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INFLUENCE OF THE VELOCITY OF THE MEDIUM LAYER ON ITS DYNAMIC PARAMETERS IN THE PROCESS OF VIBRATION SEPARATION

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Abstract. A review of recent research in the field of vibration separation of bulk media has been done. It was found that the productivity of the separation process is influenced not only by the design characteristics of the vibrating separator, in particular the length, angle and capacity of the working housing, but also the dynamic processes that occur in bulk medium during separation. The efficiency of the separation process significantly depends on the mutual influence of the velocity of the bulk medium along the separator sieve and its amplitude-frequency characteristics. Based on the review, the relevance of further study of these parameters was established. Using the methods of nonlinear mechanics, a mathematical model of the motion of the layer of bulk medium on the sieve of the vibrating separator was built. The layer of bulk medium was modeled by an elastic beam, which is in contact elastically, rigidly, or as hinged. Graphical dependences of the influence of the frequency of external perturbation and the velocity of the bulk medium along the sieve of the separator on its oscillation amplitude were obtained. The obtained mathematical model and graphical dependences showed that small velocities of the medium layer lead to an increase in the amplitude of oscillations of the bulk medium and a decrease in its frequency of oscillations, which increases the permeability of medium particles and increases the productivity of the separation process. The obtained researches allow us to increase the efficiency of the separation process, to regulate the processes that take place in the bulk medium and to increase the speed of its passage through the sieve openings. The constructed mathematical model can serve as a basis for further studies of the influence of changes in the physical and mechanical characteristics of the bulk medium on its dynamic parameters in the process of vibration separation.

Keywords: vibrating separator, bulk medium, amplitude-frequency characteristics, dynamic parameters.

Introduction

Processing of raw materials and semi-finished products is common in various production cycles. Intermediate stages of processing of bulk raw materials include separation, mixing, transportation, dosing, compaction, etc. The use of vibrating equipment in these processes and the direct impact of vibration on the processed raw materials, contribute to improving the quality of raw materials. In particular, due to constant shaking, the particles of raw materials are loosened and a high degree of their separation by physical and mechanical properties is achieved. The efficiency of the passage of bulk raw material's particles through the holes of the sieve is influenced by geometric dimensions, mass, structure of particles, their amplitude and frequency of oscillation, the interaction of particles with each other. Accordingly, the productivity of the separation process is affected not only by the design parameters of the vibrating separator, but also listed above characteristics of the loaded raw materials.

To date, a large number of studies and simulations of the movement of the bulk medium on the sieve of the vibrating separator. It was considered on the basis of many hypotheses, in particular, as the motion of a single particle, the motion of a set of particles, the motion of a solid body, the layering of layers of particles, etc. However, given that bulk raw materials perform complex spatial motion on the vibrating separator sieve, none of these hypotheses describes the process of the vibration separation in full. Therefore, the implementation of further research is still relevant.

Problem Statement

Modern industrial development requires constant research and improvement of production equipment. This applies to both light and heavy and processing industries. In all its branches, separation plays an important role in the initial and intermediate stages of raw material processing. Therefore, research is relevant to improve the design of separators and optimize separation processes. Quite often volume separators are used in production. Their use allows you to reduce the working area of production, separation time and material costs, due to the possibility of layering more sieves, and, accordingly, the separation of multicomponent mixtures in one operation. Previous research has shown that the productivity and efficiency of separation are influenced not only by the design parameters of the vibrating separator, but also the characteristics of the bulk medium. This includes the composition and shape of the bulk material, humidity, thickness of the layer on the sieve. All these indicators during separation determine the interaction of particles and layers of the medium, which affects the speed of particles passing through the sieve. These issues are poorly studied and need further study.

It is determined that the efficiency of the vibrating separator depends not only on its dynamic and structural parameters, but also on the properties of the bulk media that are separated. It is established that during vibration separation of bulk cargoes the process of movement is significantly influenced not only by the nature of the separation organ, but also by the peculiarities of the interaction of constituent layers and particles with each other. The main disadvantage of separators with a fixed work surface is the scattering of the rebound range in the medium being separated. The reason is the incorrect shape of the lumps of material, which leads to oblique impact. In this case, the centre of gravity of the particle is shifted from the vertical at the point of contact of the particle and the sieve. As a result, the flight range of the particle decreases. The large variance of the rebound range of the particles makes it possible to use such separators only for components with significant differences in strength. More effective in this case is the separation by elasticity for minerals with a rounded shape of particles, such as gravel. Quite interest for research is the case of isolation of a set of such particles and modeling them in one common layer. In particular, the behavior of the material layer during separation and the interaction of the layers with each other. It is suggested to consider it below.

Review of Modern Information Sources on the Subject of the Paper

Current research shows that the physical and mechanical characteristics of bulk raw materials and its interaction with the sieve surface affect the efficiency of separation. Recent studies have focused on the dependence of productivity and quality of screening on the feed rate. It is established that the feed rate of bulk raw materials should be increased with increasing sieve surface length. Otherwise, increasing the feed rate will lead to clogging and sticking of the mixture in the separator container and reduce the separation efficiency [1, 2]. Also, by the method of mathematical modeling, it was found that increasing the feed capacity of bulk raw materials by more than 80 % leads to a complete loss of separation efficiency. It means that changes in the feed rate and its physical and mechanical properties directly affect the screening efficiency. Also, increasing the volume of the working body of the vibrating separator leads to a decrease in screening efficiency [3]. Based on the EDEM module, the behavior of the bulk material on the surface of the separator sieve was modeled. In particular, the velocity of the material, the change of the material layer along the sieve, both at a constant and at variable oscillation amplitude are considered. It is established that the velocity of particles of bulk material decreases along the length of the sieve [4]. Also, reducing the length of the sieve, the thickness of the layer of bulk material and changing the shape of the material lead to sticking, difficulty in passing particles and reducing the efficiency of separation [5, 6]. Important factors that affect the interaction of bulk material with the working container of the vibrating separator are also the angles of the sieve, the amplitude and frequency of oscillations of the raw material. In particular, reducing the amplitude and angle of the sieve reduces the impact force of the bulk material and can prevent damage to the sieve in the case of separation of heavy and sharp materials [7]. Most studies give a partial idea of the movement of the bulk medium through the sieve of the vibrating separator [8–17], so it is proposed to consider the bulk material on the basis of an integrated approach, characterizing the material layer with some generalized parameters and taking it as a solid elastic body. Based on the above model, it is proposed to investigate the relationship between the velocity of bulk raw materials along the sieve of the vibrating separator wand its amplitude-frequency characteristics.

Main Material Presentation

During the separation of the bulk medium, the layer in contact with the working surface of the sieve receives power pulses from it. Pulses are transmitted from the lower layer to the layers located above. Due to the presence of friction forces and necessary deformations, the pulses during their transmission from layer to layer are gradually weakened, and the degree of their attenuation is determined by the properties of the bulk medium and the property and magnitude of force pulses generated by the working body. The energy of the oscillating motion of the working body is spent on accelerating the separating medium and restoring losses in the case of irreversible deformations. This process is influenced by the height of the bulk layer, the frequency and amplitude of oscillations of the layer on the sieve and the speed of movement of the bulk medium along the sieve. Modeling of the bulk raw material layer as a layer of flat, elastic-plastic beams, the equation of it will look like:

$$\frac{\partial^2 u(x,t)}{\partial t^2} + 2V\frac{\partial^2 u(x,t)}{\partial x \partial t} - \nu(\alpha^2 - V^2)\frac{\partial^2 u(x,t)}{\partial x^2} = \varepsilon f\left(x, \frac{\partial u(x,t)}{\partial x}, \frac{\partial u(x,t)}{\partial t}\right), \qquad (1)$$

where α – function that describes the physical and mechanical characteristics of the layer of bulk raw materials; $u(x,t)$ – movement along the sieve a section of the elementary layer of bulk raw materials with the coordinate x in any period of time t; ν – coefficient that takes into account the elastic properties of bulk raw materials; V – the speed of movement of the bulk raw material's layer along the sieve; ε – some small parameter that indicates the deviation of the elastic integral properties of bulk raw materials from the linear law; f – function that characterizes the nonlinear deviation of the narrow properties of the bulk raw material from the linear law. A small parameter ε indicates that the maximum value of the influence of nonlinear and periodic forces in the layer of bulk raw materials is small compared to the reducing force. The terms of equations (1) $2V\frac{\partial^2 u(x,t)}{\partial x \partial t}$ and $\nu(\alpha^2 - V^2)\frac{\partial^2 u(x,t)}{\partial x^2}$ take into account the movement of bulk raw materials along the sieve.

As noted in previous studies, given that the layer of bulk raw material in contact with the walls of the working container of the vibrating separator is elastic, the boundary conditions will be as follows:

$$u(x,t)\big|_{x=0} = u(x,t)\big|_{x=l} = 0. \qquad (2)$$

Given that the average elastic properties of bulk raw materials satisfy a close to linear law of elasticity, the basis for the mathematical model of the dynamics of bulk raw materials will be equation (1) with boundary conditions (2).

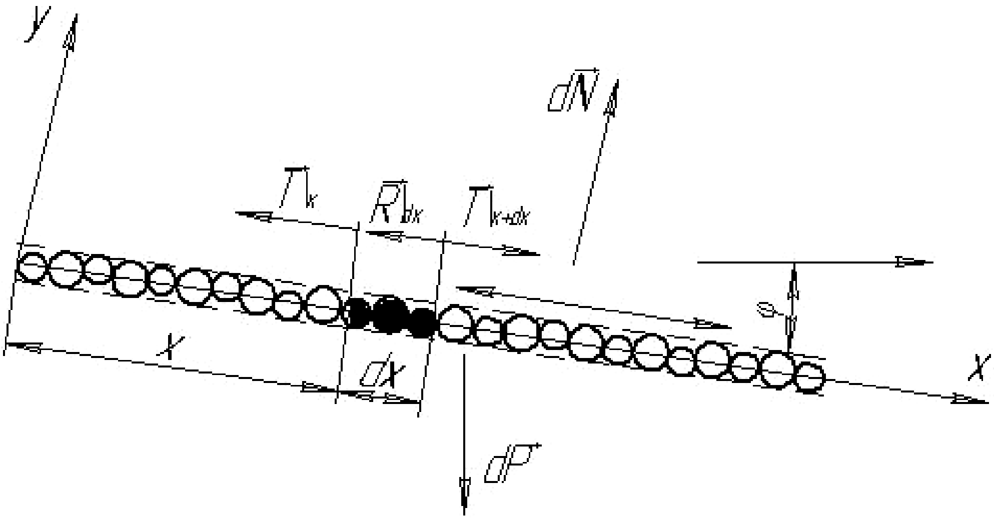


Fig. 1. Calculation scheme of the bulk medium layer and the forces acting on its particle

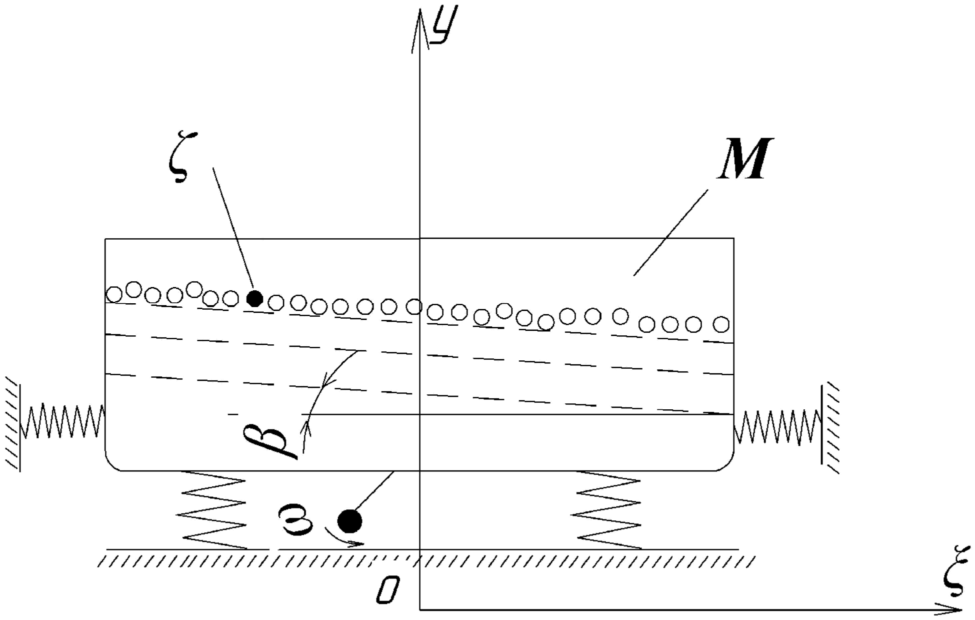


Fig. 2. The scheme of movement of the bulk medium on the sieve of the vibrating separator.
ζ – elementary particle of bulk medium

The speed of movement of the bulk medium along the sieve can be different and, accordingly it differently affects on the value of its amplitude-frequency parameters.

If we consider the case of low velocity of bulk medium along the sieve, then by the method of Krylov-Bogolyubov the first single-frequency approximation will be obtained in the form:

$$\omega^2 \frac{\partial^2 u}{\partial \gamma^2} + \mu^2 \frac{\partial^2 u}{\partial \varphi^2} + 2\mu\omega \frac{\partial^2 u}{\partial \varphi^2 \partial \gamma^2} - \alpha^2 \frac{\partial^2 u}{\partial x^2} = \sin\frac{n\pi}{l} x (2a\omega K(a)\cdot \sin\gamma +$$
$$+ 2\omega a N(a)\cdot\cos\gamma + \left(\frac{n\pi}{l}\right)^2 V^2 a\cdot\cos\gamma) + 2\left(\frac{n\pi}{l}\right) Va\omega\cos\frac{n\pi}{l} x\sin\gamma + F(a,\gamma,\varphi,x), \quad (3)$$

where ω, μ – respectively, the natural frequency of the loose medium and the frequency of external perturbations; γ – phase of single-frequency process.

Then the first approximation of the amplitude and the phase characteristics of the bulk medium's dynamic process is determined by the dependences:

$$\frac{da}{dt}=\varepsilon\frac{1}{P}\frac{1}{2\omega\pi^2}\int_0^l\int_0^{\pi}\int_0^{2\pi}F(a,\gamma,\varphi,x)F(a,\gamma,x)\sin\frac{\pi}{l}x\sin\gamma\,dx\,d\gamma\,d\varphi$$
$$\frac{d\gamma}{dt}=\omega-\left(\frac{\alpha\pi}{l}\right)^2\frac{1}{\omega}V^2+\frac{1}{P}\frac{1}{2\omega\pi^2 a}\int_0^l\int_0^{2\pi}F(a,\gamma,x)\sin\frac{\pi}{l}x\cos\gamma\,dx\,d\gamma\,. \tag{4}$$

In the resonant case, the amplitude and frequency of oscillations are related to the phase of external forces, so we introduce into the system of differential equations "phase difference" $\varphi_k=\psi_k-\frac{\Pi_T}{\pi}\gamma$. Taking into account the latter, the equation for the amplitude and phase of the dynamic process is written in the form:

$$\frac{da}{dt}=\frac{\varepsilon s a\left(1,\nu+1,\frac{\Pi_T}{\pi}\gamma+\varphi_k\right)}{R\omega_k\left(a^*\right)}\int_0^l X_k(x)F_1\left(a,x,\frac{\Pi_T}{\pi}\gamma+\varphi_k,\gamma\right)dx,$$

$$\frac{d\varphi_k}{dt}=\frac{d\omega_k(a^*)}{da}\left(a-a^*\right)+\frac{\varepsilon(\nu+2)ca\left(\nu+1,1,\frac{\Pi_T}{\pi}\gamma+\varphi_k\right)}{2aR\omega_k\left(a^*\right)}\times \tag{5}$$
$$\times\int_0^l X_k(x)\left[\varepsilon F_1\left(a,x,\frac{\Pi_T}{\pi}\gamma+\varphi_k,\gamma\right)-V^2\left(\frac{k\Pi_x}{l}\right)^2 aX_k(x)\right]dx,$$

where a^* – the real root of the equation $\omega_k(a^*)=\pi^{-1}\Pi_T k\mu$ in the case of resonance at a frequency multiple of the frequency of external periodic perturbation.

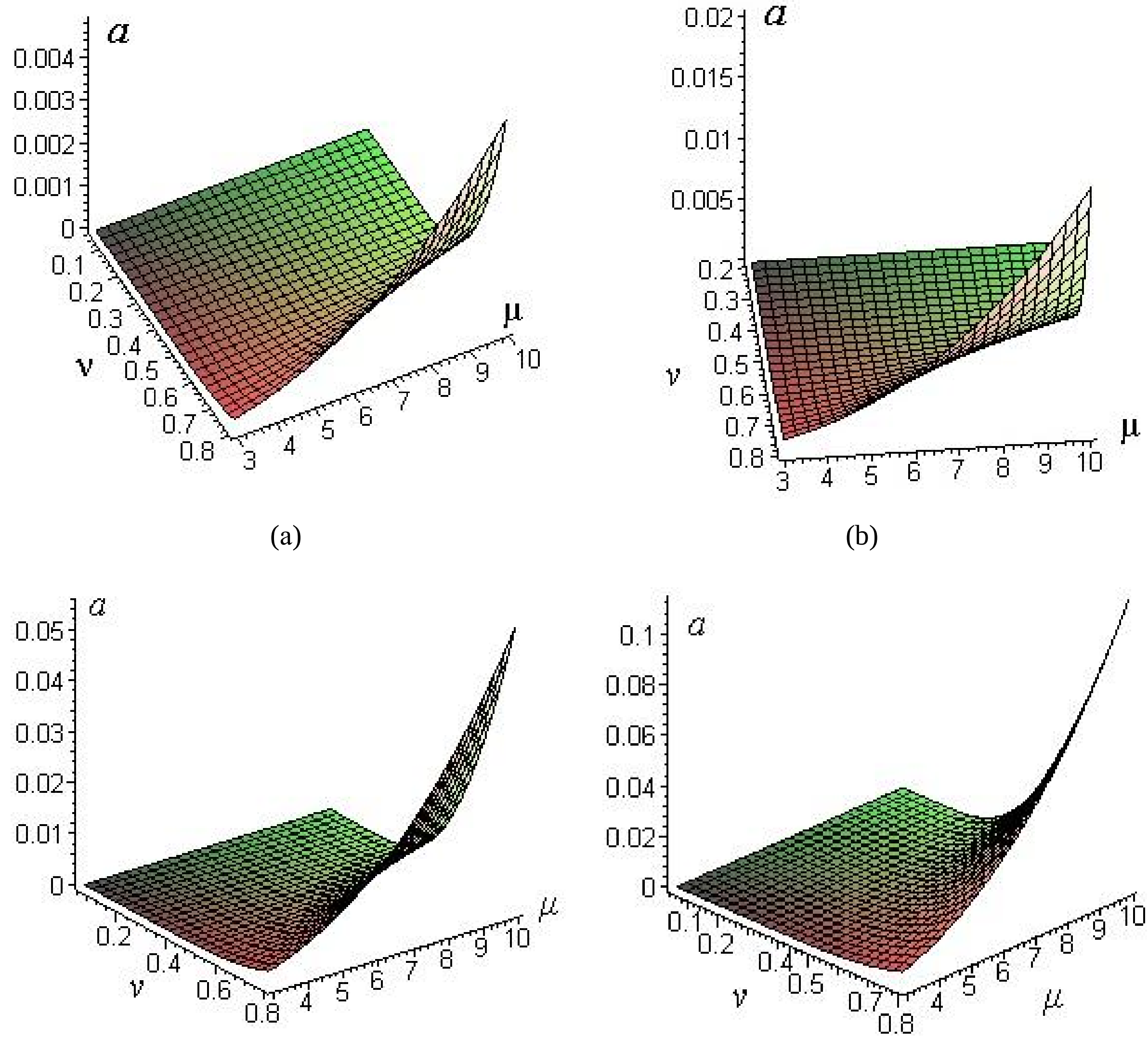
The study of solutions of mathematical models of different types of dynamic processes in a bulk medium, taking into account the whole set of forces, including periodic, allows you to design rationally vibration separation machines with maximum productivity. Obtaining in parametrized form, convenient for engineering calculations analytical ratios that describe the dynamic processes in the layer of material and are characterized by a constant speed of longitudinal motion, taking into account the full range of force factors, including periodic is an important task. It should be noted that the effect on the medium layer of periodic forces, the frequencies of which are close to the natural frequencies of the bulk medium, or rather, is in rational relation to the fundamental frequency of the whole, leads to a significant increase in amplitude. This leads to the occurrence of sufficiently large amplitudes of oscillations in the bulk medium, which improves the process of loosening and separation. Therefore, when building a mathematical model of the motion of the bulk layer, it should be borne in mind that the dynamic process is influenced not only by nonlinear forces, but also the relationship between the frequencies of natural and forced oscillations. This effect is best seen in the resonant case, when there is a relationship between the frequency of external periodic perturbations μ and the natural frequency ω.

Assuming that the frequency of natural oscillations of the bulk medium will approach the frequency of external perturbation, the amplitude and phase of oscillations are determined by the following dependences:

$$\frac{da}{dt}=-\frac{\varepsilon Sl}{\pi(\omega-\mu)}\cos\gamma$$
$$\frac{da}{d\gamma}=\omega-\mu-\varepsilon\left(\frac{E\pi^3a^4}{8\omega l}+\frac{V^2\pi^2}{4\omega l}\right)+\frac{h}{\pi(\omega+\mu)a}\sin\gamma\,, \tag{6}$$

It is assumed that the length of the sieve l = 1 m, the cross-sectional area of the layer of bulk raw materials S = 0.00072 m^2, the mass of the loading layer 12 kg/m^2, the natural frequency of the loading layer ω=31,46 c^{-1}.

Figure 3. shows graphs of the amplitude of oscillations of the bulk medium in the resonant case on the frequency of external perturbation, the velocity of the bulk medium along the separator sieve and the coefficient indicating the deviation of the elastic integral properties of the bulk medium



(c) (d)

Fig. 3. Graph of the dependence of the amplitude of oscillations of the bulk medium a on the frequency of external perturbation μ and the coefficient ν that takes into account the elastic properties of the medium layer. The speed of the medium along the sieve a) V= 0 m/s; b) V= 0.01 m/s; c) V=0.02 m/s; d)V = 0.03 m/s

As can be seen from the graphical dependences, a slight increase in the velocity of the longitudinal motion of the bulk medium leads to increase in the amplitude of oscillations of the loading layer. For small values of the velocities of the longitudinal motion of the bulk medium, the resonant frequency is lower and the amplitude of oscillations is smaller. When separating hard bulk media, the separation process will be more intense with larger amplitudes of oscillations of the medium layer.

Conclusions

The constructed mathematical model and the obtained graphical dependences make it possible to further adjust the amplitude-frequency characteristics of bulk raw materials depending on the physical and mechanical properties, the loading material, the angle of the separator sieve to the horizon and the loading speed of raw materials. It is established that the constant components of velocities affect the increase in the natural frequency of fluctuations of bulk raw materials, which accordingly impairs the efficiency of the passage of particles through the sieve of the separator. Low velocities of the bulk raw material layer lead to an increase in the oscillation amplitude and a decrease in the oscillation frequency, which helps to increase the possibility of raw material particles and increase the productivity of the separation process. The obtained researches allow you to improve the efficiency of the separation process, to regulate the processes that take place in the bulk raw material and to increase the speed of its passage through the sieve openings. The constructed mathematical model can serve as a basis for further studies of the influence of physical and mechanical characteristics of bulk raw materials on the efficiency and productivity of the separation process.

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