Comparative evaluation of the effectiveness of the separation process with various types of movement of the separating surface

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Abstract. An analysis is made of the comparative efficiency of the process of separating spherical particles of finely divided loose product with different types of motion of the separating surface. The influence on the efficiency of the process of separation of the kinematic parameters of the motion of the screen surface is considered. A probabilistic approach to the analysis of sieving efficiency is used.

1. Introduction

The problem of separation of a dispersed product using a horizontal separating surface for various types of its movement is considered. This task is relevant when creating new technological equipment for the implementation of the separation process of finely divided bulk products. An important element in choosing a process scheme is the type of movement of the separating surface. According to various sources [1, 2, 3], horizontal screen surfaces with rectilinear harmonic or circular translational vibrations are quite common in the designs of separating machines.

The aim of the work is to obtain recommendations on the use of a certain type of motion of the separating surface with the selected process model. A model of the process of separation of spherical particles through round holes of horizontal sieves with circular translational and reciprocal movements is considered. The efficiency of the sifting process was estimated by the extraction coefficient, which was determined as the number of sifted particles over a certain period of time to the total amount received during this time on the sieve surface. To assess the effectiveness, a probabilistic approach is used. The fundamentals of the theory of relative continuous motion of a particle along a flat screen surface as applied to separating devices were first developed by N.E. Zhukovskim. According to a number of researchers [1, 3], the main parameter determining the sieving intensity is the relative velocity of the lower layer of particles along the sieve. In a comparative analysis of the particle sieving intensity during reciprocating and circular translational movements for the process model under consideration, all other significant parameters were considered identical except for the relative speed: the dimensions of spherical particles, their weight, the height of the granular product layer on the sieve surface, the size of the sieve openings, particle surface state.
2. Analysis of the effectiveness of the separation process

Consider a scheme that corresponds to the following separation task: sift the maximum amount of granular product, all particles of which are pass-through, through a unit of sieve area per unit time, which corresponds to the maximum sifting intensity. The following assumptions should be formulated for the analysis of this scheme.

1. Only particles whose centers of gravity pass over a circle of diameter \( d \) (\( d = D - a \)), where \( D \) is the diameter of the hole, and \( a \) is the diameter of the particle, will be able to through the sieve opening.

2. Sifting occurs only from the lower layer and only one at a time is sifted into the considered particle hole. This assumption is explained by the fact that, in the practice of screening, the sizes of the openings of the screens are, as a rule, close to the sizes of the particles.

3. Sifting of a particle is possible if, during the time the particle’s center of gravity stays above the hole with a diameter \( d \), it moves in the direction perpendicular to the sieve plane by an amount \( h \), which is determined by the ratio

\[
 h = \frac{\dot{a} \cdot t^2}{2}
\]

where: \( \dot{a} \) - acceleration of the center of gravity of the particle when moving in the direction of the perpendicular plane of the sieve,

\( t \) - is the time of movement of the center of gravity of the particle to a height \( h \).

The probability of sifting \( P \) of an individual particle of diameter \( a \) through the hole of diameter \( D \) under consideration is a complex event, the probability of which can be defined as the product of two elementary events \([1, 4]\). One of them (probability \( P' \)) is the passage of the particle's center of gravity over the circle \( D - a \). The probability of another event (probability \( P'' \)) depends on the position of the center of gravity of the particle in a certain area in front of the hole at the initial instant and will be taken into account when analyzing the sieving scheme for the case of straight-line vibrations. \([4, 5]\).

The horizontal projections of the trajectories of the centers of gravity of all particles of the lower layer in motion relative to the sieve are circles of radius \( \mu \gg D \) and the portion of such a projection of the relative trajectory of the particle over one hole is a straight line segment. The velocity of the center of gravity of a particle in relative motion is \( V = \omega \mu \). Thus, with circular translational vibrations, the vector of horizontal velocity of the center of gravity of the particles relative to the sieve continuously rotates with the angular velocity of the sieve, the modulus of this vector remains constant. where: \( \omega \) is the angular frequency of rotation. With rectilinear vibrations, the vector of horizontal velocity of the center of gravity of the particles relative to the sieve does not change the line of action, its modulus and direction changes. The movement of particles occurs according to a harmonic law.

To assess the comparative efficiency of the separation process for various types of screening motion, it is necessary to take into account the optimal kinematic motion parameters. In both cases, such parameters are the frequency and amplitude of the oscillations, which directly affect the relative velocity of particles in the sit. Further, for each type of motion, the dependences of the sifting intensity on the frequency and amplitude of oscillations are determined and the probability of sifting \( q \) is estimated for optimal combinations of kinematic parameters.

The value of \( P' \) can be defined as the ratio of the part of the area, the passage over which the center of gravity of the particle to the entire area of the hole.

\[
P' = \frac{(D-a)^2}{D^2}
\]

The analysis of the proposed model showed that in circular translational oscillations the amount of bulk product \( q \), which sifts through one sieve opening in one second
\[ q = k \cdot d \cdot V \cdot \sqrt{1 - \left(\frac{t}{d}\right)^2} \cdot V^2 \cdot P' \]  \hspace{1cm} (3)

where \( V \) - is the relative velocity of the lower layer of the product according to which the maximum number of passes.

\( P' \) - is the probability of sifting.

\( k \) - is a coefficient characterizing the ratio of the particle diameter and the diameter of the sieve hole.

Analyzing the expression, we note that for \( V = 0 \) and \( V^2 = \left(\frac{d}{t}\right)^2 \) the amount of bulk product sifted through the hole is 0.

The sieving intensity with the speed of the lower layer at which the number of passes is maximum [6]

\[ q = k \frac{d^4}{2tD^2} \]  \hspace{1cm} (4)

We introduce the dimensionless coefficient, \( z \) - characterizing the sieving intensity for the considered process model.

At optimal speed, in the case of circular oscillations, this parameter can be determined in the formula:

\[ z = \frac{q t D}{k d^4} \]  \hspace{1cm} (5)

For rectilinear vibrations, similar dependences of the relative \( \pi \) velocity and sifting intensity at optimal kinematic oscillation parameters were obtained taking into account changes in the relative speed of the granular product in situ. In one complete cycle, such a change from 0 to the maximum value of \( V \) occurs twice. In this case, the probability \( P'' \) of sifting an arbitrary particle into the hole depends on the position of its center of gravity in front of the hole at the initial instant of each half-period of oscillations [7]. The value of \( P'' \) is determined by:

\[ P'' = \frac{F'}{F} \]  \hspace{1cm} (6)

where: \( F' \) - part of the area in front of the hole, the location on which favors screening;

\( F \) - is the area of this figure.

The corresponding formulas for determining the amount of sifted bulk product and the dimensionless coefficient characterizing the sieving intensity in this case have the form

\[ q = k \frac{d^2}{\pi t \cdot \delta \cdot P' \cdot P''}; \]  \hspace{1cm} (7)

\[ z = \frac{1}{\pi \cdot \delta \cdot P''} \]  \hspace{1cm} (8)

in formula (8), the influence on the number of passes \( q \) of the oscillation frequency is reflected through the quantity \( \delta \), and the influence of the oscillation amplitude is reflected by the parameter \( \lambda \). Moreover, the influence of kinematic parameters was obtained indirectly through \( \lambda \) and \( \delta \).

When comparing the intensity of sifting of spherical particles of a finely dispersed product with circular translational and rectilinear vibrations, we note that for the same sizes of sieve holes \( d \) and time \( t \) for optimal vibrations for both types of vibrations and at optimal relative particle speed relative to the sieve for sieving particles, the intensity value sifting \( z \) is achieved with circular gradual oscillations. This was established as a result of calculations carried out according to the method
proposed in [1, 7, 8] within the limits covering almost all separation modes that take place in technological machines for fractionation of finely divided bulk products.

3. Conclusion
Thus, under optimal conditions for each type of vibration, the highest sieving intensity for the considered process scheme is achieved with circular gradual oscillations, which should be taken into account when choosing separator design.

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