Journal of Siberian Federal University. Engineering & Technologies 5 (2012 5) 585-591
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УДК 621.928.2

On Creation of Multi-Wave Screens

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Received 06.09.2012, received in revised form 13.09.2012, accepted 20.09.2012

In this article, an attempt on theoretical justification of design of a multi-wave separator for dispersion of ultrafine powders is made. The advantages of such separator, as compared to the ordinary one, are specified. The characteristics of materials appropriate for creation of real designs of multi-wave screen-separators are considered.

Keywords: multi-wave screen, ultrafine powder, non-isometric particles, Van der Pol oscillator, aramid fiber, diamond powder, carbon-containing stock.

Introduction

Dispersion of loose materials into conditioned fractions is a very frequently encountered technological operation in many production processes. Technical devices used for this purpose are called industrial or laboratory screens. Presently there are several dozens of various modifications of screens different in the type of power drive, dimensions, performance and features of their design. Despite considerable differences, all common modifications of screens are characterized with a general fundamental drawback – an extremely low coefficient of efficiency. The coefficient of efficiency of most screens made in Russia and abroad is not more than 1-2 %. First of all, it is caused by single-frequency nature of oscillations of working mesh, presence of a massive rigid frame for its attachment, and great losses of power consumed by the drive motor. However, the mesh of an ordinary screen oscillating with the drive frequency does not actually screen particles but simply distribute them over its surface until all particles with dimensions less than the dimension of the working mesh cells pass through it under action of gravity. In most cases such process is very time- and power-consuming.

When dispersing ultrafine materials using screens of common designs, there are problems connected with permanent clogging of mesh with non-isometric particles; besides, when screening galvanic materials, particles stick together under Coulomb force making hard-separate aggregates. In order to overcome the above difficulties, we have made an attempt to create a multi-wave vibration screen.

Adhesion effects increase with decrease in degree of material dispersion, that is why screening of particles with dimensions about 10 micrometers and less using common design screens is impossible.

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To overcome the above difficulties, in year 2000, a group of authors suggested an original design of multi-wave vibration separation system and a vibration screen including the system [1].

The suggested method of multi-wave vibration separation has a number of principal advantages as compared to any traditional single-frequency methods used before. It makes it possible to considerably increase the efficiency of dispersion of ultrafine materials, enhance coefficient of efficiency of vibration separators by 15-20%, decrease their energy consumption several times, completely solve the problem of plugging of meshes with non-isometric particles and at the same time exclude the possibility of formation of secondary adhesive aggregates in powders being dispersed.

At the same time, the principle of excitation of multi-wave separator system with a single vibration source realized in this invention led to an excessive complication of design resulting in a considerable decrease of its reliability and significant increase in the cost of multi-wave separators produced by Kroosher Technologies.

Considering this, a possibility is offered below to simplify and upgrade the design of a high-performance multi-wave vibration separator preserving basic principal advantages of the above prototype but, as distinguished from it, excited with several independent low-power generator-type vibration sources.

Materials and methods

The mechanical characteristics of the most important elements of design of modified multi-frequency vibration separator are specified in study [2]. Among such design elements, first of all, there are elastic carbon rods forming the basis for a modified vibration system and determining its geometry, and also, elastic aramid fibers collectively forming the working mesh of a multi-frequency vibration separator.

The principal features of this vibration system include the absence of rigid massive frame with metal working mesh pulled on it and attachment of electromechanical vibrators of external low-power excitation source directly on its elastic elements. It is offered to use a modified generator of low-frequency electric oscillations on the basis of two electrically connected Van der Pol oscillators with synchronously changing parameters as an excitation source of the multi-frequency (multi-wave) vibration system. The generator executive devices are two electromechanical vibrators with magnetic coupling between their electric and mechanical elements.

The multi-frequency vibration system excited with several (two in the case being considered) sources of nonlinear mechanical oscillations is a complex dynamic system. Theoretical study of such oscillatory systems is quite complicated and difficult in most cases when there are quasi-elastic mechanical couplings between the design elements of such systems. Until now only few Russian papers have been published dealing with theoretical research of simple models of such mechanical systems and their units [3-8].

An example of the offered system may be an elastic fiber of the working mesh of a vibration system attached at the ends of rectilinear rods of circular section forming its structural basis. In their turn, the ends of the rods are attached in special suspensions with identical quasi-elastic characteristics. This dynamic system is excited with two sources of energy the executive elements of which are rigidly fixed at the opposite rods in their geometric centers. To be definite it is assumed that the quasi-elastic rods are excited by means of sinusoidal random impulses of external forces applied to the center of each rod.

Results

The differential equation system describing the dynamics of this oscillatory system is as follows [5,8]:

$$\ddot{q} + \omega^2 q = -\varepsilon\left[\lambda \frac{\dot\varphi}{\dot\theta} q \sin\theta + h\dot{q} + f(q)\right];$$
$$\ddot{\varphi} = \varepsilon\left[M_1(\dot\varphi) - N_1(\dot\varphi, \dot\theta) - \lambda q^2 \cos\theta - \nu_1 \frac{\dot\varphi}{\dot\theta} \sin 2\theta + \nu_2 \dot\varphi\dot\theta \sin 2\theta\right]; \quad (1)$$
$$\ddot{\theta} = \varepsilon\left[M_2(\dot\theta) - N_2(\dot\varphi, \dot\theta) - \lambda \dot\varphi^2 \sin 2\theta\right],$$

where $\omega^2 = \frac{\pi^4 EI}{ml^4}$, $\lambda = \frac{\pi^2 EFk}{ml^3}$, $\nu_1 = \frac{E_1 F k_1^2}{2I_1 l_1^2}$, $\nu_2 = \frac{E_1 F k_1^2}{2I_2 l_1^2}$, $h = \frac{\beta}{m_1}$. (2)

Points above the values in (1) mean differentiation with respect to time t.

Here $f(q)$ is a function characterizing nonlinearity of characteristics of quasi-elastic suspensions; q is the displacement of small fiber element; ω is the natural oscillation frequency of the elastic fiber; m is the weight of the fiber's unit of length; φ is the angular coordinate of fiber horizontal deviation in the vertical plane; θ is the frequency of impact of the external force in a small period of time; I_1 is the impulse of impact force of the first excitation source; I_2 is the impulse of impact force of the second excitation source; $M_1(\dot\varphi)$ is a function characterizing the dependence of dynamic characteristic of an excitation source (rod) on the speed $\dot\varphi$, of coordinate change; $M_2(\dot\theta)$ is a function characterizing the dependence of dynamic characteristic of an excitation source (rod) on the speed $\dot\theta$, of external force impact change; $N_1(\dot\varphi,\dot\theta)$ and $N_2(\dot\varphi,\dot\theta)$ are functions characterizing the dynamics of elastic stresses of the first and second sources in a fixed moment of time; λ, h, ν_1, ν_2 are dimensionless coefficients; ε is a small parameter; E is the fiber elasticity modulus; m is the weight of the unit of fiber length; l is the fiber length; F is the external force influencing the system; k is the fiber damping coefficient; k_1 is the rods damping coefficient; E_1 is the rods elasticity modulus; l_1 is the rods length; β is the rods rigidity coefficient; m_1 is the weight of the rods unit of length.

The most active interaction of this dynamic system with the sources of power is in the frequency domain of the main resonance [6, 7].

$$\omega - \frac{\theta}{2} = \varepsilon\Delta. \quad (3)$$

Let's consider the system oscillatory motion in this frequency domain. For this purpose it is convenient to introduce new variables.

$q = a\cos\psi$, $\eta = \dot{q} = -a\omega\sin\psi$, $\dot\varphi = \Phi$, $\dot\theta = \Omega$, where $\psi = \frac{\theta}{2} + \xi$ is the resonance frequency of this resonance domain. Then

$$M_1(\dot\varphi) = M_1(\Phi), \quad M_2(\dot\theta) = M_2(\Omega),$$
$$N_1(\dot\varphi, \dot\theta) = N_1(\Phi, \Omega) \text{ и } N_2(\dot\varphi, \dot\theta) = N_2(\Phi, \Omega).$$

Besides, to be definite, in the initial system (1) it is necessary to specify a function $f(q)$ characterizing the nonlinearity of characteristics of quasi-elastic couplings.

Let's assume that at the first approximation the function *f*(*q*) can be expressed in the form [7] characteristic of many quasi-elastic materials.

$$f(q) \approx \nu \alpha^3 \cos\psi. \tag{4}$$

As the rods have circular section, the characteristic function (4) takes the following form in the new coordinate system

$$G(\alpha) = \frac{1}{2\pi}\int_0^{2\pi} f(q)\cos\psi\, d\psi = \frac{\nu\alpha^3}{2\pi}\int_0^{2\pi} f(q)\cos^2\psi\, d\psi = -\frac{3}{8}\nu\alpha^3. \tag{5}$$

After introduction of new variables, consideration of relation (5), and standardization by means of commonly used averaging operation a new system of equations is obtained equivalent to (1):

$$\begin{aligned}
\frac{d\eta}{dt} &= \frac{\varepsilon}{\nu}\left(\frac{\lambda\Phi}{2\Omega}\cos 2\xi - h\omega^2\eta - h\omega^2\right),\\
\frac{d\xi}{dt} &= \varepsilon\left(\frac{h\omega^2\eta}{\upsilon\lambda} - \frac{\lambda\Phi}{\Omega}\sin 2\xi - \nu\omega\cos\xi - \frac{\lambda\Phi}{2\Omega}\cos 2\xi\right),\\
\frac{d\Phi}{dt} &= \varepsilon\left(\mathrm{M}_1(\Phi) + N_1(\Phi,\Omega) - \frac{\nu}{2\omega h}\sin\xi - \frac{\nu}{4\omega h^2}\cos\xi\right),\\
\frac{d\Omega}{dt} &= \varepsilon\big(M_2(\Omega) - N_2(\Phi,\Omega)\big).
\end{aligned} \tag{6}$$

Equations (6) make it possible to study both transient processes in the dynamic system and the stationary oscillations.

The numerical study (modeling) of the dynamic system described with these differentiable first-order equations is complicated with the fact that for this purpose it is necessary to assign the explicit forms of functions M_1, M_2, N_1, and N_2 describing dynamic characteristics of each of the excitation sources. The analytic forms of these functions can be determined only experimentally with the relevant physical model of this dynamic system with its real excitation sources.

However, when there are two excitation sources identical in their dynamic characteristics, it is possible to suppose with the relevant degree of accuracy that in the frequency domain of the main resonance (3) the condition [8] is satisfied

$$M_1(\varPhi) \approx M_2(\Omega) \approx M(\omega) \tag{7}$$

and functions N_1 and N_2 are also approximately equal.

$$N_1(\Phi,\Omega) \approx N_2(\Phi,\Omega). \tag{8}$$

In this case, if conditions (7) and (8) are satisfied, the condition [8, 9] is also met.

$$\frac{d\Phi}{dt} \approx \frac{d\Omega}{dt}. \tag{9}$$

Considering the equation (7)-(9) let's sum up the third and the fourth equations of the system (6), and obtain an equivalent equation instead of them

$$\frac{d\Phi}{dt} = \varepsilon\left(M(\omega) - \frac{\nu}{\omega}\sin\xi - \frac{\nu}{2\omega h}\cos\xi\right). \tag{10}$$

In the case of the dynamic system excitation with two identical sources of energy it can come into resonance only providing the following condition is met:

$$\frac{d\eta}{dt} = \frac{d\xi}{dt} = \frac{d\Phi}{dt} = 0. \tag{11}$$

It is possible only in case when function M (ω)has the following form:

$$M(\omega) = \frac{h\lambda\omega^2\Phi}{2\Omega} cos2\xi. \tag{12}$$

In this case the system of equations (6), considering (11) and (12), takes the following form:

$$\begin{aligned} &\frac{1}{\omega}\left(\frac{\lambda\Phi}{2\Omega} cos2\xi - h\omega^2\eta - h\omega^2\right) = 0, \\ &\left(\frac{h\omega^2\eta}{\nu\lambda} - \frac{\lambda\Phi}{\Omega}\sin 2\xi - \nu\omega\cos\xi - \frac{\lambda\Phi}{2\Omega} cos2\xi\right) = 0, \\ &\left(\frac{h\lambda\omega^2\Phi}{2\Omega} cos2\xi - \frac{\nu}{\omega h}\sin\xi - \frac{\nu}{2\omega h^2} cos\xi\right) = 0. \end{aligned} \tag{13}$$

The system of equations (13) by means of substitution

$$\mathrm{X} = h\omega^2; \;\; Y = \frac{\lambda\Phi}{2\Omega} cos2\xi \;; \;\; \mathrm{Z} = \frac{\nu}{\omega h} cos\xi. \tag{14}$$

is transformed to a well-known Lorentz system of equations

$$\begin{aligned} &\dot{\mathrm{X}} = \sigma(Y - X), \\ &\dot{\mathrm{Y}} = rX - Y - XZ, \\ &\dot{\mathrm{Z}} = \mathrm{XY} - bZ \end{aligned} \tag{15}$$

in which, in this case, the dimensionless coefficients σ, r, and b take the following values

$$\sigma = \frac{1}{\nu}; \;\; r = \frac{1}{\nu\lambda}; \;\; b = \frac{\nu}{2h}. \tag{16}$$

For a case of identical frame-forming rods these coefficients take the following form

$$\sigma = \frac{2I_1 l_1^2}{E_1 F k_1^2} \;; \quad r = \frac{2I_1 l_1^5 m}{\pi^2 E E_1 F^2 k k_1^2} \;; \quad b = \frac{E_1 F k_1^2 m_1}{4\beta I_1 l_1^2} \tag{17}$$

gning the relevant magnitudes of values included in expressions (17) for a model structure of multi-wave screen with carbon rods and aramid fibers, that is $l = l_1 = 1m$; $m = 3{,}2 \cdot 10^{-3}\, kg$; $m_1 = 5{,}4 \cdot 10^{-2}\, kg$;

$E_1 = 136 \frac{GN}{m^2}$; $E = 385 \frac{GN}{m^2}$; $k = 2{,}7 \cdot 10^{-3} \frac{\mathrm{m^2 \cdot c^3}}{\mathrm{kg}}$; $k_1 = 3{,}9 \cdot 10^{-6} \frac{\mathrm{m^2 \cdot c^3}}{\mathrm{kg}}$; $\beta = 0{,}047$; $F = 0{,}1\ N$;

$I_1 = 9{,}8\ kg \cdot m^2$; $\pi \approx 3{,}1416$, we obtain the values of dimensionless coefficients σ ≈ 10; r ≈ 177.8; b ≈ 2, with which this dynamic system is in the state of main parametric resonance.

With these values of σ, r, and b the phase diagram of Lorentz attractor is shown in Fig. 1, and with the values σ = 10; r = 164.3; b = 2.7 it is shown in Fig. 2, from which it can be seen that Lorentz attractor preserve its properties in quite a wide variation range of parameters σ, r, b.

Lorentz equations (1) can be comparatively easily solved and studied using numerical modeling by means of mathematics package Maple 7.0.

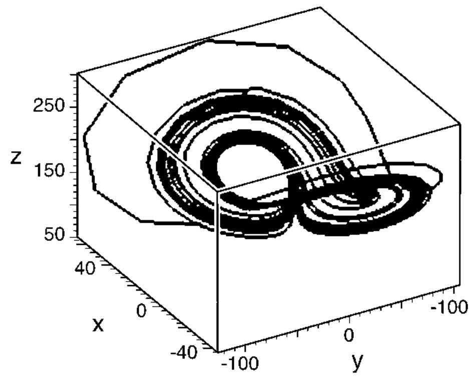

Fig. 1

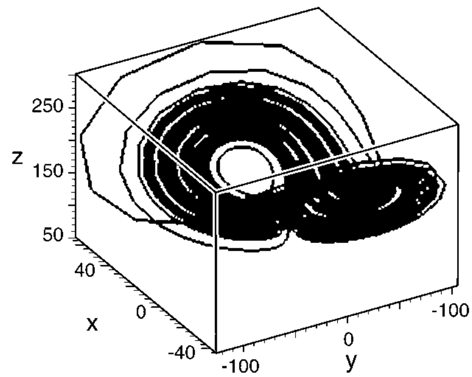

Fig. 2

In the course of their operation multi-wave screens are permanently in the resonance domain that is in a frequency domain where vectors of external exciting forces and displacement of the vibration system itself coincide. When particles of loose material are on the surface of the working mesh of a multi-wave screen each particle immediately finds its resonant frequency as a great variety of frequencies is present on the mesh and distribution of such frequencies over the surface of the mesh changes dozens of times per second. Its high efficiency is due to constant mixing of loose material under the influence of quickly changing dynamic moments having effect on every particle with a frequency coinciding with the natural resonant frequency of such particle. In the result small particles able to pass through the mesh are not blocked by large ones but freely reach the surface of the mesh and pass through it, even if they initially were in upper layers of the material. It conditions high technological efficiency of multi-wave screen.

Duscussion of risalts

An essential condition for making real designs of multi-wave screens is a selection of appropriate construction materials suitable for manufacturing of working meshes and rods of their structural basis. The results of numerical modeling of the relevant dynamic operating modes of a multi-wave screen show that for this purpose the materials are necessary with unique physical mechanical properties. More specifically, their high strength (>1000 MPa) shall be combined with high elasticity modulus, low temperature coefficient of elasticity modulus, high frequency quality factor, low elastic hysteresis, stability of these properties, wear resistance, corrosion resistance close to similar characteristics of best strain-hardening metal alloys of type 40KXHMB.

However, as distinguished from them, such materials shall have far higher fatigue strength.

A study has been made on synthetic fiber "Carbolon", carbon fibers type BMH-4 and "Kulon", and aramid fiber "Avco", which have been found suitable for manufacturing of elements of a laboratory multi-wave vibration screen.

Conclusion

This study represents the first experience of research of multi-wave dynamic systems. The results obtained evidence the possibility of creating multi-wave separators able to disperse loose media with the dimensions of particles in the order of units of micrometers. Such devices may be used in different sectors of industry such as chemical, pharmaceutical, and many others. We are planning to use the device for dispersing ultrafine diamonds. In our Department of Nanophase Materials and Nanostructures of Institute of Engineering Physics and Radioelectronics a method has been developed for obtaining diamond powder by means of explosion technology with characteristic dimensions of diamond particles and their coagulation conglomerates from 4 to 2000 nm, where such particles are resistant to ultrasound disintegration due to their extremely high surface energy. Besides, due to specifics of the technology used, carbon-containing stock, which is the main product of explosion synthesis of nanodiamonds, contains not only nanodiamonds, but ferrous carbides, nanotubes, fullerenes, and other admixtures. To simply the process of their extraction from the stock it is offered to flow it through a multi-wave separator with extraction of fine fractions of necessary dimensions.

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О создании многоволновых грохотов

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В статье изложено теоретическое обоснование проектирования многоволновых грохотов для разделения ультрадисперсных порошков. Указаны преимущества предлагаемых грохотов по сравнению с известными сепараторами. Приводятся характеристики материалов, подходящих для создания реальных проектов многоволновых грохотов.

Ключевые слова: многоволновой грохот, ультрадисперсный порошок, неизометрические частицы, трудноразделимые конгломераты, адгезия, осциллятор Ван дер Поля, арамидное волокно, алмазный порошок, углеродосодержащая шихта .