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SUBSTANTIATION OF PHYSICAL AND MATHEMATICAL MODEL AND DETERMINATION OF ACCELERATIONS UNDER THE ACTION OF THE ELASTIC MIXER DRIVING FORCES

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ABSTRACT

This paper deals with the justification of physical and mathematical model of flexible mixer having enclosure as the working body in the form of a cylindrical container, made of an elastic material. It has been shown that the accelerations, arising from driving forces of the working bodies of the mixer and the elastic forces of the elastic material acting on the mixture, are the determining factor in the formation of multi-component granular mixtures. The presented physical-mathematical model of the elastic mixer allows determining the acceleration and, therefore, regulating and managing the process of mixing.

Keywords: multi-component granular mixture, flexible mixer, cyclical fluctuations, physical-mathematical model, granular material.

INTRODUCTION

A variety of mixers is dictated by the need to prepare mixtures under different conditions and for different purposes, and to use the components of mixtures with different physical and mechanical properties [1, 2, 3]. One of the basic requirements to be met by the design of mixers developed is the possibility of scientific evidence and the modernization ability due to the improvement of the technological process [4, 5].

The advantages of mixers with flexible working bodies include the fact that all known methods of creating mobility of particles in the entire mixing volume are intensified by fluctuation of elastic walls of the mixer, without complicating the structure and increasing the energy capacity of the process [6]. Elastic mixers without internal mixing devices are most frequently used because of the ability of self-purification and the lack of material sticking to the walls of the working container [7, 8, 9].

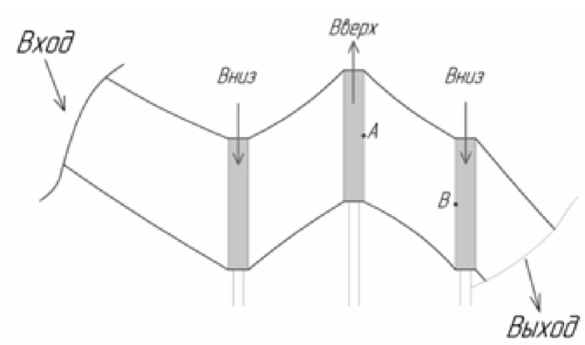

Figure-1. Scheme of flexible working body of the mixer.

The technique

The formation of multicomponent granular mixture in the elastic mixer occurs due to the cyclical fluctuations of the mixing container, made of an elastic material in the form of a cylindrical enclosure, with the reciprocating motion of the annular clamps having an enclosure secured at equal distances (see Figure-1). The clamps are mounted on the vertical rods attached to the crank drive mechanism (not shown) [10]. Part of the elastic membrane between the clamps will be called a compartment. Enclosure elongates while clamps movement due to elastic properties of its material and is pulled, causing bounce of the particles of granular material located on its surface. Mechanism of influence of an elastic enclosure of material on the mixture particles resembles the mechanism of the trampoline motion - a flexible device for sport jumps.

Movement of mixer drive elements allows changing the horizontal position of an elastic enclosure to the slant position. Such movement causes flexible container to bend in the transverse planes. An accumulated potential energy of an elastic material enclosure is transferred to the mixture particles impacting with the surface of the working body in the form of kinetic energy of the random disordered movement. Mixture layers particles being close to the walls move along the inner surface of the flexible working body and perform arbitrary movements with variable acceleration in the longitudinal, transverse and inclined planes. The particles of the mixture components are mixed when penetrating into the free space between adjacent particles in arbitrary trajectories [10].

Cyclical fluctuations of mixer sections occur relatively to central part of each compartment, which remains fixed during the entire cycle of operation. We shall mark it in the analytical model, by setting a virtual hinge O into the central part of each compartment (see Figure-2).

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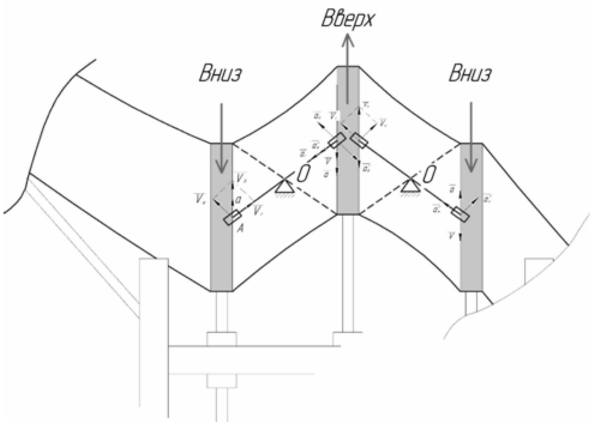

Figure-2. For the substantiation of mixer analytical model.

RESULTS

Granular material placed in the container and moving with acceleration, experiences a dynamic stress. It should be noted that the elastic mixer is in elastically deformable stress state during the entire working cycle, which depends on the geometrical, kinematic parameters of the mixer and the elastic properties of the elastic enclosure. Dynamic stress (dependence 1) is determined by the force acting on a unit of granular material volume, from the elastic working body of the mixer, and depends on the acceleration acquired by particles of granular material in a flexible working body of the mixer:

$$\sigma = \frac{F}{A_{см}} = \frac{M \cdot a}{A_{см}}, \tag{1}$$

where *F*- force acting on the granular material from the flexible working body of the mixer;
$A_{см}$ - the contact area of the granular material and flexible working body; *M* - the mass of the granular material;
a - acceleration of particles of the granular material.
Therefore, acceleration is the determining factor in the formation of a multicomponent mixture.

Acceleration, acquired by granular material in the mixer, depends on the geometrical, kinematic parameters of the mixer and the elastic properties of the elastic enclosure:

$$\bar{a}_{дин.} = \bar{a}_{\text{см.}} + \bar{a}_{упр.}, \tag{2}$$

where $\bar{a}$ - acceleration of granular material; $\bar{a}_{\text{см.}}$ - acceleration that occurs under the action of the driving forces of the mixer; $\bar{a}_{упр.}$ - acceleration arising from the action of the elastic forces of the elastic membrane.
We shall determine the components of the acceleration $\bar{a}_{\text{см.}}$, which occurs under the action of the elastic mixer driving forces. Movement of mixture in the compartment is complex, where a portable motion shall be an oscillatory movement of the mixture portion made by compartment in relation to the virtual hinge O (Figures 2 and 3), and the movement of mixture portion along the guide path of the mixing chamber compartment will be relative.

Figure-4 shows the analytic model of the compartment of the elastic working body. The model shows the velocities and accelerations of the representative points. Up-ward movement of a connecting rod 1 with absolute speed v, which can be defined as the geometric sum of the transfer velocity directed perpendicular to the compartment surface and the relative velocity along the wall compartment stretched to the size of 2S (Figure-3).

The absolute acceleration, which occurs under the action of the elastic mixer driving forces, $\bar{a}_{\text{см}}$ is a geometric sum of normal transfer a_e^n and tangential a_e^τ, relative a_r and the Coriolis a_k accelerations.

Since the acceleration $\bar{a}_{\text{см}}$, which depends on the geometric and kinematic parameters of the mixer, is one of the determining factors influencing the stress state of the mixture, we shall define its components:

$$\bar{a}_{\text{см}} = \overline{a_e} + \overline{a_r} + \overline{a_k} = \overline{a_e^n} + \overline{a_e^\tau} + \overline{a_r} + \overline{a_k}, \tag{3}$$

where

$$a_e^n = \omega^2 s = \frac{V_A^2 \cdot b^2}{(b^2+y_A^2)^{3/2}} - \tag{4}$$

transfer centripetal acceleration of the mixture;

$$a_e^\tau = \varepsilon s = \frac{(b^2+y_A^2)a_A - 2y_A \cdot V_A^2}{(b^2+y_A^2)^{3/2}} \cdot b - \tag{5}$$

transfer tangential acceleration of the mixture;

$$a_r = \frac{dV_r}{dt} = \frac{V_A^2 + y_A \cdot a_A}{(b^2+y_A^2)^{1/2}} - \frac{y_A^2 \cdot V_A^2}{(b^2+y_A^2)^{3/2}} - \tag{6}$$

relative acceleration of the mixture;

$$a_k = 2\omega_e V_r = \frac{2b \cdot y_A \cdot V_A}{(b^2+y_A^2)^{3/2}} - \tag{7}$$

Coriolis acceleration of the mixture portion.

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where *2b* - the length of the compartment; *S* - the distance from the hinge O to point A located on the actuator rod in its oscillatory motion; a_A and V_A - velocity and acceleration of point A belonging to the rod; y_A - movement of a point belonging to the rod; ω - angular velocity of the point A in relation to the hinge O; ε - the angular acceleration of the point A in relation to the hinge O; ω_e and V_r - the relative angular velocity, the velocity of point A.

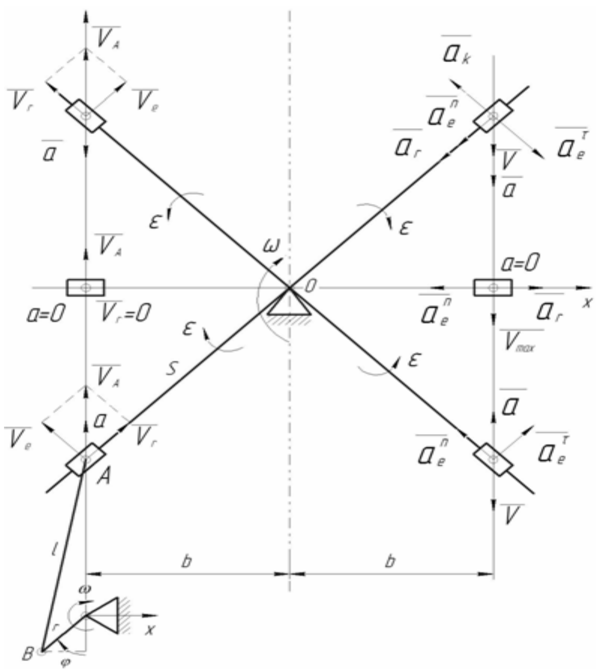

Figure-3. The analytic model of the compartment of the mixer elastic working body.

Elastic working body is extended during its operating cycle, and its generator line represents a straight line. Therefore, the description of the motion of any arbitrary point of this line for a certain period of time will characterize the motion of the entire generator line of the working body. For such point, we shall choose an arbitrary point A on the wall of the elastic working body. Absolute acceleration of point A in the lowest position is directed upward during the motion of this part of compartment from the bottom upwards. The left side of compartment rises, and the relative velocity goes to zero upon reaching the neutral position coinciding with the horizontal axis of the hinge O. Absolute velocity of the point in this position is similar in magnitude and direction to a transfer velocity. Absolute acceleration of the point goes to zero at this moment. The length of the elastic working body compartment is 2b (Figure-3).

The considered part of the compartment continues to move up to the end position and the length of the compartment increases again to 2S by stretching the material of elastic enclosure. Upon reaching the maximum upward position, the absolute velocity of the point A is directed upwards, the absolute acceleration reaches its maximum value and is directed vertically downward. An opposite movement similar in nature occurs on the right side of the compartment.

During moving a connecting rod *l* down from the uppermost position the velocity and the absolute acceleration of point A are directed downwards. Upon reaching the neutral position, located on the horizontal axis of the hinge O, the relative velocity is reduced to zero, and the absolute velocity is similar in magnitude and direction to the transfer one and is directed downwards. Absolute acceleration goes to zero at this moment. The length of the compartment is reduced to a size 2b.

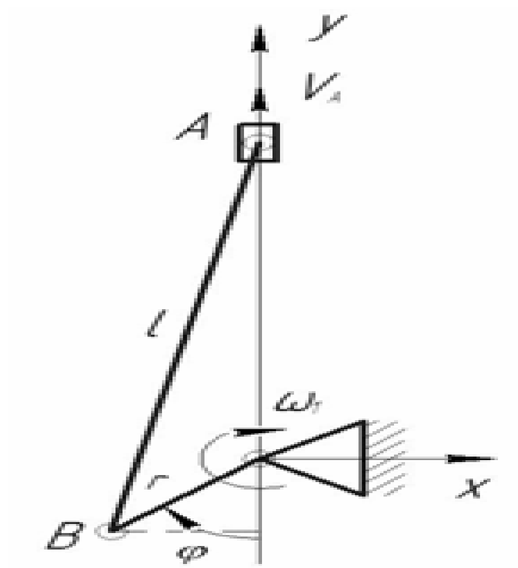

Figure-4. Kinematic diagram of the transfer mechanism of mixer drive rods.

The considered part of the compartment continues to move down to the end lower position and the length of the compartment increases to a size 2S. The absolute velocity is directed downward in the end lower position, and the absolute acceleration - upward.

Unknown values in the equations (4-7) are determined from the equations of movement of the crank drive mechanism (Figure-4).

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$$\varphi = \omega_1 t; \tag{8}$$

$$y_A = l\cos\alpha - r\cos\varphi; \tag{9}$$

$$l\sin\alpha = r\sin\varphi\,; \tag{10}$$

$$\sin\alpha = \frac{r}{l}\sin\varphi\,; \tag{11}$$

$$\cos\alpha = \sqrt{1-sin^2\,\alpha} = \sqrt{1-sin^2\alpha}; \tag{12}$$

$$y_A = l\sqrt{1-\frac{r^2}{l^2}sin^2\varphi} - r\cos\varphi = \sqrt{l^2 - r^2 sin^2\omega_1 t} - r\cos\omega_1 t, \tag{13}$$

Where
φ = rotation angle of the crank
r = cranck radius
l = crank length
ω_1 = angular velocity of the crank

$$V_A = \frac{dy_A}{dt} = \dot{y}_A = \frac{-2r^2\omega_1\sin\omega_1 t\cdot\cos\omega_1 t}{2\sqrt{l^2 - r^2 sin^2\omega_1 t}} + r\omega_1\sin\omega_1 t; \tag{14}$$

$$V_A = \dot{y}_A = \omega_1\cdot r\left(sin\,\omega_1 t - \frac{sin\,2\omega_1 t}{2\sqrt{\frac{l^2}{r^2} - sin^2\omega_1 t}}\right). \tag{15}$$

$$a_A = \frac{dV_A}{dt} = \omega_1 r\left\{\omega_1\cos\omega_1 t - \frac{1}{4\left(\frac{l^2}{r^2} - sin^2\omega_1 t\right)}\cdot\right.$$

$$\left.\cdot\left[2\sqrt{\frac{l^2}{r^2} - sin^2\omega_1 t}\cdot(\sin 2\omega_1 t) - sin2\omega_1 t\left(2\sqrt{\frac{l^2}{r^2} - sin^2\omega_1 t}\right)\right]\right\} \tag{16}$$

$$a_A = \omega_1^2\cdot r\left[\cos\omega_1 t - \left(\frac{\cos 2\omega_1 t}{\sqrt{\frac{l^2}{r^2} - \sin\omega_1 t\cdot\left(\frac{l^2}{r^2} - sin^2\omega t\right)}}\right)\right] \tag{17}$$

Then: $$a_A = \omega_1^2\cdot r\left(1 - \frac{r}{l}\right),\quad \text{при}\ \varphi = 0; \tag{18}$$

$$a_A = \frac{\omega_1^2\cdot r^2}{\sqrt{l^2 - r^2}},\quad \text{при}\ \varphi = \frac{\pi}{2}; \tag{19}$$

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$$a_A = -\omega_1^2 \cdot r\left(1 + \frac{r}{l}\right), \quad \text{при } \varphi = \pi; \tag{20}$$

$$a_A = \frac{\omega_1 r^2}{\sqrt{l^2 - r^2}}, \quad \text{при } \varphi = \frac{3}{2}\pi; \tag{21}$$

$$\bar{V} = \bar{V_e} + \bar{V_r}, \tag{22}$$

$$V = \sqrt{V_e^2 + V_r^2}, \tag{23}$$

$$V_e = \omega \cdot OA = \omega s, \qquad (OA = s), \tag{24}$$

$$s = \sqrt{l^2 + y_A^2}. \tag{25}$$

The ratio of the absolute and transfer velocity of the granular material is equivalent to the ratio of the length of the compartment to the maximum distance between the rods (Figure 5):

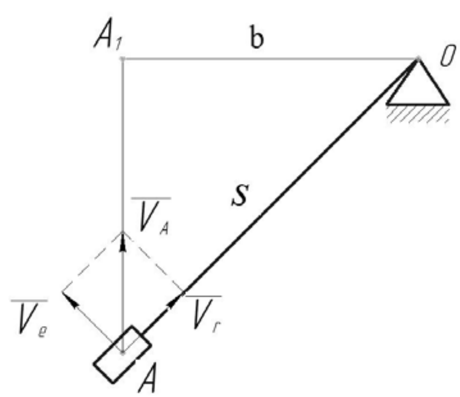

Figure-5. For the determination of velocity and acceleration of the point A.

$$\frac{V_e}{V} = \frac{b}{s}; \quad V_e = V\frac{b}{s}; \quad \omega s = V\frac{b}{s}, \tag{26}$$

$$\omega = \frac{bV}{s^2} = \frac{b\dot{y}_A}{b^2 + y_A^2} = \frac{\dot{y}_A}{b} \cdot \frac{1}{1 + \left(\frac{y_A}{b}\right)^2}, \tag{27}$$

$$\varepsilon = \frac{d\omega}{dt} = \frac{d}{dt}\left(\frac{b\dot{y}_A}{b^2 + y_A^2}\right) = \frac{1}{(b^2 + y_A^2)^2} \cdot (b(b^2 + y^2)\ddot{y}_A - b \cdot \dot{y}_A \cdot 2y_A \cdot \dot{y}_A) = \frac{(b^2 + y_A^2)\ddot{y}_A - 2y_A \cdot \dot{y}_A^2}{(b^2 + y_A^2)^2} \cdot b; \tag{28}$$

$$V_r = \frac{ds}{dt} = \frac{y_A \cdot \dot{y}_A}{\sqrt{b^2 + y_A^2}}, \tag{29}$$

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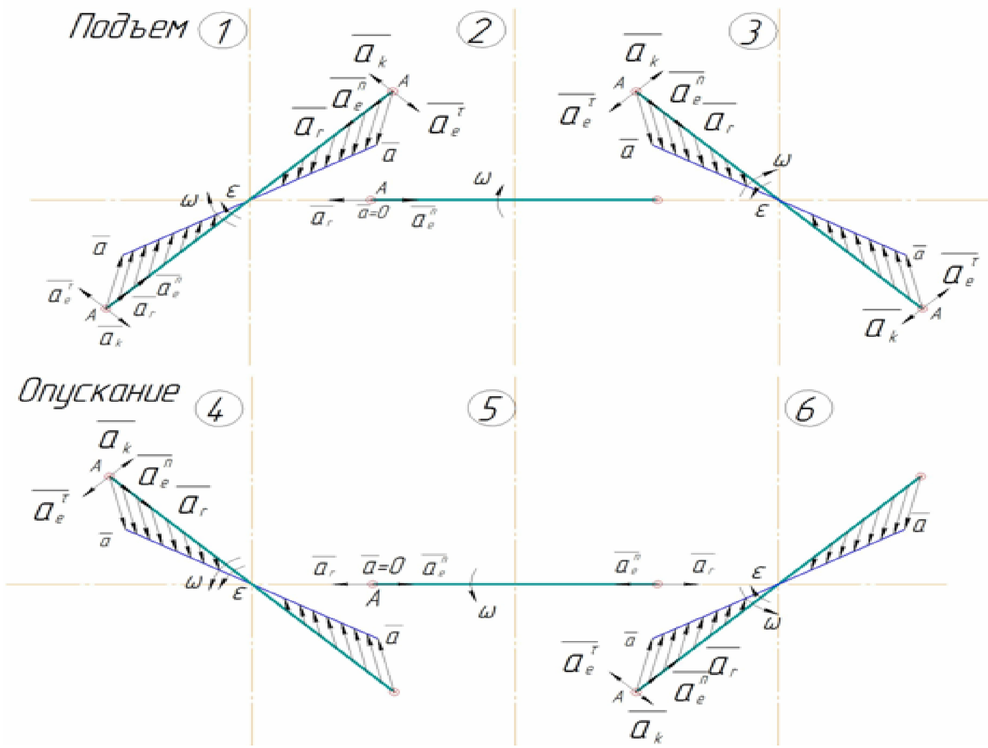

Figure-6. Plan of accelerations of mixer points.

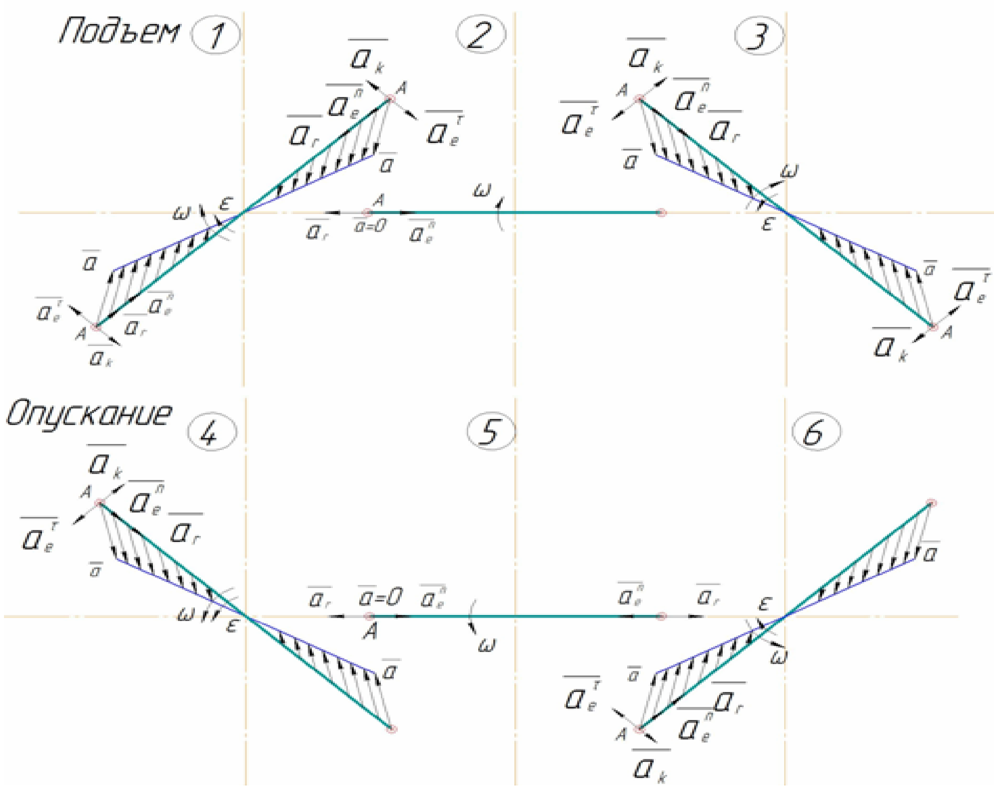

Figure-7. Plan of forces acting on the mixture particles from the mixer.

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Considering the movement of mixture portions along the axis of mixer compartment and using a the dependencies obtained, we shall make a plan of accelerations acting on the granular material from the elastic wall (Figure-6) and a plan of forces acting on the mixture from the mixer when raising or lowering the compartment (Figure-7).

CONCLUSIONS

The designed plans of accelerations and forces allow determining the accelerations resulting from the action of the driving forces of the mixer $a_{см}$. Analyzing the plans of accelerations and forces we can prove the cyclical nature of the movement and the impact of driving forces of the elastic mixer on the particles of the mixture.

At the same time, the cyclic oscillatory movement of the mixer working compartment is affected by the elastic forces of the elastic material of the mixer. As already has been noted, the enclosure is stretched during movement of rods to the end positions, lengthening to the value of absolute deformation Δl, and accumulating kinetic energy. Part of this energy is released and transferred to the granular material, causing the acceleration from the action of the material elastic forces of the elastic mixer $a_{упр}$.

Based on the above we can conclude that the accelerations, arising from driving forces of the working bodies of the mixer and the elastic forces of the elastic material acting on the mixture, are the determining factor in the formation of multi-component granular mixtures. The considered physical-mathematical model of the elastic mixer allows us to define acceleration, acquired by the granular material from the driving forces of the mixer $a_{см}$, and regulate the formation of multicomponent granular mixtures. The use of the elastic elements as a mixing working body is more effective than the use of rigid, non-elastic elements, since the features of elastic material of working body ensure two types of accelerations such as the acceleration occurring under the action of driving forces of the mixer $a_{см}$ and acceleration arising from the action of the elastic forces of the elastic enclosure $a_{упр}$. Further studies will deal with the influence of elastic forces of elastic enclosure on the formation of multi-component granular mixtures.

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