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VIBRATORY CONVEYOR FOR LOADING FOOD MIXTURE MIXER

The uniform supply of components to the mixing chamber is one of the main keys to the high-quality performance of this technological process. Currently, there is a lack of reliable feeders for mixers of food mixtures, especially of low productivity. This led to conducting analytical studies that make it possible to develop an effective design of the feeder, to determine the rational parameters of its work. As the analysis of the existing designs of feeders for loose materials showed, the problem of providing dosed supply of seeds or other particles in small volumes to the working chamber of the mixer can be solved by using oscillating conveyors, in which the transportation process is carried out due to high-frequency oscillations with a small amplitude. Depending on the operating modes, the material can move in the oscillating conveyor without detachment from the working surface (inertial conveyors) or with detachment (vibratory conveyors). Studies have shown that the most effective in terms of ensuring a stable material supply is the detachable mode of operation of bulk material feeders (vibratory type of feeders). In addition, this mode of operation helps to create a fluidized bed of material, which also increases the reliability of the feeders. The analysis of the movement of the seed along the oscillating plane made it possible to determine the influence of the main factors on the rational parameters that ensure a reliable dosed supply of the seed mass to the mixer of low productivity. The use of the proposed vibrating feeder scheme allows for the required performance, but significantly complicates the design of the food mixer. The conducted analytical and experimental studies made it possible to propose rational constructive and technological parameters of the feeder for the mixer of food mixtures of low productivity. It should be noted that when determining the nature of the movement of the seed mass along the oscillating plane, it is necessary to take into account the effect of the fluidized bed, which is the subject of additional research.
Key words: mixer, seed, food mixture, vibration, feeder, amplitude, frequency, coordinate.

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ВІБРОТРАНСПОРТЕР ДЛЯ ЗАВАНТАЖЕННЯ ЗМІШУВАЧА ХАРЧОВИХ СУМІШЕЙ

Рівномірна подача компонентів в змішувальну камеру є однією з головних запорук якісного виконання цього технологічного процесу. Наразі має місце відсутність надійних живильників для змішувачів харчових сумішей, особливо малої продуктивності. Це спонукало проведення аналітичних досліджень які дають змогу розробити ефективну конструкцію живильника, визначити раціональні параметри його роботи. Як показав аналіз існуючих конструкцій живильників сипких матеріалів, задачу забезпечення дозованої подачі насіння або інших частинок в малих об'ємах до робочої камери змішувача можна вирішити шляхом застосування коливних конвеєрів, в яких процес транспортування здійснюється за рахунок коливань високої частоти з малою амплітудою. Аналіз руху насінини по площині, що коливається, дозволив визначити вплив основних факторів на раціональні параметри, що забезпечують надійну дозовану подачу насіннєвої маси до змішувача малої продуктивності. Проведені аналітичні та експериментальні дослідження дозволили запропонувати раціональні конструктивно-технологічні параметри живильника для змішувача харчових сумішей малої продуктивності.
Ключові слова: змішувач, насіння, харчова суміш, вібрація, живильник, амплітуда, частота, координата.

Statement of the problem in a general form and its connection with important scientific or practical tasks

For mixers of food mixtures, in particular for baking, the uniform supply of components plays a decisive role in ensuring the quality of the final product. For example, to prepare a baking mixture with flax seeds or walnut pieces, their uniform feeding into the mixer will then ensure the proper quality of the finished bread, that is, their equal distribution in the volume of the bread. The lack of reliable feeders for supplying additives in the form of whole seeds or other solid parts in a mixer of low productivity, capable of ensuring a stable and uniform supply of material to the mixing chamber, justified the need to conduct own research on this issue. The conducted analytical studies will make it possible to develop the structure of the feeder, to determine the rational parameters of its operation.

Analysis of recent research and publications

As the analysis of the existing designs of feeders for loose materials showed, the problem of providing dosed supply of seeds or other particles in small volumes to the working chamber of the mixer can be solved by using oscillating conveyors, in which the transportation process is carried out due to high-frequency oscillations with a small amplitude. This type of dispensers is widely used in the mining industry, and in recent years - in the engineering and food industry, to ensure stable directional loading of various equipment [1, 2, 3]. The advantage of oscillating conveyors lies in the simplicity of the design and the high reliability of the process, especially with small material

feeds.

Depending on the operating modes, the material can move in the oscillating conveyor without separation from the working surface (inertial conveyors) or with separation (vibration conveyors). Studies have shown that the most effective, from the point of view of ensuring a stable supply of material, is the detachable mode of operation of loose material feeders (vibrating type of feeders) [1, 4]. In addition, this mode of operation contributes to the creation of a fluidized layer of material, which also increases the reliability of the feeders.

The purpose of this article is to ensure a dosed supply of material to the working chamber of low-productivity food mixture mixers by using a vibrating type feeder.

Presentation of the main material of the article

Consider the movement of a seed with a mass of m_3 along the surface AB of a vibrating tray installed with a negative angle of inclination α to the horizon (Fig. 1).
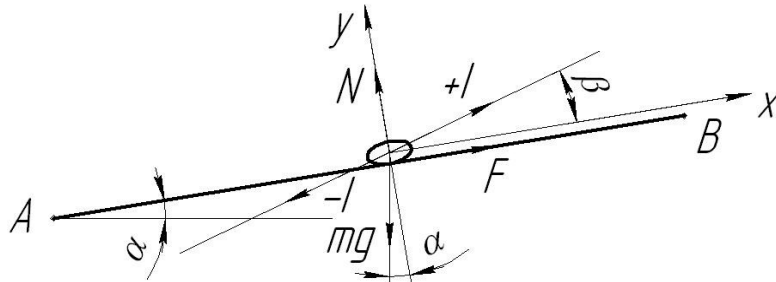

Fig. 1. Scheme of the forces acting on the seed placed on the surface of the vibrating tray

The value of the angle of inclination of the surface of the vibrating tray to the horizon is insignificant and is within, $1^0 \leq \alpha \leq 3^0$ which will ensure a stable dosed supply of seeds without its chaotic shifting along the tray.

If the plane AB is given oscillating movements directed at an angle β to the surface of the plane, then the seed of mass m_3 located on this plane will be acted upon by the force of gravity $G = m \cdot g$, the force of friction $F_T = N \cdot f$, the force of normal pressure N and sign-changing inertial force $I = a \cdot \omega^2 \cdot m_3 \cdot \sin\varphi$.

The condition of equilibrium of the seed on the AB surface in the fixed coordinate system XOY can be written in the form:

$$\begin{cases} F_T = m_3 \cdot g \cdot \sin\alpha \pm I \cdot \cos\beta \\ N = m_3 \cdot g \cdot \cos\alpha \pm I \cdot \sin\beta \end{cases} \tag{1}$$

To move the seed along the surface of the tray from point A to point B, the condition must be met:

$$\sum X(F_{x_i}) > 0, \text{ або } I \cdot \cos\beta > m_3 \cdot g \cdot \sin\alpha - F_T,$$

where

$$a \cdot \omega^2 \cdot \sin\phi > \frac{m_3 \cdot g \cdot \sin\alpha - N \cdot f}{m_3 \cdot \cos\beta}. \tag{2}$$

Condition (2) can be fulfilled only in the presence of the phenomenon of microdetachment of the seed from the AB surface, i.e $\sum Y(F_{y_i}) > 0$. The separation of the seed occurs in the case when the pressure force of the seed on the surface of the tray is equal to 0:

$$N = m_3 \cdot g \cdot \cos\alpha - a \cdot \omega^2 \cdot m_3 \cdot \sin\phi \cdot \sin\beta = m_3 \cdot (g \cdot \cos\alpha - a \cdot \omega^2 \cdot \sin\phi \cdot \sin\beta), \tag{3}$$

where a – is the amplitude of plane oscillations;

ω – angular velocity of the source of oscillations;

φ – phase angle of oscillations, $\varphi = \omega t$.

Provided that $g \cdot \cos\alpha > a \cdot \omega^2 \cdot \sin\phi \cdot \sin\beta$, the seed is pressed against the surface of the tray AB and moves with it, and in the opposite case, when $a \cdot \omega^2 \cdot \sin\phi \cdot \sin\beta > g \cdot \cos\alpha$ - the seed will come off the surface of the tray. The phase angle of oscillations φ varies in the range from 0 to 2π, so the maximum value of the expression $a \cdot \omega^2 \cdot \sin\phi \cdot \sin\beta$ will be at $\sin\varphi = 1$ ($\varphi = \pi/2$). Therefore, the maximum acceleration relative to the OY axis of the tray (and the seed along with it) will be achieved in the case when $I_{max}^{y^2 \sin\beta}$.

In the event that $g \cdot \cos\alpha = a \cdot \omega^2 \cdot \sin\phi \cdot \sin\beta$, boundary conditions occur (beginning of separation of the seed from the AB surface). The ratio $\Gamma = \frac{a \cdot \omega^2 \cdot \sin\beta}{g \cdot \cos\alpha} = 1$ is called the limit, and the coefficient Γ is called the dynamic coefficient of the operating mode of the vibrating conveyor. When $\Gamma < 1$, the cargo does not detach from the surface of the tray (inertial conveyors), and when $\Gamma > 1$ – it moves in the detachment mode (vibrating conveyors) [1].

Taking into account that the plane of the tray AB carries out harmonic oscillations under the action of the inertial force I in the direction of its action (at an angle β to the plane AB), the scheme of movement of the seed can be displayed as follows (Fig. 2).
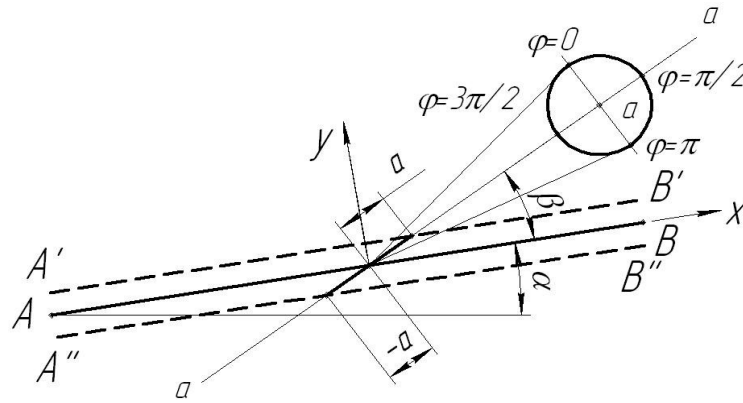
Fig. 2. Scheme of movement of seeds on the tray of the vibratory feeder

The diagram of the movement of the seed along the vibratory tray of the feeder of the mixer under the action of external forces is shown in Figure 3.
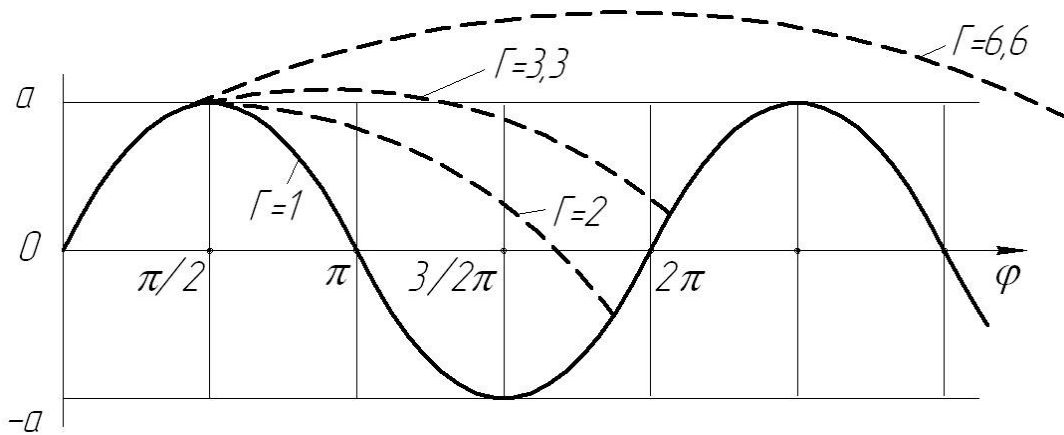

Fig. 3. Diagram of seed movement on the tray of the vibratory feeder

Starting from the middle position ($\varphi_0=0$) the plane *AB* moves in the *a-a* direction by the amount of eccentricity *a* to the uppermost position($\varphi_1=\pi/2$). In this case, the force of inertia $I = m_3 \cdot a \cdot \omega^2 \cdot \sin\varphi$ will press the seed to the surface *AB*, and under the condition that $F_T \geq m_3 \cdot g \cdot \sin\alpha \pm I \cdot \cos\beta$, they move together without mutual slippage. With a further increase in the angle φ ($\pi/2 < \varphi < 3\pi/2$), the plane *AB* moves down a distance of 2*a*, the force of inertia tears the seed from the surface of the tray *AB* and it makes a free flight, the trajectory of which is determined by the throwing angle β, the initial speed of the seed V_0 and depends on the value of the coefficient of the dynamic mode Γ of the vibratory feeder.

The moment of meeting the seed with the surface of the vibrating tray *AB* must be selected in such a way that it falls on the tray when it is moved forward and up ($3\pi/2 < \varphi < \pi/2$) in a position where the time of their joint movement would be minimal, but sufficient for giving the grain the necessary acceleration for the next separation and movement along the surface of the tray in the direction from point *A* to *B* (Fig. 3). Research has established that the following modes of operation of the vibratory feeder should be considered rational, in which the coefficient of the dynamic mode Γ is within $1 < \Gamma < 3.3$. When $\Gamma < 1$, the feeder works as an inertial conveyor, without separation of the material from the surface of the tray, and when $\Gamma > 3.3$, significant dynamic loads occur in the drive system [4].

From the point of view of ensuring a stable supply of material to the mixing chamber, it is necessary to find the speed of its movement along the tray *AB* in the direction from *A* to *B* (along the *OX* axis). Taking into account the cyclicity of the longitudinal movements of the tray, we determine its maximum speed:

$$V_{Л_{max}}^{x2\, cos\, \beta\, cos\, \beta}, \tag{4}$$

where $\omega = \pi \cdot \gamma$ is the frequency of oscillations of the tray.

The average speed of the seed in the direction of the OX axis will be less than the maximum speed of the tray, $V_{з_{cep}}^{x} < V_{Л_{max}}^{x}$. Therefore, to determine the average speed of the grain along the tray, it is necessary to take into account the speed coefficient $K_{ш}$, which is determined from the expression [4]:

$$K_{ш} = \frac{V_{з_{cep}}^{x}}{V_{Л_{max}}^{x}} \tag{5}$$

The value of the Ksh coefficient depends on the kinematic modes of operation of the vibratory feeder and is determined analytically or graphically by measuring the corresponding areas on the tray speed graph with a planimeter [5].

In the most general case, the movement of seeds on the surface of the vibrating tray can be divided into five stages and, depending on their combinations, six modes of material movement are distinguished [1, 5]. Based on our conditions (high speed of movement of the vibrating tray), we will adopt the 1st mode of seed movement, which includes three stages: acceleration, free flight and braking of the seed (Fig. 4).
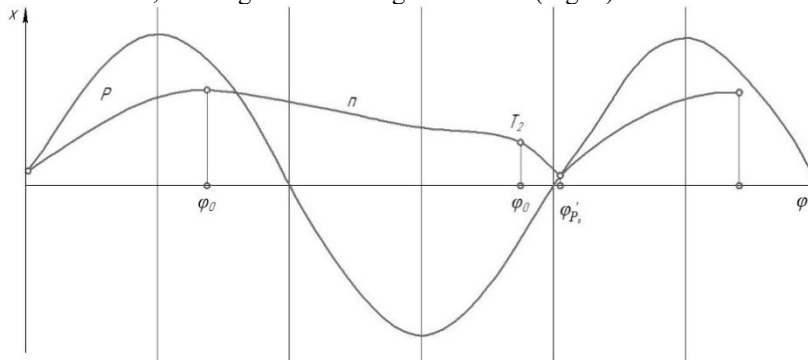

Fig. 4. The schedule of the movement of seeds along the surface of the vibrating tray of the feeder in mode 1

Based on the physical and mechanical properties of the seed and in order to ensure its necessary supply to the mixing chamber (5...15 kg/h), there was a need for an analytical justification of the rational parameters and modes of operation of the vibrating tray of the feeder:
- dimensions and angle of inclination to the horizon of the bottom of the vibrating tray;
- frequency and direction of oscillations of the vibrating tray;
- oscillation amplitudes (crank eccentricity);
- speed of movement of seeds along the vibrating tray.

To ensure the effective movement of seeds along the surface of the vibrator tray in the direction from *A* to *B*, the angle of application of the exciting force of the vibrator should be within $20^0<\beta<30^0$ [4]. It is desirable that the line of action of the exciting force (angle *β*) passes through the center of inertia of the vibrating tray, which, as a rule, coincides with the center of mass when the nodes of the vibrating feeder are symmetrically placed In case of non-compliance with this requirement, the system will receive additional loads in the form of torque, which prevents the movement of seeds along the tray and reduces its forward speed.

The loading nozzles of the feeder should not be rigidly connected to the vibrating tray in order not to affect the kinematic modes of its operation.

The application of the proposed scheme of the vibratory feeder allows to ensure the required productivity, but significantly complicates the design of the mixer of food materials. To eliminate this shortcoming, we will hinge one end of the surface at point *O*, and the other will oscillate around this hinge (Fig. 5).
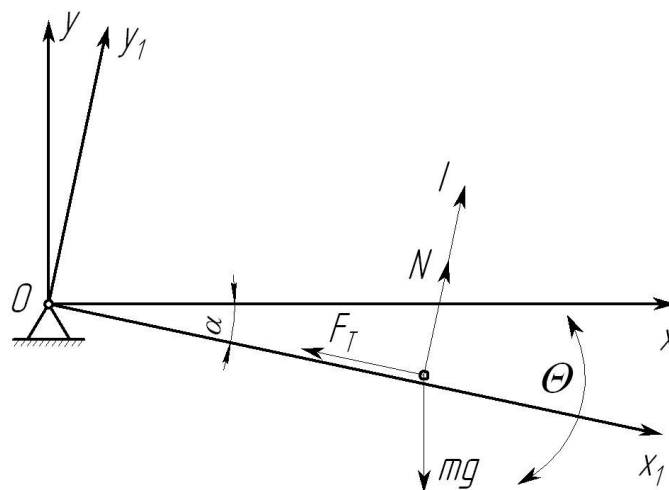

Fig. 5. Analysis of forces acting on a seed that is on a vibrating surface

Let's analyze the trajectories of particle movement on the oscillating surface and the surface itself, taking into account that the surface has an angle of inclination *α* to the horizontal axis *OX*.

Consider the forces acting on a particle (a seed or elementary volume of material) located on the surface of OX_1 at point x_1 when it performs angular oscillations with angular parameters $\Theta, \dot{\Theta}, \ddot{\Theta}$.

From the point of view of ensuring the transportation of material on an oscillating surface, it is important to know the components of displacements, velocities and accelerations of points on this surface. To determine the specified components, consider their angular displacements, velocities and accelerations of surface rotation around point *O*, which are expressed by the following dependencies (Fig. 5):

$$\Theta = arctg\frac{Y_{1M}}{X_{1M}} = arctg\frac{r\cdot sin(\omega t)}{L+r\cdot cos(\omega t)};$$

$$\dot\Theta = \frac{r\cdot \omega\cdot (r+L\cdot cos(\omega t))}{L^2+r^2+2\cdot L\cdot r\cdot cos(\omega t)}; \tag{6}$$

$$\ddot\Theta = -\frac{L\cdot r\cdot (L^2-r^2)\cdot \omega^2\cdot sin(\omega t)}{(L^2+r^2+2\cdot L\cdot r\cdot cos(\omega t))^2}$$

In the vertical plane, the material located on the surface of OX_1 (seed, for the sake of simplicity, we will take one seed) acts on the force of gravity $G = m\cdot g$ and the force of inertia I, the projection of which on the axis OY is determined by the expression:

$$I = m\cdot \ddot\theta \cdot x_1\cdot cos(\theta + \alpha), \tag{7}$$

where m – is the weight of the seed, kg;

$\ddot\Theta$ – angular acceleration of the seed , c^{-2};

x_1 – the distance of the seed to the center of oscillations, m.

Then, the condition for separation of the particle (volume element) from the surface of the oscillating plane:

$$m(\ddot\theta \cdot x_1\cdot cos(\theta + \alpha) - g) \geq 0 \tag{8}$$

At the moment of separation of the seed from the oscillating surface, the balance equation in the projection on the axis will have the form:

$$m\cdot \ddot\theta \cdot x_1\cdot cos(\Theta + \alpha) - m\cdot g = 0 \qquad\qquad vv \tag{9}$$

Substituting the values of Θ and $\ddot\Theta$ from (6) into expression (9), after appropriate transformations, we obtain:

$$\frac{L\cdot r(L^2-r^2)\omega^2\cdot x_1\cdot sin(\omega t)}{(L^2+r^2+2L\cdot r\cdot cos(\omega t))^2}\cdot cos\left(arctg\frac{r\cdot sin(\omega t)}{L+r\cdot cos(\omega t)}+\alpha\right)+g = 0 \tag{10}$$

Denoting the left side of equation (10) by G, let's plot graphs $G = f(\omega, r, L, x_1, \alpha, m_3)$ depending on the angle of rotation of the crank $\varphi = \omega t$ the analysis of which showed that the function t at the moment of separation of the seed from the plane is most significantly influenced by the change in the angular speed ω of rotation AM crank. The separation of the seed occurs when the plane is moved from the uppermost position at the moment of the transition of the curve through the X axis $(G = 0)$. Fig. 6 shows an example of determining the moment of separation of the seed from the plane at different values of the angular velocity of the crank and with fixed other parameters ($r= 1{,}5$mm, $L= 0{,}2$m, $x_1 = 0{,}05$m, , $\alpha = 2^0, m_3 = 0{,}04$g).
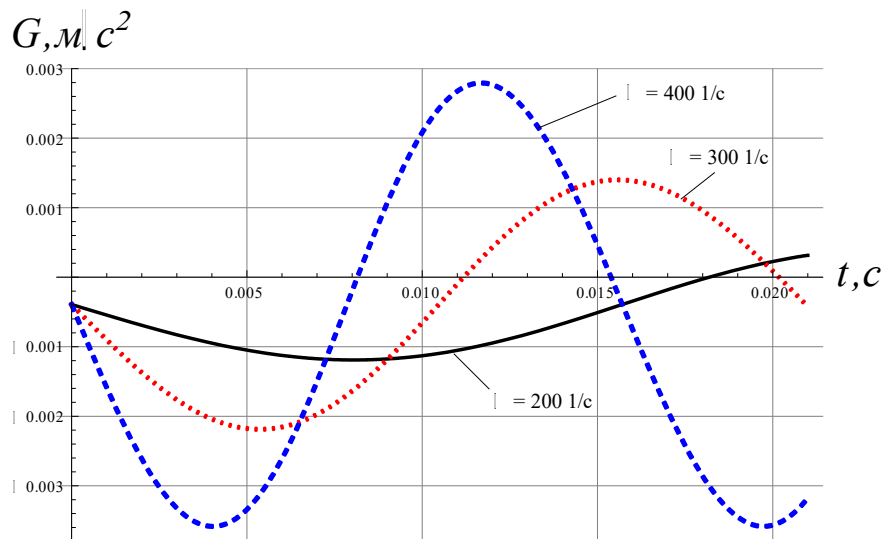

Fig. 6. Determination of the moment of separation of the seed from the vibrating surface at different values of ω

Similarly, the influence of the remaining factors on the conditions of seed separation is determined and dependence graphs are constructed.

Conclusions

The most expedient method of dosed supply of seed mass to the working chamber of a mixer of low productivity should be considered the vibration method, which is characterized by a high frequency of oscillations and a small amplitude.

The analysis of the movement of the seed along the oscillating plane made it possible to determine the influence of the main factors on the rational parameters that ensure a reliable dosed supply of the seed mass to the mixer of low productivity.

The conducted analytical studies are the basis for calculating the numerical values of seed mass supply to the mixer.

It should be noted that when determining the nature of the movement of the seed mass along the oscillating plane, it is necessary to take into account the effect of the fluidized bed, which is the subject of additional research.

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