Section: STRUCTURAL OPTIMIZATION OF TECHNOLOGICAL COMPLEXES

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INVESTIGATION OF THE DYNAMICS OF FRIABLE LOAD OF VIBRATING TECHNOLOGICAL MACHINES WITH VERTICAL INDIGNATION

Abstract: *Built model of loose load of vibration technological machines with the vertical indignation of working parts, which is presented by stratification of flat parallel beams which carry out the nonlinear vertical vibrations. The dynamic processes of the technology of vibration compression of the friable environment and separation (mixing) of its constituents are explored with the purpose of intensity rise of the given technological processes. It is got dependences for determination of physic-mechanical properties influence on constituents of friable loading of vibratory technological machines on its dynamics.*

Keywords**:** *friable load, vertical indignation, nonlinear oscillations, technological machine, dynamical process, vibratory technologies.*

INTRODUCTION, PROBLEM STATEMENT

The practical experience of using vibrating technological processes has shown, that they are highly efficient, have a high productivity, consume a relatively small amount of energy, requiring relatively small material and time costs.

The physical effects connected with vibration processes are rather complicated and various - these are strike, abrasive wear, reusable interaction of processable objects, adhesion effects etc. To number of common attributes of vibration systems should be related: drive (source of fluctuations) and working space in which the transformation of vibration oscillating energy into the energy of the corresponding technological process or influence on the detail, the billet or their totality. To the descriptive quantitative characteristics of vibration technological processes contains amplitude-frequency characteristics and trajectories of some parts (system points) movement. The qualitative result of the vibration treatment can be enhanced by the influence of different temperatures, electromagnetic fields, and various chemical phenomena.

The area of use of vibration technologies is very wide: machine-building, mining, building and others. In particular in mechanical engineering it is finish-cleaning, strengthening, stabilizing processing, combined processes of finishing processing and coverings, washing, grinding and dryings, transportation, improvement of process folding, intensification of galvanic and chemical processes, tiresome tests of materials, change of material condition etc. In food and process industry vibration technologies are used for separation according to density and weight of compound mixes, their grinding, prepare of mixes necessary dispersion compound, clearing of edible root surfaces etc.

LITERARY ANALYSIS

The large attention in use of vibration technologies should be given to the further improvement of equipment designs on which they are realized, increase of its work capacity, operational convenience and safety. Modern method of designing of machines construction, on which vibration technologies are realized, development of the technologies, realization of various researches in this direction with the purpose of optimization is use of systems of the automated designing, and, accordingly, development of their analytical base and algorithms.

A characteristic feature, in particular, of vibration technological machines is their diversity in constructive performance on the one hand and universality of designs application of one type for various technological operations - on the other hand. Therefore, the developed analytical device created Computer Aided Design for maintenance of its wide application should take into account these aspects. With this purpose the authors developed software of dynamics research of vibration technological machines for the implementation of surface treatment of products and separation of friable media (nonlinear mathematical models of movement of a working body of vibration machine and its loading) (Babychev 1994, Stotsko, Topilnytsky 2000 – 2001), which has made possible the of the programs creation of factors research of the process efficiency on the basis of applied systems of the automated mathematical accounts, in particular MathCad and MatLab. Below the task of creation of a software of the automated research of dynamics of friable loading of vibration technological machines for vibration condensation of loading or separation (mixing) of its compound with the purpose of intensity increase of these technological processes.

MAIN ARTICLE

Research were carried out on the basis of a class of vibratory machines with unbalance type of a drive and spring suspension bracket, as such, that have a number of the basic advantages before other types of vibratory machine: a) simplicity of a design both service and rather high reliability of units; b) small sensuality to inertial, elastic and dissipative properties of working environment. Unbalance vibration exciter can effectively work in a very wide range of these parameters change while machines of other types (hydraulic, pneumatic, electrodynamic) rather sensitive to overloads. The work principle of the given machines such: exciter (unbalanced rotary weight) starts up the machine (working body - container placed on an elastic suspension bracket, and working loading, placed in it), creates exciting force necessary for overcoming of internal and external forces resistance, which act on loading. In result in the working container of vibratory machine there is an intensive hashing and interaction of loading fractions which intensity is determined depending on parameters of system - amplitude and frequency of its fluctuation movement, physical and mechanical parameters of friable media, exciting force of drive etc.). At vibration volumetric processing of products it is possible to achieve that exciting force changes both on size and in a direction. It can ensure even transportation hashing) of loading particles.

In case of vibration condensation of the friable loading of working container or separation (mixing) of its fractions (by geometric and weight characteristics) it should be made possible the vertical change-changing direction of movement of the working body of the vibration machine. In this case friable loading of vibration technology machines will have a dominant vertical movement, the intensity of which will be determined by the characteristics of the machine drive, its suspension and the characteristics of friable loading.

In the Fig.1. are shown the diagrams of some vibration process machines, the working chambers of which have dominant vertical oscillations. Accordingly, this kind of motion of the working chambers provides vertical fluctuations of the friable loading of these machines.

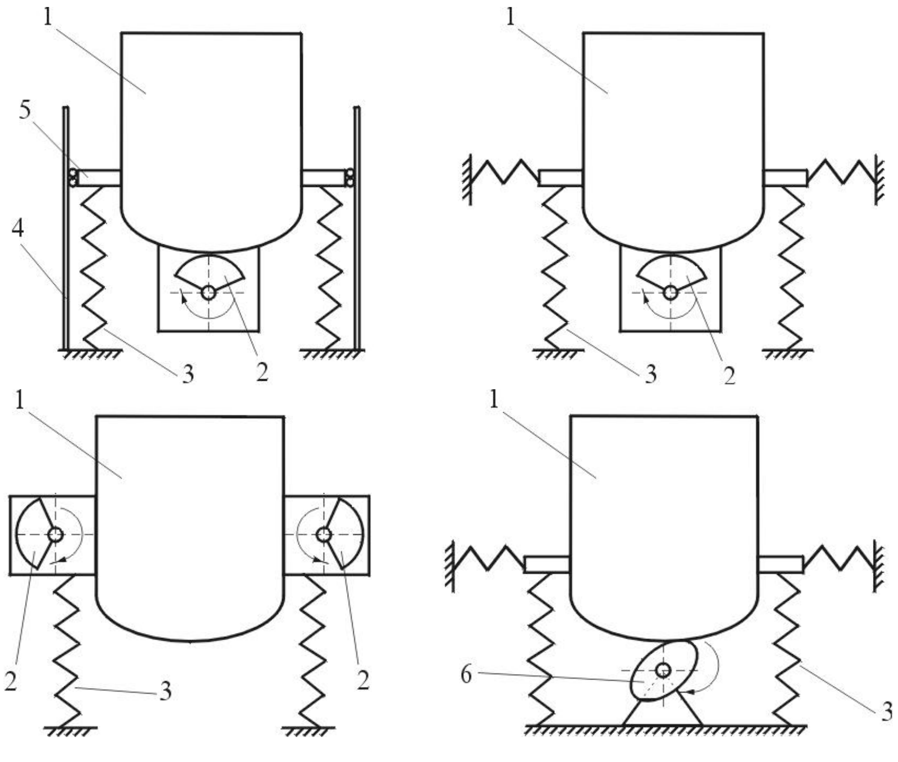

Fig. 1. *Vibration technological machines for the implementation of compression of friable or tough moving loading or separation (mixing) of its constituent fractions, authors' (1 - working container, 2 - drive disbalance, 3 - spring suspension, 4,5 - horizontal movement limiters, 6 - cam drive.*

Vibration technological machines, the schemes of which are presented in Fig.1. (a,b,c), have drive unbalanced rotating masses - debalances (one or more). They are affixed directly to the working chamber and determine its oscillating movement on an elastic suspension (in this case in the form of twisted springs). The working chamber of a technological machine, shown in Fig 1(d) vibrates with the cam drive. Its elastic suspension is also made with steam of twisted springs. They have different stiffness and are installed vertically and horizontally. Horizontal movement limitation system, which consists of the actual guide 4 and roller stops 5 of vibration technology machines (see fig. 1a) - one of the options for implementing its vertical oscillations. The vibrating machine (see fig. 1b) has a suspension of each support from two mutually perpendicular springs. The stiffness of the spring, whose axis is horizontally positioned, has much greater stiffness over a vertically-mounted spring. It also serves as a horizontal support. Accordingly, this machine will have, of course, a component of oscillations in the horizontal direction, but its effect on the character of the motion of the working chamber will be negligible compared with the influence of the vertical component. Vibration technological machine (see fig.1c) is installed only on vertical springs of suspension 3 without horizontal movement limiter. But the presence of a system of unbalances 2 that are independent of each other allows implementing different modes of movement on the machine. The working chamber will be in a clearly expressed flat-parallel motion, when the system of driving unbalances will rotate unidirectionally. Such mode of operation of the machine allows it to be used for surface treatment of products loaded in it - strengthening, cleaning, etc. If the same parameters for each independent balance will be set (mass, eccentricity, etc.) and it'll be ensured their opposite rotation, then the working chamber of the machine in this case will move vertically. It should be emphasized on such feature of vibratory technological machines, which have several independent drive unbalances: If after completing by machine its technological function one of unbalances will be stopped then the presence of the disturbing force of the working chamber on one side, caused by one working balance, will ensure the separation of the components of the working chamber (for example, the parts processed and the parts of the medium that processed them) by weight, and, accordingly, their separation. This mode of machine work is very convenient for unloading the processed parts from the volume of the working chamber. The vibration machine (Fig. 1g) can be equipped with a suspension similar to Fig. 1a - 1c. In these types of machines you can use similar principles instead of a spring suspension - pneumatic.

Summarizing the above follows that vertical movement of the working camera of vibratory technological provides the vertical indignation, which is creating by the suspension construction, regime and construction of its drive. The purpose of the given work is studying of dynamic processes of working vibration machines of such type. It is known [1], mathematical model of loose homogeneous loading of working camera of vibratory machine can be stratification of flat homogeneous beams which by the certain grade cooperate with walls of the container. Dynamics of such environment at exciter indignation of the container and under conditions that the stratification of flat beams is carried out only by longitudinal fluctuations was studied in (Stotsko, Topilnytsky 2000-2001). However, the offered type of kinematic indignation of working camera of machine results to other movement of loading - its vertical fluctuations and nature of such movement not investigated. As well as in the mentioned above works, environment will be simulated also as stratifications of flat beams, for them we shall examine cross fluctuations. Such movement of loading provides the given type of kinematic indignation and restriction concerning movement of the container. The differential equation of movement of the conditionally allocated layer of loading accepts a look:

$$\frac{\partial^2 u}{\partial t^2} + \alpha^2 \frac{\partial^4 u}{\partial z^4} = \varepsilon f\left(u, u_t, u_z, ..., u_{zzz}, \mu t\right), \tag{1}$$

where $\alpha^2 = \frac{EI}{\rho F}$ (E , I , F, ρ - parameters which characterize physical-mechanical properties of loading);

$u(t,z)$ - vertical moving of a layer loading with coordinate z at the any moment of time t;

$\varepsilon f(...)$ - analytical 2π periodic till μt function which takes into account: a) a deviation of the elastic characteristics of loose loading from the linear law of elasticity; b) influence dissipative and other nature of viscous-elastic forces on dynamics of process; c) influence of kinematic indignation on vertical fluctuations of loading (μ - frequency of kinematic indignation, ε - small parameter which specifies the maximum order of smallness of the mentioned above nonlinear and external forces in comparison with linearly elastic forces of environment).

In particular: a) if to take into account only that fact that the material of loading satisfies close to the technical law of elasticity (Kauderer, 1961), the function $f(...)$- accepts a look:

$$f(...) = -\alpha_1^2 \frac{\partial^2}{\partial z^2}\left(\frac{\partial^2 u}{\partial z^2}\right)^3 \tag{2}$$

b) If the forces of resistance and dissipative forces satisfy the law of Bolotin, $f(...)$- accepts a look:

$$f = u_t\left(B + B_0 u^2\right) \tag{3}$$

c) If to take into account only kinematic indignations, the specified function with sufficient accuracy is represented by the sum Furie by harmonics $k\mu t$ $(k = 1,2,...)$.

Accepting to attention a kind of contact of loading and walls of the container we shall consider that for the differential equation (1) the following regional conditions are carried out:

$$u(z,t)\big|_{z=0} = u(z,t)\big|_{z=l} = 0 \tag{4}$$

where l - geometrical parameter of the working camera.

The physical contents of regional conditions (4) answers contact of stratifications of beams to walls of the working camera, which approximately can be simulated immovable articulate fastening.

We shall proceed to construction solution of the equation (1). With this purpose we shall consider the not indignant equation, which answers (1):

$$\frac{\partial^2 u}{\partial t^2} + \alpha^2 \frac{\partial^4 u}{\partial z^4} = 0 \quad \textbf{(5)}$$

Separating in (5) replaceable according to the formula $u(z,t) = Z(z) \cdot \cos(\omega t)$ for a finding of unknown function $Z(z)$ is received the differential equation:

$$Z_{zzzz} - \lambda^4 Z = 0 \quad \textbf{(6)}$$

where $\lambda^4 = \dfrac{\omega^2}{\alpha^2}$. The function $Z(z)$, proceeding from (2), satisfies regional conditions: $z(0) = z(l) = 0$

$$z_{zz}(0) = z_{zz}(l) = 0 \quad \textbf{(7)}$$

Common solution of equation (6) is expressed through function of Krylov

$K_1(\lambda z) = \frac{1}{2}(ch\lambda z + \cos\lambda z)$,

$K_2(\lambda z) = \frac{1}{2}(sh\lambda z + \sin\lambda z)$,

$K_3(\lambda z) = \frac{1}{2}(ch\lambda z - \cos\lambda z)$,

$K_4(\lambda z) = \frac{1}{2}(sh\lambda z - \sin\lambda z)$ as follows:

$$Z(z) = \sum_{i=1}^{4} C_i K_i(\lambda z) \quad \textbf{(8)}$$

Satisfying the condition (7), we shall receive

$$Z(z) = a_k \, sin \frac{k\pi z}{l} \quad \textbf{(9)}$$

where a_k - any constant

In view of last, value of frequency and one-frequency solutions of the not indignant equation (6) look like

$$\omega_k = \alpha \frac{k^2 \pi^2}{l^2} \quad \textbf{(10)}$$

$$u_k(t,z) = a_k\ cos(\omega_k t + \alpha_k) \cdot sin\frac{k\pi z}{l} \quad \textbf{(11)}$$

The presence of forces of resistance and other dissipative forces results to fast fading of high-frequency load fluctuations and the occurrence of a dynamic process with one (in most cases by first) frequency. Through it in the specified system we shall consider mode with one oscillatory frequency equal by first one- $k=1$ (main frequency). This assumption somewhat simplified the resolution of the indignant equation (1), and at finding of its solution an index k we shall omit. We shall accept the solution of regional task (1-2) as

$$u(t,z) = a\ cos(\psi) \cdot sin\frac{\pi z}{l} \quad \textbf{(12)}$$

where a- amplitude, γ - initial phase one-frequency of dynamic process (replaceable in time).

In view of properties of completeness of system functions $\{Z_k(z)\} = \left\{\sin\frac{k\pi z}{l}\right\}$

for the finding of the laws of change of amplitude and frequency of fluctuations of a loading layer in a not resonant case ($\omega \neq \mu$) the differential equation are received:

$$\dot{a} = \frac{1}{2\pi^2 \omega l}\int_0^{2\pi}\int_0^{2\pi}\int_0^{l} f_1(z,a,\psi,\theta) sin\frac{\pi z}{l} cos\ \psi d\psi d\theta dz$$

$$\dot{\psi} = \omega + \frac{1}{2\pi^2 a\omega l}\int_0^{2\pi}\int_0^{2\pi}\int_0^{l} f_1(z,a,\psi,\theta) sin\frac{\pi z}{l} sin\ \psi d\psi d\theta dz\ .\ \theta = \mu t \quad \textbf{(13)}$$

where

$$f_1(z,a,\psi,\theta) = f\left(a\cos\psi\ sin\frac{\pi z}{t}, -a\omega\ sin\psi\ sin\frac{\pi z}{t}, \frac{\pi}{l} a\cos\psi\ cos\frac{\pi z}{t}, ..., -\left(\frac{\pi}{l}\right)^3 a\cos\psi\ sin\frac{\pi z}{t}, \theta\right)$$

For a case of the main resonance $\omega \approx \mu$ the laws of change of amplitude both the differences of phases of the own and compelled fluctuations can be found from system of the differential equations:

$$\dot{a} = \frac{1}{2\pi\omega l}\int_0^{2\pi}\int_0^{l} f_1(z,a,\varphi+\theta,\theta) sin\frac{\pi z}{l} cos(\varphi+\theta) d\theta dz$$

$$\dot{\varphi} = \omega - \mu + \frac{1}{2\pi a\omega l}\int_0^{2\pi}\int_0^{l} f_1(z,a,\varphi+\theta,\theta) sin\frac{\pi z}{l} sin(\varphi+\theta) d\theta dz \quad \textbf{(14)}$$

where $\varphi = \psi - \theta$.

As an example we shall consider cross fluctuations of loading only in view of its nonlinear-elastic properties, that is for a case, if the function $f(...)$ looks like (2). amplitude-frequency characteristics of cross fluctuations of loading changes according to parities:

$$\dot{a} = 0$$

$$\dot{\psi} = \alpha \frac{\pi^2}{l^2} + \frac{9}{32}\alpha_1 \frac{\pi^4}{l^4} a^2 \quad \textbf{(15)}$$

Last formulas show that the own frequency of loading depends both on its phisic-mechanical properties and on amplitude (initial indignation), because for accepted assumptions the system is conservative.

If in addition to take into account action of external periodic indignation, that is the right part of the equation (1) looks like

$$f(...) = -\alpha_1^2 \frac{\partial^2}{\partial z^2}\left(\frac{\partial^2 u}{\partial z^2}\right)^3 + \varepsilon b_0 \sin \mu t \quad \textbf{(16)}$$

the equation which describe dynamic process in close to a resonant case, accept a look:

$$u(z,t) = a \sin \frac{\pi z}{l} \cos\left(\frac{\pi^2}{l^2}\alpha t + \varphi\right) \quad \textbf{(17)}$$

$$\dot{a} = -\frac{4\varepsilon b_0 l^2}{\pi\left(\pi^2\alpha + l^2\mu\right)} cos\,\varphi$$

$$\dot{\varphi} = \alpha\frac{\pi^2}{l^2} - \mu + \frac{9}{32}\alpha_1 \frac{\pi^4}{l^4} a^2 + \frac{4\varepsilon b_0 l^2}{\pi a\left(\pi^2\alpha + l^2\mu\right)} sin\,\varphi$$

In the given dependences εb_0- is expressed through amplitude of external indignation b. $\left(b_0 = \frac{b}{\rho F}\right)$.In the fig. 2 is represented, as an example, resonant curve development of fluctuation amplitude of loading of the vibratory technological machine with the vertical indignation.

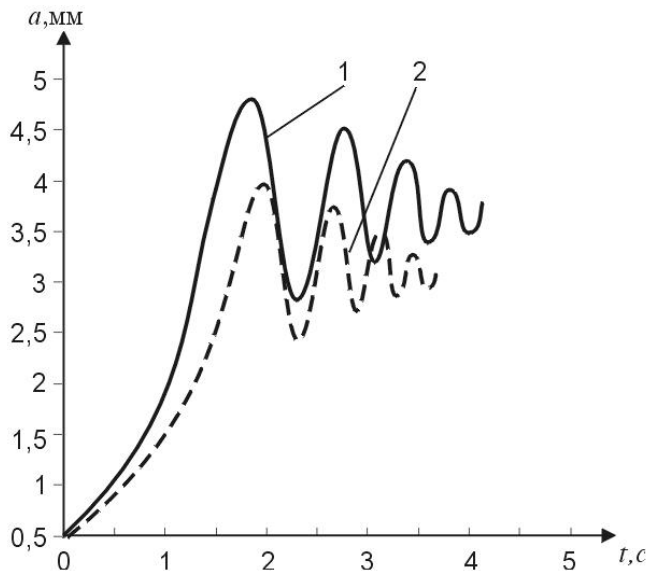

Fig. 2. *The diagram of change of vertical fluctuations amplitude of a loading layer in resonant case for* $b_0 = 0{,}0014 m^2 \cdot kg^{-1}$ *(curve 1),* $b_0 = 0{,}0009 m^2 \cdot kg^{-1}$ *(curve 2), authors'*

The physical and mechanical parameters of the investigated loading of the vibrating technological machine are: modulus of elasticity of the first degree - $E = 2 \cdot 10^7 H \cdot m^{-2}$, length of the loading layer (width of the working chamber of the machine) - $l = 1m$, the product of the loading density on the area of the cross-section of its layer - $\rho F = 7{,}2 kg \cdot m^{-1}$.

CONCLUSIONS

Thus, the received software enables analytically to investigate dynamics of technological vibromachine loading, to determine amplitude and frequency of fluctuations of loading depending on its properties and properties of vibromachine. Analytical solutions of the nonlinear differential equations of the description of movement of loading make the possible automated definition of amplitude, frequencies, trajectory of compound loading movement depending on parameters of system "vibromachine-loading" in way of their algorithmization in applied systems of the automated mathematical accounts.

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