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On the approach to the complex research into the vibratory technological process and some factors having an influence on the process regularity

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A B S T R A C T

Vibratory transportation and technologic machines are widely used for transportation and processing of the friable materials in many spheres of industry (agriculture, mining industry, construction etc.). At the same time, many factors influencing the process are not thoroughly revealed; among them, influence of so called parasitic vibrations of the working member is not studied sufficiently. A three-mass vibratory system, an analogue of the vibratory transportation and technologic system "vibro-drive – working member – technologic load" was studied holistically. A relevant mathematical model of the spatial interconnected vibratory movement is drawn up in the form of the differential equations. The real possible reasons of generation of the spatial vibrations in the mentioned systems and possibility of their influence on the technologic process are considered. The influence of the constructional errors and resulting spatial (non-working) vibrations of the working member on the regularity of the friable material vibratory movement is studied by mathematical modeling. The researches have shown that some non-working (so called parasitic) vibrations in combination with the basic vibrations can improve the technological process - increase intensity of movement of the friable material. The graphical illustrations are presented.

Keywords: Vibratory system, Spatial vibrations, Vibratory displacement, Mathematical modeling, Friable material; Vibratory technology.

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1. INTRODUCTION

The vibratory technologic processes are in fact the useful movements of the friable materials and single small parts under influence of vibrations: transportation, metered feeding, sorting, mixing and etc.[1-4].

The vibratory technologic machines and processes are widely used in metallurgy, construction, mining industry, agriculture, chemical industry and confectionaries [5-7].

A vibratory technologic process is a dynamically sensitive process in which participate many physically different components: vibro-drive, elastic system, working member (absolutely rigid or of finite rigidity), diverse friable loads. Dynamical interaction of these components stipulates behavior of the friable material on the working member surface.

The mathematical models of vibratory transportation and technological processes presented in the existent researches [1, 2, 5] are mostly simplified. For example, non-linear excitation is replaced by harmonic vibrations; reaction of the material on the working member is provided by so called coefficient of connection that is 1/3 of the whole mass; non-working vibrations that accompany vibratory technologic processes and have influence on them, are not often taken into account neither etc. Because of such approaches many nuances that could be important from the standpoint of influence on the process, are ignored.

Consequently, the attempt is made in the work to create a more or less universal model, where more perfect mathematical description of the vibratory transportation and technologic processes of the friable materials and study of influence of various parameters on the process would be possible.

2. A DYNAMICAL MODEL

Since a vibratory technologic process is in fact a vibratory movement of the system "vibro-drive – working member – technologic load" in space then it is evident that besides pre-determined working vibrations the working member and consequently technologic load can be subjected to non-working (spatial) vibrations [4, 8] not envisaged by the calculation.

This in the first place concerns the spatial, so called parasitic vibrations of the working member that can be caused by various factors such as inaccuracy of transmission of the exciting force, errors of relative disposition of the vibratory machine units, elastic specificity and etc.

In Fig.1 is presented a two-mass system "vibro-drive – working member" and are shown deviations of the working member caused by various possible errors: I – nominal (designed) position of the working member; II – position of the working member considering the errors including the eccentricities e_x, e_y, e_z of displacement of the center of gravity from position O_1 to point $O_1^{'}$; $\theta_0, \psi_0, \varphi_0$ - turnings of the coordinate axes caused by the assembly errors of the vibratory machine and transition from position $O_1x_1y_1z_1$ to position $O_1^{'}x_1^{'}y_1^{'}z_1^{'}$ (Fig.1 a, b); III – dynamical (working) position of the working member. System of coordinates $O_vx_vy_vz_v$ is connected to the vibro-drive; 1 – basic elastic system of the vibro-machine; 2 – suspensions of the vibro-machine; Q – exciting force; m_v, m_1 – masses of the vibro-drive and working member.

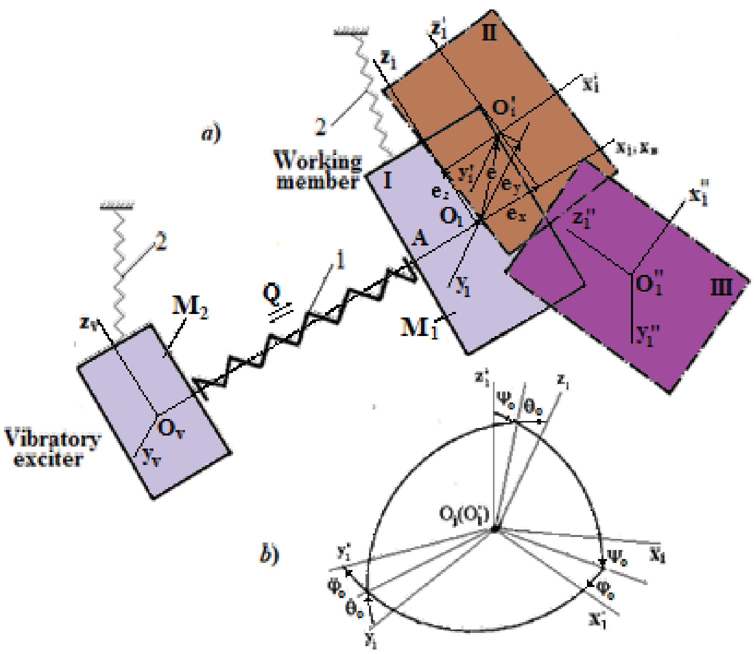

Fig. 1. *The Average Clinical Indicators of the Cows*

In the Fig.2 are shown spatial schemes of the three-mass spatial vibratory system, a generalized dynamical model of the vibratory technologic system “vibro-drive – working member – technologic load” (Fig.2a), elastic system of the vibro-drive – working member (Fig.2c) and conventional elastic system of the technologic load (Fig.2b). At that, the latter imitating phenomenological properties of the friable material is restricted unilaterally by the working member surface.

For full description of the spatial vibratory movement of the presented system it is expedient to use classical methods of relative movement of rigid bodies [8]. For this purpose a friction material (load) is presented as a rigid body in the form of cube where total mass of the load is located and which is provided with conventional elastic elements describing phenomenological properties and elastic and damping connections between layers as well as with surfaces of the working member [4, 9].

For obtaining general vector expressions of the kinetic energy of a body it is necessary to determine absolute movement of a free point of this body. Such points in Fig.2 are A_i (M_1), B_i (M_2), C_i (M_3) that are connected to the origins of the own coordinate axes as well as to the origins of coordinate axes inertial relative to them. Besides, mass M_3 is connected to mass M_2 at the center of gravity (at the origin of coordinate system).

Consider expressions of each component part of the three-mass system (Fig, 2a). Vector equations of absolute velocities of free points A_i, B_i, C_i of masses M_1, M_2 and M_3 have the form:

$$V_{Ai} = V_{01} + \omega_{01} \times r_{1i}\,;\;\; V_{Ci} = V_{02} + \omega_{02} \times r_{2i}\,;\; V_{Bi} = V_{01} + \omega_{01} \times R_{3i} + V_{03} + \omega_{03} \times r_{3i}\,, \quad (R_{3i} = R_3 + r_{3i}) \quad (1)$$

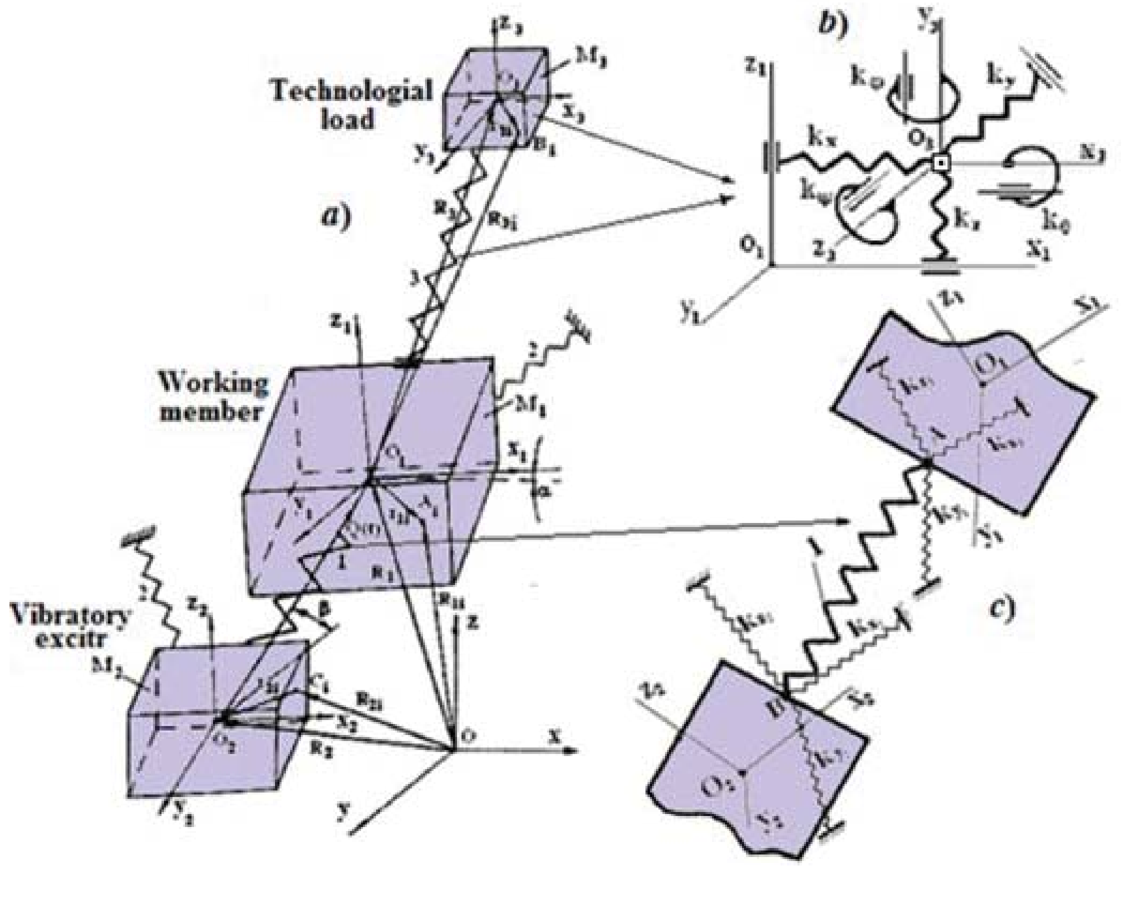

Fig. 2. *Three-mass spatial vibratory system – an analogue of the vibratory technologic system “vibro-drive – working member – technologic load”*

where V_{01}, V_{02} are translatory velocities of the particles A_i and C_i ; r_{1i}, r_{2i}, r_{3i} – position vectors of the particles A_i, B_i, C_i ; ω_{01}, ω_{02}, ω_{03} – velocities of rotary movement of masses M_1, M_2 and M_3; V_{03} – velocity of relative movement of mass M_3; r_{1i}, r_{2i}, r_{3i} - position vectors of points A_i, B_i, C_i relative to the origins of the proper coordinate axes.

Consequently, the vector expressions of kinetic energies of masses M_1, M_2 and M_3 will have the form (is shown kinetic energy of mass M_1 only):

$$T_1 = \frac{1}{2}\sum_{i=1}^{n_1} M_{1i}[V_{01}^2 + (\omega_{01} \times r_{1i})^2 + V_{01}(\omega_{01} \times r_{1i})], \qquad (2)$$

where M_{1i}, M_{2i}, M_{3i} are masses of the particles A_i, B_i, C_i .

The vector expressions are converted into the analytical form with the help of the direction cosines and Euler's angles [8]. Then they (T_1, T_2, T_3) are reduced on the coordinate axes of the working member (M_1).

Kinetic energy of mass M_1 relative to the coordinate system $O_1'' x_1'' y_1'' z_1''$ has the following form:

$$\begin{aligned} T_1 = {} & \frac{1}{2} M_1 (\dot{x}_1^2 + \dot{y}_1^2 + \dot{z}_1^2) + \frac{1}{2}[(J_{x1}\cos^2\alpha_1 + J_{z1}\sin^2\alpha_1)\dot{\theta}_1^2 + (J_{x1}\sin^2\alpha_1 + J_{z1}\cos^2\alpha_1)\dot{\varphi}_1^2 + \\ & + J_{y1}\dot{\psi}_1^2] + (J_{x1} - J_{z1})\sin\alpha_1 \cos\alpha_1 \dot{\theta}_1 \dot{\varphi}_1 + (J_{x1}\cos^2\alpha_1 + J_{z1}\sin^2\alpha_1 - J_{y1})\dot{\theta}_1 \dot{\psi}_1 \varphi_1 + \\ & + (J_{z1} - J_{x1})\cos\alpha_1 \sin\alpha_1 \dot{\theta}_1 \dot{\psi}_1 \theta_1 + (J_{x1} - J_{z1})\cos\alpha_1 \sin\alpha_1 \dot{\varphi}_1 \dot{\psi}_1 \varphi_1 - \\ & - (J_{x1}\sin^2\alpha_1 + J_{z1}\cos^2\alpha_1)\dot{\varphi}_1 \dot{\psi}_1 \theta_1; \end{aligned} \qquad (3)$$

where $x_1, y_1, z_1, \theta_1, \psi_1, \varphi_1$ are linear and angular displacements of the center O_2 of mass M_2; J_{x1}, J_{y1}, J_{z1} - moments of inertia of mass M_2 about axes $O_1 x_1 y_1 z_1$.

Similar forms will have kinetic energies of masses M_2 and M_3.

3. EQUATIONS OF SPATIAL MOVEMENT OF THE WORKING MEMBER AND TECHNOLOGIC LOAD

The main difference between the system under research – vibratory technologic machine and classical n-mass system is stipulated by the following aspects: 1) Specificity of mass M_3 (load) performing relative movement with respect to mass M_1; 2) Predetermined location relative to each other of masses M_1, M_2, M_3 (vibro-drive, working member, load); 3) Pecularity of interaction of masses M_1 and M_3.

On the base of method of Lagrange we obtain the following differential equations of spatial movement of the system

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}} - \frac{\partial T}{\partial q}\right) = Q_q + Q_q', \qquad (4)$$

where T is the system kinetic energy; q – generalized coordinate that takes the values $x_1, y_1, z_1, \theta_1, \psi_1, \varphi_1$; $x_2, y_2, z_2, \theta_2, \psi_2, \varphi_2$; $x_3, y_3, z_3, \theta_3, \psi_3, \varphi_3$; Q_q - elastic and resistant forces stipulated by the machine elastic and damping system; Q_q' - forces that are not related with deformations of the elastic system or inertness of masses of the vibratory system under consideration (external exciting forces, forces of gravity, external forces resistant forces of the friction type and etc).

For illustration of the proposed approach consider a vibratory feeder with electromagnetic vibro-exciter (Fig.3) and its mathematical model with some assumptions. Namely, influence of the material on the working member dynamics will not be taken into account (kinetic and potential terms in the working member equations are presented in the linear form in contrast to the equations of the load, where kinetic terms are presented by the products of second order of the working member coordinates, their velocities and accelerations).

The research considers influence of the machine design errors and non-working spatial vibrations on the friable material vibratory movement.

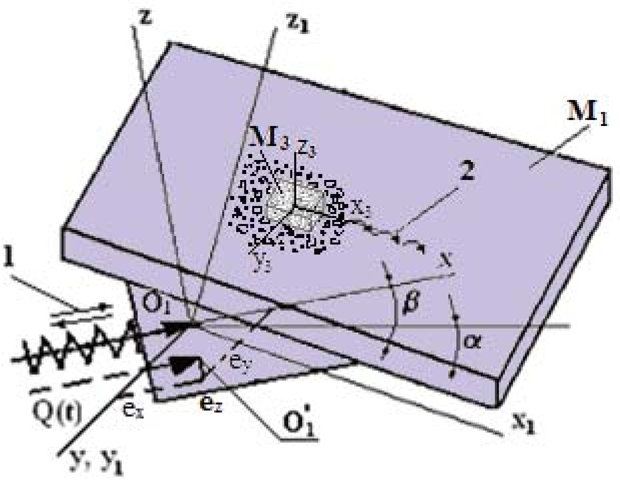

Fig. 3. *The errors of the force transmitted to the working member*

The equations of the working member will have the form

$$\begin{aligned}
&M_1\ddot{x}_1 + c_x\dot{x}_1 + k_x x_1 - k'_x\theta_1 = Qf(\psi_0,\psi_1,\alpha_1);\\
&M_1\ddot{y}_1 + c_y\dot{y}_1 + k_y y_1 - k'_y\psi_1 = Qf(\varphi_0,\varphi_1,\theta_0,\theta_1,\alpha_1)\\
&M_1\ddot{z}_1 + c_z\dot{z}_1 + k_z z_1 - k'_z\varphi_1 = Qf(\psi_0,\psi_1,\alpha_1)\\
&J_\theta\ddot{\theta}_1 + c_\theta\dot{\theta}_1 + k_\theta\theta_1 - k'_\theta x_1 = Qf(e_y,e_z,\theta_0,\psi_0,\varphi_0,\alpha_1)\\
&J_\psi\ddot{\psi}_1 + c_\psi\dot{\psi}_1 + k_\xi\theta_1 - k'_\theta y_1 = Qf(e_x,e_z,\psi_0,\alpha_1)\\
&J_\varphi\ddot{\varphi}_1 + c_\varphi\dot{\varphi}_1 + k_\varphi\varphi_1 - k'_\varphi z_1 = Qf(e_x,e_y,\theta_0,\psi_0,\varphi_0,\alpha_1)
\end{aligned}\tag{5}$$

where c_x, c_y, c_z, c_θ, c_ψ, c_φ, Q_q are coefficients of damping of the elastic system; $k_x, k_y, k_z, k_\theta, k_\psi, k_\varphi$ - coefficients of rigidity; $k'_x, k'_y, k'_z, k'_\theta, k'_\psi, k'_\varphi$ - coefficients relating lateral-rotary and longitudinal-torsional vibrations; $Q = Q_0 f$ (t), Q_0 – coefficient of the exciting forcr; f (t) – regularity of variation of the exciting force.

Spatial vibratory movement along the coordinate axes will have the following form

$$\begin{aligned}
&M_3[\ddot{y}_3 + \ddot{y}_1 + (\ddot{z}_1\theta_1 - \ddot{x}_1\varphi_1)\cos a_1 + (\ddot{x}_1\theta_1 + \ddot{z}_1\varphi_1)\sin a_1 - \ddot{\theta}_1 z_3 - 2\dot{\theta}_1\dot{z}_3 +\\
&+2\dot{\varphi}_1\dot{x}_3 - \ddot{x}_1(\varphi\cos a_1 - \theta_0\sin a_1) + \ddot{z}_1(\theta_0\cos a_1 + \varphi_0\sin a_1)] + B\dot{y}_3 - C'y_3 =\\
&= -fN_z sign(\dot{y}_3);
\end{aligned}\tag{6}$$

$$\begin{aligned}
&M_3[\ddot{z}_3 + (\ddot{z}_1 + \ddot{x}_1\psi_1)\cos a_1 + (\ddot{x}_1 - \ddot{z}_1\psi_1)\sin a_1 - \theta_1\ddot{y}_1 + y_3\ddot{\theta}_1 + 2\dot{y}_3\dot{\theta}_1 -\\
&-2\dot{x}_3\dot{\psi}_1 - \ddot{z}_1\psi_0\sin a_1 + \ddot{x}_1\psi_0\cos a_1 - \ddot{y}_1\theta_0] + D_1\dot{Z}_1 + E\dot{x}_1 + E'\dot{z}_3 + Cz_3 =\\
&= -fN_y sign(\dot{z}_3) - M_3 g\cos a_1,
\end{aligned}$$

where coefficients *A, B, B*1, *C*", *D, E, E*1, *C* characterize state of the load relative to the working member surface (movement together with the surface or separately from it) and vary properly; $N_z = f(z_3, \dot{z}_3, \dot{z}_1)$, $N_y = f(y_3, \dot{y}_3, \dot{y}_1)$ - forces of the material normal reaction whose coefficients vary similarly to the above mentioned.

Equations (6) differ from generalized equations of the material spatial movement [4] by the terms generated from the errors of $\theta_0, \psi_0, \varphi_0$.

$$Q'_{x1} = Q(x,t); \tag{7}$$

where $Q(x,t)$ is a nonlinear exciting force;

$$Q = A\Phi^2;\ \dot{\Phi} = BF_1(t) - C(\delta - x_1)\Phi;$$

Φ – electromagnetic flow; *A, B, C* - coefficients depending on parameters of the electromagnetic vibro-exciter; *δ* – clearence of the electromagnet.

The system of equations was solved by the method of Runge-Kutta in the following limits of errors: for angular deviations $\theta_0, \psi_0, \varphi_0 = (0 - 0{,}15)$ rad; for deviations of the force direction $e_x, e_y, e_z = (0 - 0{,}015)$ m.

For greater visualization of influence of the mentioned deviations on the process the vibrations were enhanced in one concrete direction or another by resonating with the exciting force (in combination of variation of the errors).

Below are given some results of the modeling (Fig. 4-7), where are shown dependences of the material velocity *V* and other dynamical characteristics (z_3, y_3, N_z, N_y) on the non-working vibrations (y_1, φ_1, z_1, ψ_1) caused by the working member design errors ($\theta_0, \psi_0, \varphi_0, e_0, e_0, e_0$).

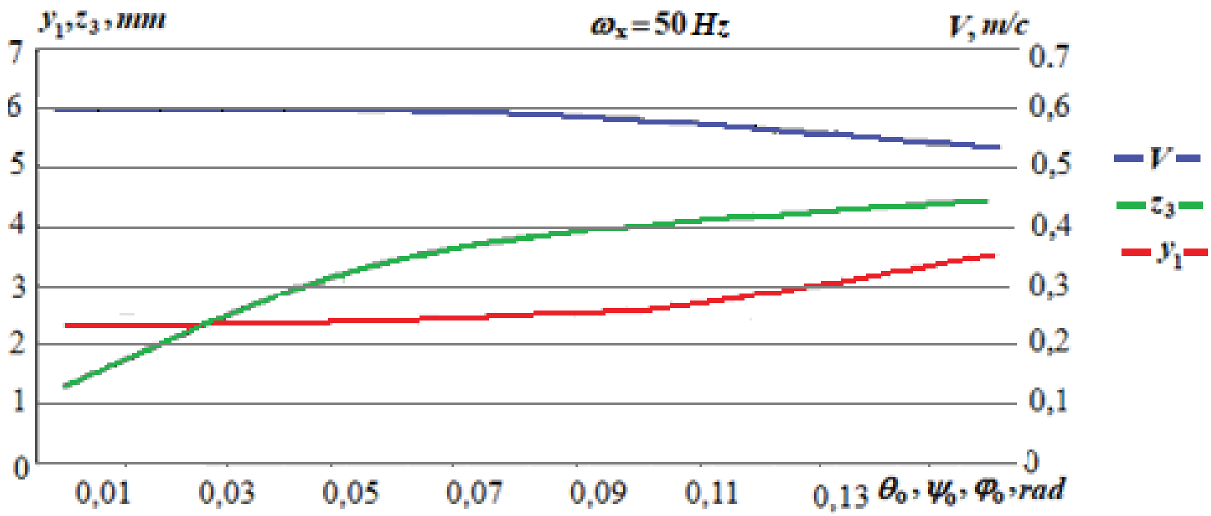

Fig. 4. *Dependences of V and z_3 on $\theta_0, \psi_0, \varphi_0$ and y_1.*

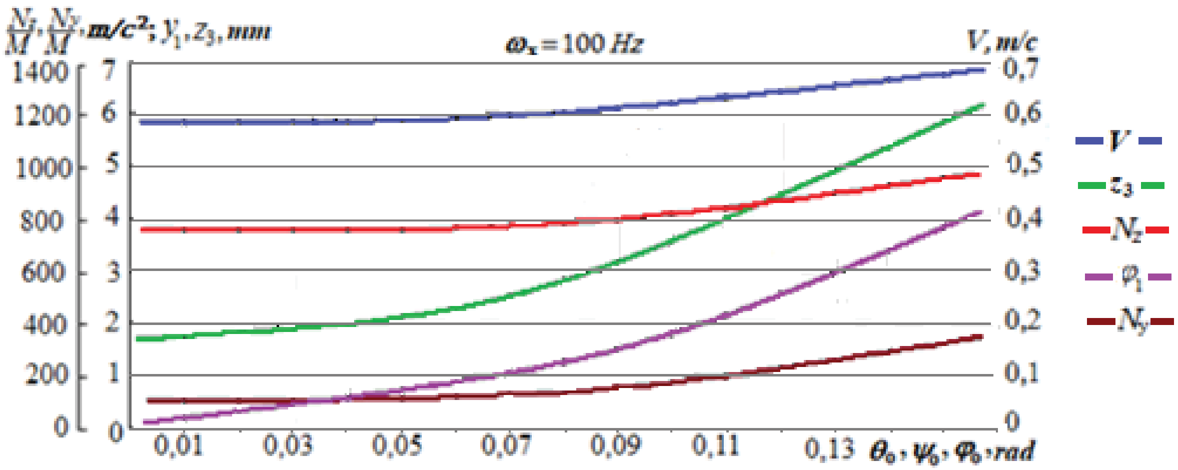

Fig. 5. *Dependences of V, z_3, N_z and N_y on $\theta_0, \psi_0, \varphi_0$ and ϕ_1*

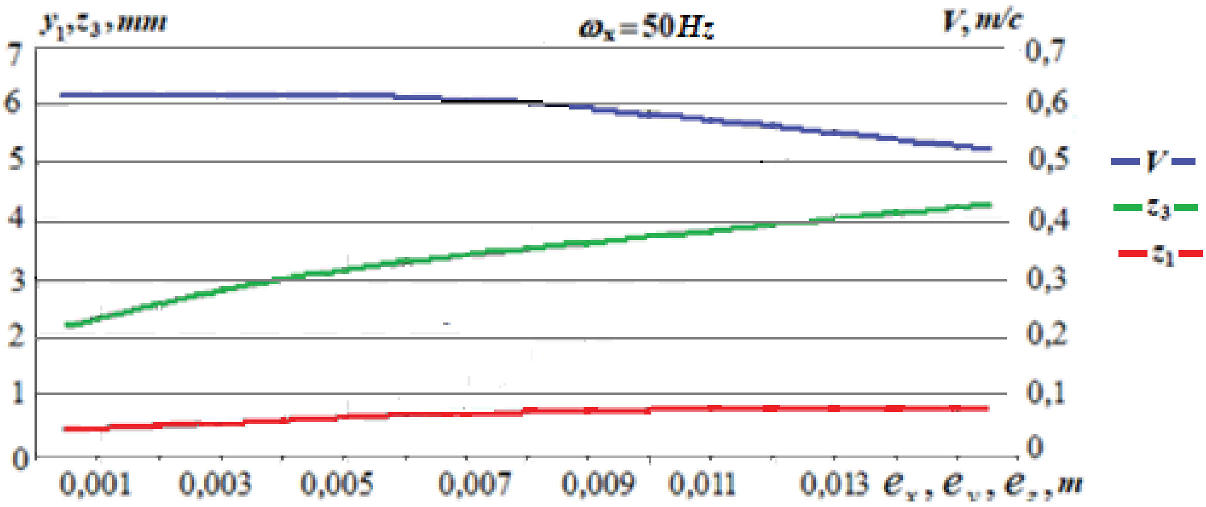

Fig. 6. *Dependences of V and z_3 on e_x, e_y, e_z and z_1*

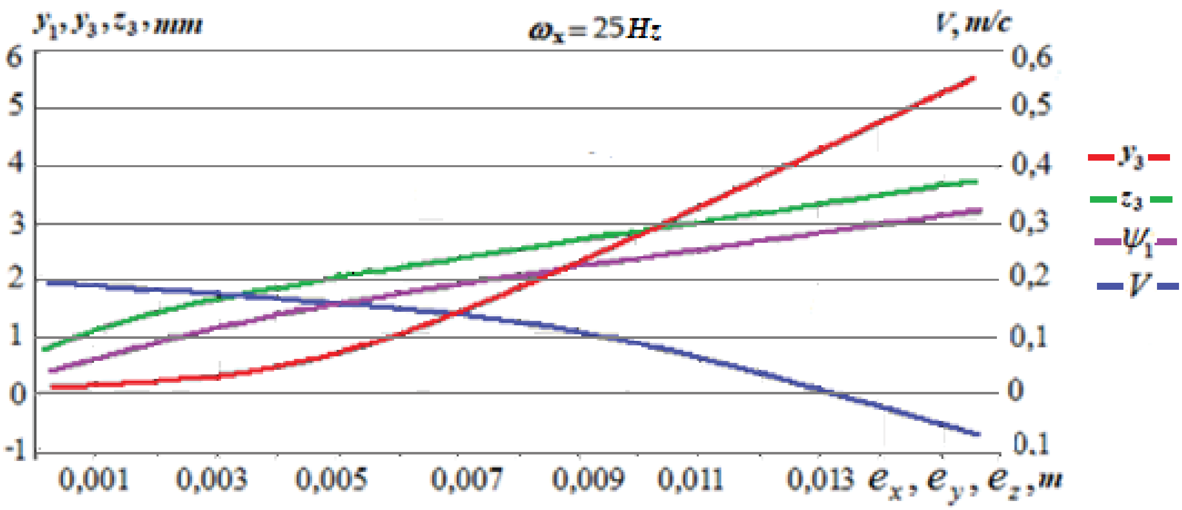

Fig. 7. *Dependences of V, y_3 and z_3 on e_x, e_y, e_z and ψ_1*

4. DISSCUSION

The design and assemblage errors in the vibratory transport and technologic machines (especially in the resonant ones) can cause a significant distortion of conformity with a law of the technologic process. Development of the spatial dynamical and corresponding mathematical models of the vibratory technologic system (vibrator – working member – load) was considered expedient for complex study of this problem.

The obtained mathematical model is universal and it ensures complex research into the technologic process. The results of influence of the spatial (non-working) vibrations (Fig.2) and eccentricity caused by the improper transfer of the force (Fig.3) on the process of vibratory displacement of the friable material are presented in the work.

The approach to the research envisaged enhancing of each non-working ("parasitic") spatial vibration at retaining other vibrations in the admissible limits. As the results of modeling have shown, in most cases, the non-working vibrations have a negative influence on the velocity of the material displacement (Fig. 4, 6, 7) but in some cases, increase of velocity takes place (Fig 5). It should also be noted that non-working spatial vibrations have a significant influence on the material displacement in the vertical direction (z3) (Fig.4, 5, 6, 7) or on the intensity of displacement.

The analysis of the research results have shown that improvement of the vibratory technologic process is mainly possible by combination of the basic working vibrations and some non-working, so called parasitic vibrations that implies design changes of the vibratory machine and will present the subject of the author's further research.

4.1. CONCLUSION

1. The considered approach and a mathematical model of spatial movement of the system "vibro-drive – working member – friable load" allows to realize complex research into the vibratory technologic process by the mathematical modeling;
2. Design errors of the vibratory transportation technologic machine have an influence on the process that is more expressed in the resonant machines;
3. The errors at their certain combination can promote improvement of the process indices (velocity for example, Fig.5) that may be realized in the machine.

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REFERENCES

[1]. I.I. Blekhman, Theory of Vibration Processes and Devices. Vibration mechanics and vibration technology, Ore and metals, SPB, 2013 (in Russian).

[2]. I. Goncharevich. Theory of Vibratory Technology. Hemisphere Publisher, 1990 (in Russian).

[3]. I. I. Fedorenko, Vibration processes and devices in the agroindustrial complex: monograph. RIO of the Altai State University, Barnaul, 2016 (in Russian). http://www.asau.ru/ru/mekhanizatsii-zhivotnovodstva?task=getfile&fileid=15612.

[4]. V. Zviadauri. Dynamics of the vibratory transportation and technological machines; "Mecniereba", 2001(in Russian).

[5]. L.Vaisberg, I. Demidov, K. Ivanov, Mechanics of granular materials under vibration action: Methods of description and mathematical modeling. Enrichment of ores. № 4 (2015) 21-31.

http://rudmet.net/media/articles/Article_OR_04_15_pp.21-31_1.pdf (in Russian).

[6]. V. S. Zviadauri, T. M. Natriashvili, G. I Tumanishvili, T. N. Nadiradze, The features of modeling of the friable material movement along the spatially vibrating surface of the vibratory machine working member. Mechanics of machines, mechanisms and materials, 1 (38), (2017) 21-26 (in Georgian).

[7]. V. S. Zviadauri, M. A. Chelidze, G. I. Tumanishvili, On the spatial dynamical model of vibratory displacement, Proceedings of the International Conference of Mechanical Engineering; London, U.K., 30 June - 2 July, (**2010)** 1567 – 1570.

[8]. R. Ganiev, V. Kononenko, Oscillations of solids. M. Nauka, 1976 (in Russian). http://stu.scask.ru/book_cst.php.

[9]. O. G. Loktionova, Dynamics of vibratory technological processes and machines for the processing of granular materials, Dissertation, 2008 (in Russian). http://www.dissercat.com/content/dinamika-vibratsionnykh-tekhnologicheskikh-protsessov-i-mashin-dlya-pererabotki-neodnorodnyk.