The effect of particle motion on mixing intensity in a vibrating mixer

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Abstract. The intensity of mixing bulk materials, including feed, depends on technological parameters, kinematic and design parameters of the mixing plant, physical and mechanical properties of mixed components, etc. To study the process, a laboratory-experimental vibrating mixer was designed. The main working elements are vibration contact surfaces of various designs. It is possible to intensify the mixing process by influencing the nature of movement of particles along the mixing elements, including by giving them special shapes. In most cases, such a pattern can be traced: the more complex the particle trajectories, the higher the homogeneity of the finished feed mixture. The vibration contact surfaces can be divided into two groups, depending on their working surfaces. Mixing elements of the first group have holes or recesses. The holes can be as isosceles triangles, plates and concave are located at a certain angle under the holes. These surfaces are easy to manufacture, have low cost and material consumption and high productivity. It was revealed that at intensive operating modes, there is a decrease in the homogeneity of the mixture obtained. In this regard, when it is necessary to obtain highly homogeneous bulk feed mixtures, it is recommended to use mixing elements of the second group, which have protrusions on the working surfaces of various geometric shapes. The constructed theoretical trajectories of particle motion confirm the intensification of the mixing process. In addition, there are two ways of attaching the stirring elements, which give an additional effect. The laboratory-experimental mixer has been successfully tested in an agricultural organization preparing concentrates for feeding cattle.

1. Introduction

Science and practice have proven that the use of vibration effects on materials and the use of vibration machines are effective in many industries: construction, medicine, food industry, feed production, primary processing and grain processing, theoretical analysis of automobile mufflers [1,2], etc. In fodder production, the process of mixing granular components is intensive when vibration with certain parameters is imposed on the mixing process. The vibration effect on the bulk material causes chaotic collisions of its particles, the friction forces between the particles decrease, the trajectories of their movement become more complicated and the conglomerates are destroyed. A loose medium with vibrations in a free layer behaves like a viscous liquid when heated from below [3]. The mixing process is caused by pulsating gas movement inside the vibrating layer, which occurs as a result of the formation of vacuum and gas filtration through the material layer [4]. When developing vibratory feed preparation machines, the simulation of interaction of vibrating working bodies with the technological environment plays an important role. This stage determines the structural and parametric appearance of machines [5].
The mixing intensity depends on technological parameters of the process, kinematic and design parameters of the mixing plant, physical and mechanical properties of the mixed components, etc.

The influence of physical and mechanical properties on the technological process has been already studied [6].

It is possible to intensify the mixing process by influencing the nature of movement of particles of the bulk mass, including by giving special shapes to the working surfaces of the vibration contact.

To study the mixing process, a laboratory-experimental vibrating mixer was designed. Its structure and principle of operation are described in [7]. The main working elements of the mixer are mixing elements, vibration contact surfaces, can be of various designs.

Particles of bulk feed interact with each other and with working bodies, thus performing complex movements. In most cases, the more complex the particle trajectories, the higher the homogeneity of the feed mixture. The influence of design features of the surfaces of vibration contact on the movement of particles and possibility of intensifying the mixing process is studied.

2. Research Methods

The vibration contact surfaces can be divided into two groups:
- elements with grooves and through holes of various shapes;
- elements that have protrusions of various geometric shapes.

The mixing elements of the first group have a serrated edge, and there are holes or recesses on their working surface. The holes can be isosceles triangles (Figure 1), whose tops are directed towards the supply of bulk material [8].

![Figure 1. Stirring elements with holes in the form of isosceles triangles](image)

The mixing process can be intensified due to the relative displacement of microlayers of the mass as a result of the fact that trajectories of the particles are different: the particles that "pass" through the holes enter the next mixing element earlier than the particles that "come down" on the mixing element [8]. Particles coming "by descent" are poured from the toothed edges of the mixing element towards each other, their trajectories intersect, the particles are mixed.

Stirring elements with triangular holes are easy to manufacture, have low cost and material consumption and relatively high productivity. It was revealed that intensive operating modes, a decrease in the homogeneity of the mixture is observed [8].

An alternative is mixing elements with holes in the form of similar isosceles triangles (Figure 2), but under the holes there are plates of the same shape and concave at angle $\alpha$. The plates are obtained by bending the material downwards while cutting out the triangular holes. At the tops of the triangular holes, the material is not cut by 2-3 mm on each side, and the plates are kept at the desired angle.
3. Results and discussion

The mixed mass moves in the longitudinal direction along the flat surface of the mixing element, then part of it reaches the hole and the particles are poured towards each other from its lateral sides onto a concave triangular plate located under the hole, roll to its center, where they mix with each other, are poured onto the bottom chutes and move to the next mixing element. Their trajectories are interrupted with the trajectories of particles, which are poured from the toothed edge, and the trajectories of particles moving from other triangular plates - this contributes to the intensification of the mixing process.

The described mixing elements increase the number of mixing microprocesses due to multiple intersections of the particle trajectories.

For mixing elements of the second group, it is recommended to use bodies of revolution or their fragments as special geometric shapes. The presence of smooth transition lines ensures unhindered movement of particles without their unloading and formation of conglomerates.

The experimental studies identified a positive effect when using conical (Figure 3a) surfaces of vibration contact, which can be made in the form of straight circular cones with generatrices of the same length and in the form of cones inclined along the direction of motion of the bulk mass with generators of different lengths. Conical surfaces of both types can alternate in a certain sequence with hemispheres of various sizes (Figure 3b) [8].

The configurations described above make it possible to complicate the trajectories of movement of loose particles, since they enter the conical or hemispherical surfaces at different distances from the axes of their bases, parallel to the longitudinal axis of the chute, and as a result of contact with the surfaces, different angles of reflection, different speeds and directions of movement. In combination
with a certain combination of frequency and amplitude of vibration of the vibrating groove, this significantly intensifies the mixing process and, therefore, makes it possible to increase the degree of homogeneity of the resulting mixture.

An additional effect is possible due to the fact that the particles are poured from the toothed edges of the mixing element towards each other.

The mathematical model of motion of material particles along the conical surface of a vibration contact was build[8]:

\[
\begin{align*}
\ddot{u} &= \frac{2\dot{v}u}{v} - A_1 \sin u \sin \alpha \cos \alpha - \frac{mgf l \sqrt{1 + k^2}}{k^2 + \dot{v}^2 + v^2 \dot{u}^2} \frac{\dot{v}^2}{v^2}, \\
\ddot{v} &= \left(\frac{k^2}{k^2 + 1}\right) \left(\dot{u} \dot{v} + A_1 \sin \alpha \left(\cos \alpha \cos u - \frac{\sin \alpha}{k^2 + 1} + \frac{g}{k^2 + 1}\right)\right),
\end{align*}
\]

where \( u \) and \( v \) - curvilinear Gaussian coordinates; 
\( A_1 \) - the ratio of the vibration amplitude (A) of the vibration groove to the particle mass; 
\( \omega \) - vibration chute vibration frequency; 
\( t \) - particle movement duration; 
\( m \) - particle mass; 
\( g \) - acceleration of gravity; 
\( f \) - particle friction coefficient; 
\( k \) - the ratio of the cone base radius to its height; 
\( l \) - cone length.

A computer program was developed. It was used to construct theoretical trajectories of particle motion on a conical surface in accordance with model (1). The theoretical studies made it possible to determine a rational combination of the amplitude and frequency of vibration of the vibration groove. Figure 4 shows the calculated trajectories of particle motion at \( \omega = 6 \) Hz and A = 12 mm.

![Figure 4. Calculated trajectories of particle motion at \( \omega = 6 \) Hz](image)

Analyzing the theoretical curves (Figure 4), one can see that the height of the rise of particles along the conical surface is similar (13.5 ... 15.5 mm), which indicates a relatively uniform movement of particles. The lateral displacement of particles exceeds 40 0, the trajectories of movement intersect many times, which is a prerequisite for intensifying the mixing process.
Particle kinematics is influenced by the placement and attachment of the mixing elements within the vibration chute. As a rule, they are placed evenly one after the other with an inclination to the bottom of the gutter and fixed in one of two ways:

1) The rear part of the mixing elements is pivotally attached to the bottom of the trough, and the front part is suspended through a system of rods on a special adjustment plate. By moving this plate, you can simultaneously change the angle of inclination of all mixing elements to the bottom of the chute. Individual adjustment is possible - different angles of inclination of the mixing elements to the bottom of the chute provide different speeds of movement of the microlayers of the bulk mass and, therefore, their relative displacement, which contributes to the intensification of the mixing process.

2) The back of the head is attached to the bottom of the gutter using a hinge, and the front part is attached with two springs. This allows each mixing element to perform additional micro-oscillations in the vertical plane, which contributes to the intensification of the mixing process. To simultaneously change the angle of inclination of all mixing elements to the bottom of the chute and the amplitude of their micro-oscillations, a special mechanism that allows you to change the compression ratio of the springs has been designed. Individual adjustment of the amplitude of micro-oscillations of the mixing elements is also possible.

4. Conclusion
The working bodies ensure high quality of the mixing process (the degree of homogeneity of the mixture is more than 90%) due to the intensification of the process by imparting complex motion to the particles and, therefore, relative sliding of the microlayers of the bulk mass [7].

The laboratory-experimental mixer has been successfully tested in an agricultural organization for the preparation of compound concentrates for feeding cattle. It can be used as part of a small-sized, energy-saving feed mill, which will reduce resource costs and increase the profitability of the dairy industry [9] during the modernization of agricultural production, including within the program aimed at development and revival of rural areas [10].

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