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THE DESIGN AND OPERATION OF EQUIPMENT AS CONVEYING AND SORTING DEVICES

This paper describes the use of asymmetric vibrations for special application in the operation of such equipment as conveying and screening machines. The inventive aspects of process design include the arrangement of a set of devices. Analytical aspects of vibration processes are also involved.

Keywords: vibration, design, operation, dynamic parameters.

This paper describes the use of vibratory equipment for its special application in processes involved in the primary mode of operation of such equipment as conveying and screening machines. The inventive aspect of process design includes the arrangement of a set of devices. Some analytical aspects of vibration are also involved.

The thickness factor of the solids presenting in the mixture is also essential with the screening machines motivated by the acceleration of vibration. The design of equipment for this particular operation is less developed aspects of vibration technology. Selection of the technique or techniques to be used for a particular system can be also broken down into the task to use the translational vibration motion in the direction of the Y axis of the deck of device (longitudinal vibration). The technical feasibility and engineering perspectives of a given method must be attractive.

Mixtures of dry solids can be sorted by the specific thickness differences of the components. The proper introduction to feed the screening machine is one of the keys to its performance. The batching and removal of solids require a good control. For some critical designs, the performance cannot be predicted theoretically and such systems require experimental work to determine concentration of feed, sizing (spacing for equipment), material of construction, operating conditions and costs, quality required, etc. For consistence performance dynamic models are useful in evaluating optimal performance.

The design shown below is common for sorting depended on the thickness differences of the solids present in a multicomponent mixture.

A type of equipment for sorting mixtures according to the particle thickness is shown in Fig 1. The principal part of such a device is a bar (part 1) which can be turned into three positions of 10, 20, and 30^0, and deck (part 3).

The disturbance force from electromagnetic exciter (part 4) moves the deck and the bar in opposite directions. The deck and reactive frame (part 5) are supported by elastic damper (part 8) to prevent vibrations from being transferred from the upper part of the machine to the turning frame (part 6). The machine rests on base (part 7). The base usually comprises handwheel (part 9) and screw mechanism (part 10). The initial mixture is separated into fractions: finer grains (thin) pass a clearance under the bar (part 1); larger grains (thick) with dimensions exceeding the gap are caught by the bar and directed upwards.

Characteristics of equipment (see Fig. 1)

The frequency range of the simple harmonic motion: 3000 min^{-1}

The amplitude of the displacement: 1 mm

The angle of vibration: 25º

Longitudinal tilt of the deck: 10-20º

Lateral tilt of the deck : 0-8º

* - автор, с которым следует вести переписку.

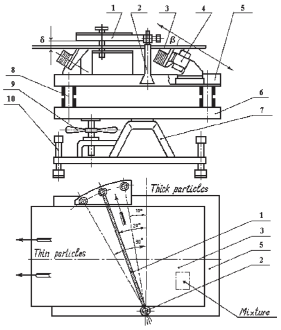

Fig. 1. Vibratory Device for sorting particles according to their thickness: 1-Separating bar; 2 – Lever; 3 – Deck; 4 – Electromagnetic exciter; 5 – Reactive frame; 6 – Turning frame; 7 – Base; 8 – Damper; 9 – Handwheel; 10 – Screw mechanism

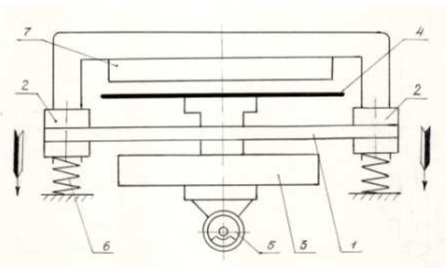

Fig. 2. Electromotive Device: 1-Leaf spring; 2-Reactive frame; 3-Active frame; 4- Deck plane; 5-Vibration exciter; 6-Isolators; 7-Separating bar

Simultaneous oscillatory movements of the bar and the deck in opposite directions prevent the narrow gaps from being clogged and promote passing fine particles through. This mechanism is provided by the device shown in Fig. 2. A schematic diagram of a typical motion is shown in Fig. 3. The gap may be calculated by the expressions:

$$\delta_{y.max} = \delta + (A_1 + A_2)\text{Sin}\beta$$

$$\delta_{y.min} = \delta - (A_1 + A_2)\text{Sin}\beta$$

where $\delta_{y.max}$ is the maximum linear shift in the direction of *Y*- axis; $\delta_{y.min}$ is the minimum linear shift in the direction of *Y*- axis; δ is a gap between the bar (part 1) and the deck (part 2) as shown in Fig. 3.; A_1 is a shift amplitude of the deck; A_2 is a shift amplitude of the bar, and β is the angle of vibration.

The schematic representation of the displacement amplitudes of the mechanical parts of VS used in the design and operation of separation process arising from differences in particle thickness illustrates possibility of passage of thin particles through opening δ between the bar and deck plane.

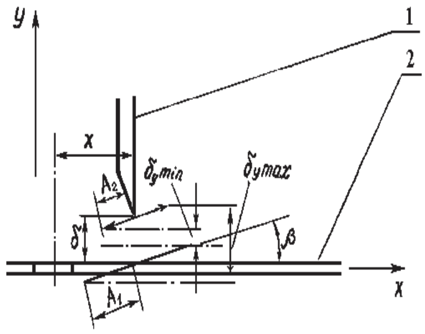

Fig. 3. Diagram depicting shift of mechanical parts of the machine used to illustrate the principle of vibrational separation by particle thickness

The device has been tried experimentally but are not in use commercially. This horizontal device can be used to estimate its performance of various sizes and it can be used to predict the effect of specific thickness difference of solids, and allows prediction of capacities at various flows of the mixtures as a function of dynamic parameters. This information will be adequate to determine the final design of vibratory equipment, provided the solids of the mix are readily characterized and the solids concentration in the feed is steady. For applications where the solids widely in thickness, a test program should be undertaken. The device of this type is applicable where separated solids are expected to be very dry.

In horizontal vibratory equipment mathematical modeling is useful in evaluating their performance. Theoretical calculations are recommended for potential design of such equipment with the deck generally placed horizontally and experiences rectangular vibration.

The mathematical basis for operating processes motivated by the rectangular acceleration of translational vibration motion and steps in exact solution of transcendental equations of particle movement are presented below. Motion of single degree-of-freedom system of the deck acted upon by the rectangular vibration in longitudinal direction (the rectangular acceleration pulse of magnitude *w* and duration *t*) is discussed. The corresponding velocities of time histories are also for various conditions. The magnitude of the velocity *u* change defines the intensity of the process. The longitudinal displacement of the deck during the vibration is characterized by three steps (for purposes of illustration in the following examples the primary time history is that of acceleration, time-histories of velocities may be derived there from by integration). If the velocity u is zero at time *t*=0, then the velocity time-history is a line of constant slope, the corresponding acceleration time-history is the acceleration step of constant value as was shown in [1]. The first step is defined as a forward motion which has value u of zero and a value of w slightly greater than zero $(w_1 > 0, u_{1H} = 0)$; the second step describes forth and back motion for the conditions $(w_2 < 0, u_{2H} = u_{1H} > 0, u_{2K} < 0)$; that is the acceleration step has a value less than zero significantly; the third step is defined as backwards motion which has a value of acceleration somewhat greater than zero $(w_3 > 0, u_{3H} = u_{2K} < 0, u_{3K} = 0)$, where w_i is the acceleration step , u_{iH} , u_{iK} are initial and finite deck velocity steps.

The motivated particle motion is defined mathematically as a function of $w_1, w_2, w_3, u_{1K}, u_{2K}$. If the accelerations are $w_1 = w_3$, $w_1 < -w_2$, with the simplest representation of the Coulomb friction force and the effect of air resistance $(F_c = 3\pi\mu D\upsilon)$ the mathematical expressions describing the motion of a particle of mass m are

$$m\frac{d\upsilon}{dt} = \chi f \cdot g - \frac{3\pi\mu D\upsilon}{m},$$

or

$$\frac{d\upsilon}{dt} = \chi f \cdot g - \frac{3\pi\mu D\upsilon}{m},$$

where f is the coefficient of friction, D is the particle diameter, μ is the air viscosity, g is the acceleration of gravity. The algebraic sign of the friction term changes when the velocity changes sign ($-I \le \chi \le +I$). For forward sliding when $\upsilon < u$ it must have a positive sign $\chi = +I$; for backwards sliding : $\upsilon > u, \chi = -I$; at rest $\upsilon = u$ it is $\chi \ne \pm I$.

By performing transformation of the latter equation the following differential equation of the particle motion is obtained

$$\frac{d\upsilon}{dt} = \chi fg - n\upsilon;$$

where $n = 3\pi\mu D/m$.

Rewriting,

$$d\upsilon = \chi \cdot f \cdot g \cdot dt - n\upsilon \cdot dt.$$

The solution for the latter equation is of the form

$$\upsilon = \chi\frac{fg}{n} + \left(\chi\frac{fg}{n} - \upsilon_{iH}\right)\exp[-n(t - t_H)];$$

$$l = \chi\frac{fg}{n}(t - t_H) - \frac{1}{n}\left(\chi\frac{fg}{n} - \upsilon_{iH}\right)\{1 - \exp[-n(t - t_H)]\};$$

where the required values of particle displacement l and its velocity υ are found.

Consider the following operating conditions:

1. $w_1 < -w_2 << fg$ is a stationary rate.

2. $w_1 < fg < -w_2$. A brief review of the complete solution evaluated from a knowledge of these starting conditions is given as follows: the particle size is a somewhat factor with the moving and separation motivated by the rectangular vibration. They occur at values of velocities not greatly different from each other; hence, attention is devoted to the next case.

3. $fg < w_1 < w_2$. For the forward sliding mode $(\upsilon < u)$ the highest possible value of the velocity is described by the following equation:

$$\upsilon_{1K} = \frac{fg}{n} - \left(\frac{fg}{n} - \upsilon_{2K}\right)\exp\left[-n\left(T - T'\right)\right],$$

and the expression for the response particle displacement is

$$l_1 = \frac{fg}{n}\left(T - T_1'\right) - \frac{1}{n}\left(\frac{fg}{n} - \upsilon_{2K}\right)\left\{1 - \exp\left[-n\left(T - T'\right)\right]\right\}$$

For the backwards sliding mode $(\upsilon > u)$ the terminal velocity and displacement function are defined by

$$\upsilon_{2K} = -\frac{fg}{n} + \left(\frac{fg}{n} - \upsilon_{1K}\right)\exp\left(-nT'\right);$$

$$l_2 = -\frac{fg}{n}T' + \frac{1}{n}\left(\frac{fg}{n} - \upsilon_{1K}\right)\left[1 - \exp\left(-nT'\right)\right],$$

where $T' = t_2 - t_1$.

The foregoing equations are alike, mathematically, and a solution may be applied to any of the others by making simple substitutions. Therefore, the equations may be expressed in the general form:

$$\frac{\left(T' - \frac{T}{2}\right)[1 - \exp(-nT)]}{\frac{fg}{n}} = \frac{1 + \left(\exp(-nT) - 2\exp\left[-n\left(T - T'\right)\right]\right)}{|w_2|} -$$
$$- \frac{1 + \exp(-nT) - 2\exp\left(-nT'\right)}{w_1};$$

$$\upsilon_{1K} = \frac{fg}{n[1 - \exp(-nT)]} \cdot \left\{1 + \exp(-nT) - 2\exp\left[-n\left(T - T'\right)\right]\right\} =$$
$$= w_1\tau - |w_2| \cdot (t_1 - \tau);$$

$$\upsilon_{2K} =$$
$$= \frac{fg}{n[1 - \exp(-nT)]} \cdot \left[-1 - \exp(-nT) + 2\exp\left(-nT'\right)\right] =$$
$$= w_1(T_2 - t_2);$$

$$l = l_1 + l_2 = \frac{fg}{n}\left(T - 2T'\right)$$
$$\upsilon_y = \frac{l}{T}$$

If the air resistance is negligible $(n = 0)$, the equations reduces to the form

$$\upsilon_{1K} = fg\tau;$$
$$\upsilon_{2K} = fg\left[\tau - \frac{T}{2}\right];$$
$$\upsilon_y = fg\left[\tau - \frac{T}{4}\right]$$

Within each case there are variations and difference of effects. For the third case 3, separation depend essentially on the size differences of the particles present in the mix. The maximum value of the velocities will hold when $w_1 \geq fg$. $w_1 \geq fg$ $(n \to 0)$ w_2.

The particle velocity forward the deck plane directly related to the friction coefficient which is a function of the particle shape and size [1]. Rectangular pulse excitation: the excitation function given by τ and T includes the natural period of the responding system and a significant period of the excitation. The excitation may be defined in terms of various physical quantities, and the response factor may depict various characteristics of the response. The purpose is to compare vibration motions, to design equipment and to obtain useful information. Care must be taken to assure that the same design and its performance can be predicted theoretically but such vibratory devices require experimental work. The mechanical design, however, may be used commercially by the application of vibration considered to be sinusoidal or simple harmonic in form. Alternate form of the excitation may be applied after making simple substitutions of vibration exciters.

An improved design for horizontal vibratory device and its application for efficient separation of mixtures on the thickness differences of the solids is shown in Fig. 4. The design of active frame (part 1) and two top and bottom plate decks (part 2) and (part 3), respectively; reactive frame (part 6) with bosses (part 7) for attaching springs, barrels (part 8) for shock-absorbers, and dividing bars (part 9); stack of springs (part 10); the direct-drive vibration exciter (part 11) consists of a rotating unbalanced mass driving a positive linkage connection between the base and decks of the machine; the bed (part 12) with turning frame (part 13) and screw mechanisms (parts 14 and 15) for regulation of longitudinal tilt if the decks and lateral tilt of the bed; electric motor (part 16) with step belt pulley (part 17); rubber shock-absorbers (part 18) isolating the upper part of the machine from the base; receptacles (part 19) for removing separated components from a mixture. A constant displacement vibration machine of this type attempts to maintain constant-displacement amplitude while the frequency is varied. Similarly, a constant-acceleration vibration machine attempts to maintain a constant-acceleration amplitude as the frequency is changed. The primary independent parameters that influence the ability of device of this type to make separation are the thickness differences of the solids and mixtures loading. Equipment the device is applicable where the amount of the material to be processed is reduced and where the separated solids are expected to be dry. The force driving the separation could also be several orders of magnitude greater than that of gravity. The proper introduced uniformly across the active cross-section of the deck and done in a way of metering bin.

An initial mixture of solids that must be separated into individual products inflows or arrives on the top desk (part 2). The driving force directs the mix toward diving bar (part 9). The finest solids directly related to particle thickness selected by the dividing bar and are passed under it downwards collection at the bottom deck (part 3). Discharge of the solids is shown schematically by pointers to receptacles (part 19). The other components are ordered to be driven along the driving bars and downward by lateral side. Efficient removal of the solids increases with acceleration of vibration. Active frame (part 1) is suitable for transmitting a vibratory force to the dividing bars contrary to the top deck vibration to correlate vertical distance δ for the finest solids to travel through the space between them and deck opening before get trapping.

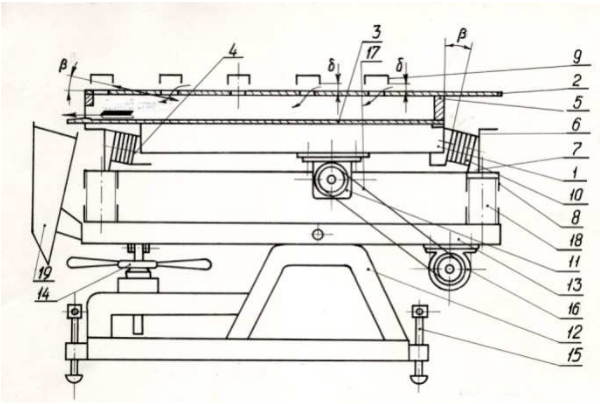

Fig. 4. The mechanical for vibratory equipment on the thickness differences of of the solids: 1- active frame; 2 – top deck; 3 – bottom deck; 4 – boss; 5 – distant strip; 6 – reactive frame; 7 – boss; 8 – barrel; 9 – dividing bar; 10 – springs; 11 – vibration exciter; 12 – bed; 13 – turning frame; 14,15 – screws; 16 – electric motor; 17 – drive belt; 18 –isolator; 19 – receptacle

The method relies on the taking of experimental data and on empirical analysis of the data to obtain a design. For this reason the recommended approach is best presented by considering a specific example. The potential problem with separation of clear bulb glass from open-circuit primary crushing of electric lamps is probably best supported by this type of device. For very efficient operations, two-stage combinations of separation are used. The device is applicable for efficient removal of needed thin bulb glass (in a way shown in Fig. 4 by arrow-pointers). The second stage may be secondary crushing with screening or vibratory processing to obtain metal wires. Caps, their fillings and glass stems are nonutilizable waste. The equipment, however, may be used commercially in some other industries.

Conclusions:

1. In the design and operation of separation processes depended essentially on the thickness differences of the solids present in the mix a problem is approached logically by first preparing an initial design. A subsequent analysis point to desirable modifications.

2. An initial prototype equipment has been designed and is then constructed in which actual operating conditions preferably are determined and considered from practical point of view.

3. From the analytical point of view and to provide some perspective for later improvement of existing process the single degree-of-freedom system of the horizontal device model acted upon by rectangular step excitation is considered with mathematical method of analysis to obtain useful information. The technical feasibility of a given separation method might be essentially attractive.

4. The optimum design must arise from careful consideration of all feasible alternatives and represents the further inventive aspect of process design.

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