluating the structure in terms of efficiency of the compaction process is shear stress. As in the presence of such stresses in the environment, there is an intense movement of particles and compaction. Since the vector of the oscillation disturbance force returns in space, time intervals corresponding to 1/4 of the oscillation period of the driving force are selected for analysis of shear stresses of the shaping structure. The nature of stress distribution in these characteristic intervals allowed analyzing the variation of the stress-strain state for the full variation period of the driving force. Stress distribution on the shaping surface is rather uniform, which indicates the correct choice of the geometric parameters of the simulated structure. Zones with the maximum positive stress values in which force is applied are determined. The presence of such zones is due to the insufficient rigidity of the elements of the bearing structure – the support frame. Obviously, individual elements of the frame structure should be replaced. Thus, the complex alternating stress-strain state of the structure under spatial load is confirmed.

This study has restrictions regarding the adopted law of variation of dissipative forces. In calculations, dissipative forces are accepted as constant for the working body and the environment. More research is needed on the laws of variation of dissipative forces. In the calculations of vibration machines using shaping structures, output numerical values of the amplitude-frequency mode of the oscillation exciter are taken into account. At the same time, the ratio of the vertical and horizontal components of the workflow parameters is not yet fully revealed. Obviously, this ratio may affect the necessary formation of a new structure of technological environments with different rheological properties. Such studies are planned as a continuation of the considered topic in terms of optimizing the design of the supports, rational arrangement of force application points on the perimeter of the shaping structure.

New solutions and results can be used in related processes, for example, in the mining industry, as active surfaces for ore transportation, for the transfer of suspensions and solutions in the chemical industry. A new direction for creating flexible working bodies with accumulation and effective use of auxiliary energy sources opens, as well as the possibility of creating flexible plate structures for the study of stress-strain state.

7. Conclusions

1. The computational model of the machine – environment system taking into account the interaction of the working body and the compaction mixture is developed. It is based on the condition for determining contact forces of interaction between the subsystems and estimation of the ratio of the time of action and time of wave propagation. The influence of elastic-inertial components was revealed, as evidenced by an increase in stresses in transitional oscillation modes by 20–25 %. The influence of dissipative forces of the medium on the system's motion is revealed by the phase shift by the angle of $\pi/4$ between the directions of the driving force and stress.

2. The study and determination of stresses and strains in time confirmed the hypothesis of a significant effect of structural features of the shaping structure on the compaction process. The maximum values of the equivalent stresses of the shaping surface within the design and technological parameters of the performed experiments are 2.5 MPa. The numerical values and the nature of stress distribution in the shaping structure are obtained, depending on the angle of the instantaneous action of the external force of vibrators. As the force turns by the angle of $\pi/4$ there are additional zones of maximum stresses with values of 0.63 MPa, indicating the transfer of load in the horizontal direction and the presence of bending and torsional oscillations. Conditions for the implementation of cophased and anti-phase directions of stresses and acting external force are determined.

3. Practical recommendations for the rational determination of technological and structural parameters of the shaping structure of spatial load are developed. On the basis of the determined stress-strain state, it was proposed to change the cross-sections of the shaping structure. The elements of the structures in which maximum stresses occur are to be replaced with elements with a larger modulus, and elements with minimum stresses need to be replaced with elements of less rigidity. Such results allow reducing the weight of structural elements and energy intensity of the process. For constructing such shaping structures, the locations of vibrators are determined.

References

1. High frequency modes meshfree analysis of Reissner-Mindlin plates / Bui T. Q., Doan D. H., Van Do T., Hirose S., Duc N. D. // Journal of Science: Advanced Materials and Devices. 2016. Vol. 1, Issue 3. P. 400–412. doi: https://doi.org/10.1016/j.jsamd.2016.08.005
2. Cho D. S., Vladimir N., Choi T. M. Numerical procedure for the vibration analysis of arbitrarily constrained stiffened panels with openings // International Journal of Naval Architecture and Ocean Engineering. 2014. Vol. 6, Issue 4. P. 763–774. doi: https://doi.org/10.2478/ijnaoe-2013-0210
3. Lee J. K., Jeong S., Lee J. Natural frequencies for flexural and torsional vibrations of beams on Pasternak foundation // Soils and Foundations. 2014. Vol. 54, Issue 6. P. 1202–1211. doi: https://doi.org/10.1016/j.sandf.2014.11.013

4. Jia Y., Seshia A. A. An auto-parametrically excited vibration energy harvester // Sensors and Actuators A: Physical. 2014. Vol. 220. P. 69–75. doi: https://doi.org/10.1016/j.sna.2014.09.012
5. Eigenstructure assignment in undamped vibrating systems: A convex-constrained modification method based on receptances / Ouyang H., Richiedei D., Trevisani A., Zanardo G. // Mechanical Systems and Signal Processing. 2012. Vol. 27. P. 397–409. doi: https://doi.org/10.1016/j.ymssp.2011.09.010
6. Feedback linearisation of nonlinear vibration problems: A new formulation by the method of receptances / Zhen C., Jiffri S., Li D., Xiang J., Mottershead J. E. // Mechanical Systems and Signal Processing. 2018. Vol. 98. P. 1056–1068. doi: https://doi.org/10.1016/j.ymssp.2017.05.048
7. Peng Z., Zhou C. Research on modeling of nonlinear vibration isolation system based on Bouc-Wen model // Defence Technology. 2014. Vol. 10, Issue 4. P. 371–374. doi: https://doi.org/10.1016/j.dt.2014.08.001
8. Design and Development of a Test-Rig for Determining Vibration Characteristics of a Beam / Nikhil T., Chandrahas T., Chaitanya C., Sagar I., Sabareesh G. R. // Procedia Engineering. 2016. Vol. 144. P. 312–320. doi: https://doi.org/10.1016/j.proeng.2016.05.138
9. Craster R. V., Kaplunov J., Pichugin A. V. High-frequency homogenization for periodic media // Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences. 2010. Vol. 466, Issue 2120. P. 2341–2362. doi: https://doi.org/10.1098/rspa.2009.0612
10. Masutage V. S., Kavade M. V. A Review Vibrating Screen and Vibrating Box: Modal and Harmonic Analysis // International Research Journal of Engineering and Technology (IRJET). 2018. Vol. 05, Issue 01. P. 401–403.
11. Svanadze M. M. On the solutions of quasi-static and steady vibrations equations in the theory of viscoelasticity for materials with double porosity // Transactions of A. Razmadze Mathematical Institute. 2018. Vol. 172, Issue 2. P. 276–292. doi: https://doi.org/10.1016/j.trmi.2018.01.002
12. Yang Z., He D. Vibration and buckling of orthotropic functionally graded micro-plates on the basis of a re-modified couple stress theory // Results in Physics. 2017. Vol. 7. P. 3778–3787. doi: https://doi.org/10.1016/j.rinp.2017.09.026
13. Fu B., Wan D. Numerical study of vibrations of a vertical tension riser excited at the top end // Journal of Ocean Engineering and Science. 2017. Vol. 2, Issue 4. P. 268–278. doi: https://doi.org/10.1016/j.joes.2017.09.001
14. Research of energy-saving vibration machines with account of the stress-strain state of technological environment / Nazarenko I. I., Dedov O. P., Svidersky A. T., Ruchinsky N. N. // The IX International Conference HEAVY MACHINERY HM 2017. Zlatibor, 2017. P. 14–15.
15. Maslov O. H., Nesterenko M. P., Molchanov P. O. Analytical determination of resonance frequency vibrations active working organ the cassette form // Zbirnyk naukovykh prats Poltavskoho natsionalnoho tekhnichnoho universytetu im. Yu. Kondratiuka. Ser.: Haluzeve mashynobuduvannia, budivnytstvo. 2013. Issue 1 (36). P. 203–212.
16. Maslov A. G., Salenko J. S., Maslova N. A. Study of interaction of vibrating plate with concrete mixture // Visnyk KNU imeni Mykhaila Ostrohradskoho. 2011. Issue 2 (67). P. 93–98.
17. Nazarenko I. I., Dedov O. P., Svidersky A. T. Design of New Structures of Vibro-Shocking Building Machines by Internal Characteristics of Oscillating System // The Seventh Triennial International Conference HEAVY MACHINERY HM 2011. Kraljevo, 2011. P. 1–4.