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VIBRATIONAL MOVEMENT OF PARTICLE AT ASYMMETRICAL OSCILLATION OF THE WORKING SURFACE

Abstract. The practical application of asymmetric oscillations provides significant technological, and sometimes constructive, advantages over harmonic oscillations. This can lead to the rejection of more complex drive devices. For example, using non-harmonic oscillations, the process of screen separation of grain mixtures could be carried out on a horizontal sieve work surface. At the same time, it would be possible to provide an average movement of the runoff part of the grain mixture in a sieve. The article presents the results of a theoretical study of the vibrational displacement of a material particle along a horizontal surface that performs horizontal non-harmonic oscillations. An analytical solution of the problem of the vibrational displacement of a particle is proposed for asymmetric oscillations of the support surface by the method of step-by-step integration. The region of kinematic and adjusting parameters of the supporting surface is determined, under which an average motion of the particle relative to the oscillating surface is possible.

Keywords: non-harmonic oscillations of the working surface, vibrational movement of a particle (loose body) along an oscillating surface, vibrational separation of grain mixtures.

Introduction. In the vibrational technological and transport equipment, machines are widely distributed, the working organs of which perform rectilinear oscillations according to the harmonic law. Less common equipment, in which the law of oscillations of the working body is non-harmonic. This is explained by the greater complexity of the drive for reporting non-harmonic oscillations compared to the drive providing the harmonic law of oscillations of the working element of the machine. However, in the monograph of Professor I. I. Blekhman [1], devoted to the theoretical study of the process of vibrational displacement, it was noted that *"In a number of cases, the use of non-harmonic oscillations gives significant technological and sometimes constructive advantages in comparison with the use of harmonic oscillations. These advantages often pay for the need for more sophisticated drive devices. "*

It is well known that the creation of new highly efficient equipment for grain processing enterprises, in particular grain cleaning machines, is based on the development of the theory of processes and the dynamics of machines. At the same time, the most promising are the works aimed at solving the problems of choosing the law of motion of the working part of the machine when processing the grain mixture (loose body) and its optimal kinematic and dynamic parameters that ensure high technological indicators of the functional purpose of the equipment.

The effect of vibrations on the loose body during the separation of the grain mixture is manifested, firstly, in loosening and self-sorting, and secondly, in the supply, that is, in the appearance of an average unilateral movement of the granular medium along the working surface. The intensity of self-sorting of the components of the grain mix determines the efficiency of the separation process. Feeding the grain mix ensures the continuity of the process. The average speed of vibro-displacement, that is, the average speed of the one-way directional medium flow of the granular material relative to the working surface in both cases (in the technological and transport equipment) determines the productivity of the equipment.

It is known [1] that it is possible to provide a medium-directed movement of a granular medium with respect to a horizontal uniformly rough surface, performing horizontal oscillations, by communicating the surface of asymmetric (non-harmonic) oscillations. The asymmetry of the law of oscillations means the inequality of the maximum positive value of acceleration to the module of the maximum negative value of the acceleration of the surface. The value of the average speed of the loose body relative to the working surface determines the productivity of the equipment, and, what is equally important, the residence time of the loose mixture on the working surface. The latter circumstance is especially important for the separating machine, since the residence time of the granular medium on the oscillating surface affects the efficiency of the self-sorting process. In this case, the longer the residence time of the grain mixture on the working surface, the more effectively the grain mixture is stratified during its self-sorting.

Thus, the average velocity of the vibrational movement of the loose mixture is the main parameter on which the performance of the transport equipment and the productivity and efficiency of the separation process in the processing equipment of grain processing enterprises depend. Consequently, the calculated determination of the average particle velocity of a loose body relative to a vibrating working surface is the first and main task of the theory of vibrational displacement.

Objects and methods of research. The expediency of informing the working bodies of machines of asymmetrical oscillations can be explained as follows. In the case of an asymmetric oscillation law, the working process in the machine can be carried out on a horizontal working surface. With a symmetrical (harmonic) oscillation law, the process of separation is usually carried out on an inclined working surface. The slope of the surface in this case is necessary to ensure the supply of the grain mixture, that is, to ensure the continuity of the separation process. The process of screen separation on flat sieves consists in sieving through a sieve surface of particles with dimensions smaller than the size of the sieve holes. The process of sifting takes place in the field of gravitational forces, that is, the particles fall through the sieve holes under the action of gravity. On an inclined screen surface, the component of gravity, normal to the plane of the surface, is less than the gravity of the particle. Hence, when the screen surface is tilted to the horizontal, the driving force of the separation process decreases, which negatively affects the efficiency of the process. In addition, the need to tilt the working surface leads to an increase in the dimensions and metal capacity of the machine. It should be noted that for asymmetrical oscillations of the working surface, if it becomes necessary to tilt the surface, then to a much lesser degree than with the symmetric law of its oscillations.

In the research [2], devoted to the theoretical study of the vibrational displacement of a material particle along a uniformly rough horizontal plane that performs horizontal oscillations along a non-harmonic (asymmetric) law, the solution of the problem is solved by the method of graphical step-by-step integration. In this case, the dependence of the acceleration of the points of the plane on time has the form

$$a(t) = B\omega^2 \cdot (\cos\omega t + 0{,}5\cos 2\omega t), \tag{1}$$

where is a given constant.

In this research, we consider the solution of this problem using an analytical version of the method of step-by-step integration. The presence of such a solution allows to fully use the advantages of computer technology: the accuracy and speed of computation with the known solution algorithm.

The graphical method of solving is more visual, therefore, in the analytical method of solving the problem, for a better understanding of the actions performed, as appropriate, we will use the material of manuscript [2]. To consider the analytical method of solution, it is necessary to repeat the statement of the problem, the conventions adopted and the graphic interpretation of the solution.

Results and their discussion. The motion of a particle relative to the surface is considered in a portable coordinate system *XOY,* rigidly connected with an oscillating surface. Figure 1 shows a diagram of the forces acting on the particle: *mg* - gravity; *N* - normal surface reaction; *P* - the inertia force of the portable movement; *F=Nf* - the friction force, where is *f* - the friction coefficient of the particle on the surface. According to the accepted conditions - the horizontal surface performs horizontal oscillations - the particle moves relative to the surface without detachment and *N=mg*.

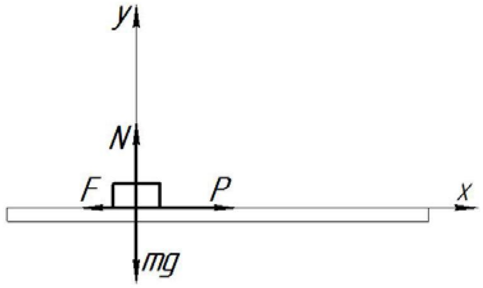

Figure 1 – Scheme of forces acting on the particle

The differential equation of the relative motion of a particle in the projection onto the axis *X* after the transformations and reduction of the equation to the dimensionless form has the form

$$x'' = \cos\delta + 0{,}5\cos 2\delta - z_{\pm}, \quad (2)$$

where $x'' = \dfrac{\ddot{X}}{B\omega^2}$ - dimensionless acceleration of the particle relative to the surface; $\cos\delta + 0{,}5\cos 2\delta$ - dimensionless acceleration of the surface points (analog of the driving force); $z_{\pm} = \pm\dfrac{gf}{B\omega^2}$ - dimensionless parameter of resistance to movement of a particle relative to the surface (analog of the resistance force to the relative motion of the particle); $\delta = \omega t$ - phase angle (dimensionless time).

Two strokes in equation (2) denote differentiation with respect to the dimensionless time δ. In the problem under consideration, the condition $z_+ = |z_-|$ or, which is the same $z_+ = -z_-$, is satisfied.

To determine the range of the parameters $z_{\pm}$ at which the particle moves relative to the surface, a study was made of the dependence of the dimensionless acceleration of the surface on the extrema.

Using the method of step-by-step integration [1, 3], given specific initial conditions, the switching phase angles (the moments of the beginning and the end of the motion in each of the directions) are determined and, accordingly, correcting the initial conditions, arrive at a certain steady-state motion.

In the solution, the following designations are accepted: δ_{1+} and δ_{1-} - phase angles of the beginning of the motion of the particle relative to the surface, respectively, in the positive and negative directions of the axis *X*; δ_{2+} and δ_{2-} - the phase angles of the end, respectively, of these movements; δ_{0+} and δ_{0-} - the phase angles corresponding to the maximum possible conditions for the beginning of the relative motion of the particle, respectively, in the positive and negative directions of the axis *X*. The values of the phase angles δ_{0+} and δ_{0-} are determined from the condition that the driving force is equal to the resistance force, and for a certain subsequent time interval the absolute value of the driving force exceeds the absolute value of the resistance force.

Figure 2 shows a graphical interpretation of the equations of particle motion, presented in work [2]. In Figure 2,a a graph of the dependence $\cos\delta + 0{,}5\cos 2\delta$ is plotted and two straight lines are drawn z_+ and z_-. The first point of intersection of the straight line z_- of the $\cos\delta + 0{,}5\cos 2\delta$ dependence during the surface oscillation period corresponds to the value of the phase angle δ_{0-}. The second point of intersection of the straight line z_+ of the $\cos\delta + 0{,}5\cos 2\delta$ dependence during the surface oscillation period corresponds to the value of the phase angle δ_{0+}.

Figure 2,b shows the plot of $\sin\delta + 0{,}25\sin 2\delta$, which is the dependence of the dimensionless velocity of points on the plane. A straight line is drawn through the point of dependence with the ordinal corresponding to the velocity with the phase angle δ_{0-}, the slope of which to the axis of abscissae is z_-. The straight line in the figure is drawn in dotted lines. The point of intersection of this inclined line with the velocity dependence determines the end of the relative slip of the particle in the negative direction of

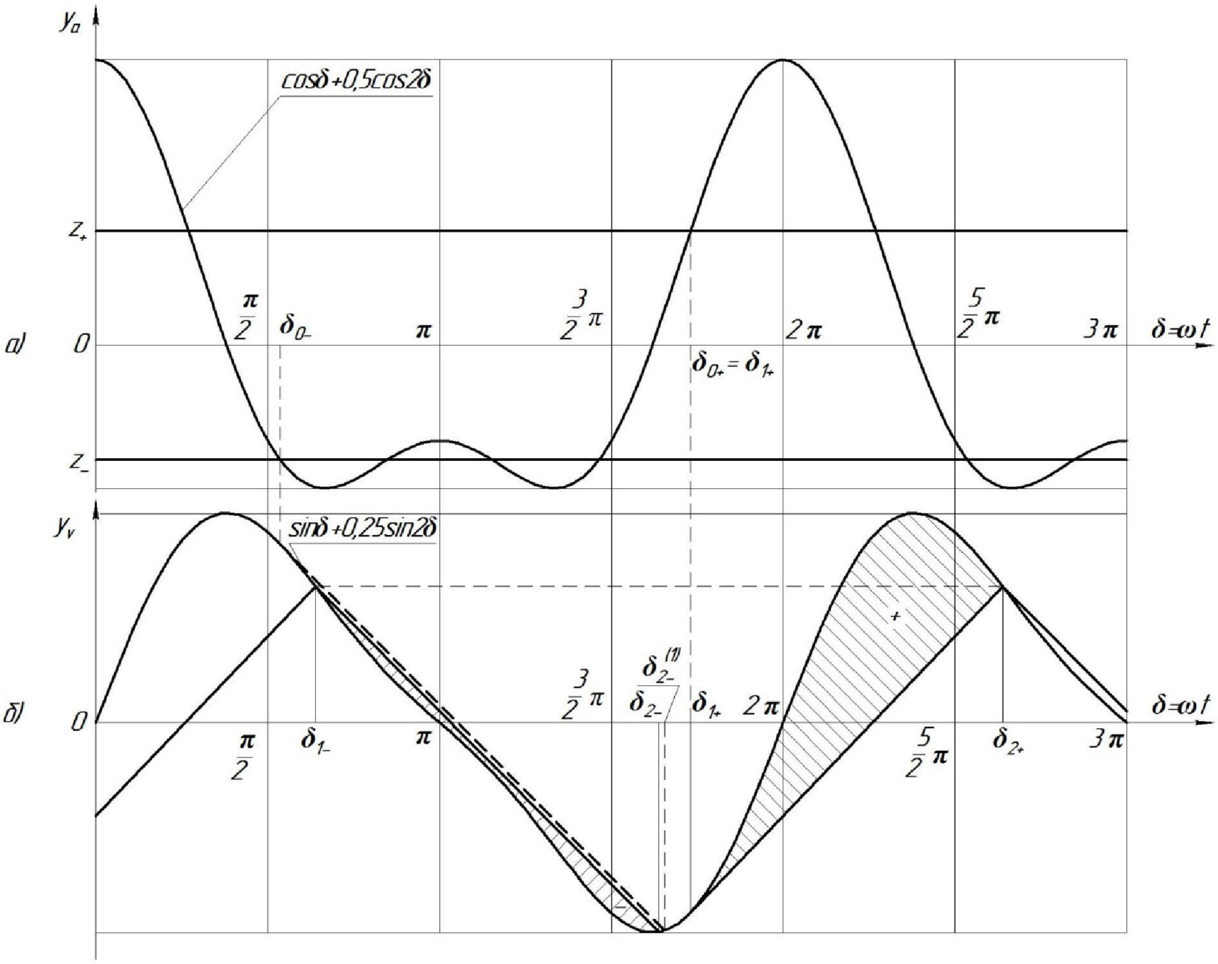

Figure 2 – Graphical interpretation of the equations of particle's motion:
a) graph of accelerations; b) speed graph

the axis *X*. The particle finishes sliding relative to the surface in the negative direction at the phase angle $\delta_{2-}^{(1)}$. As can be seen from figure 2,b, in the case under consideration the condition $\delta_{2-}^{(1)} < \delta_{0+}$ is satisfied. The fulfillment of this condition means that the motion of the particle in the positive direction is preceded by a pause. Consequently, the motion of the particle in the positive direction begins at a phase angle $\delta_{1+} = \delta_{0+}$. Similarly, we determine the phase angle corresponding to the cessation of motion of the particle in the positive direction. In this case, the straight line has an inclination angle to the abscissa axis, the tangent of which is z_+. As can be seen from figure 2,b, the condition $\delta_{2+} - 2\pi > \delta_{0-}$ is satisfied. This means that it is necessary to correct the initial conditions for the motion of the particle. That is, a particle can start moving in the negative direction of the axis *X* at a phase angle $\delta_{1-} = \delta_{2+} - 2\pi$. Such an adjustment of the initial conditions eventually leads to the determination of steady motion.

We consider the solution of the problem by the method of analytical step-by-step integration.

Slip of a particle in the negative direction of the axis *X* can begin, if $x'' \le 0$. Then the phase angle δ_{0-} corresponding to the limiting possible condition of the beginning of the motion is found when $x'' = 0$ the dimensionless acceleration of the particle

$$\cos\delta_{0-} + 0{,}5\cos 2\delta_{0-} - z_- = 0. \tag{3}$$

After the transformations, we obtain

$$\cos^2\delta_{0-} + \cos\delta_{0-} - 0{,}5 - z_- = 0. \tag{4}$$

For the case under consideration ($0{,}5 < \left|z_{\pm}\right| < 0{,}75$) the quadratic equation has four roots. The required solution of the equation, as can be seen from figure 2, is the smallest root

$$\delta_{0-} = \arccos\left(-0{,}5 + \sqrt{0{,}75 + z_{-}}\right). \tag{5}$$

Similarly, slip in the positive direction can begin under the condition $x'' \geq 0$. The phase angle δ_{0+} of the maximum possible start of motion is found from equation

$$\cos\delta_{0+} + 0{,}5\cos 2\delta_{0+} - z_{+} = 0. \tag{6}$$

After the transformations, we obtain

$$\cos^2\delta_{0+} + \cos\delta_{0+} - 0{,}5 - z_{+} = 0. \tag{7}$$

The quadratic equation (7) has two roots. Answering the condition of the maximum possible start of motion is the larger root of equation

$$\delta_{0+} = 2\pi - \arccos\left(-0{,}5 + \sqrt{0{,}75 + z_{+}}\right). \tag{8}$$

It should be noted that, according to the accepted designations, the phase angles δ_{1-} and δ_{1+} correspond to the conditions for the beginning of the slip of the particle, respectively, in the negative and positive directions in the steady motion.

If to each of the angles δ_{0-} and δ_{0+} the particle was in a state of relative rest, that is, the slip in the preceding direction has already ended, then $\delta_{1-} = \delta_{0-}$ and $\delta_{1+} = \delta_{0+}$. To verify the fulfillment of these conditions, we first determine the dependence of the velocity of the particle as it slides relative to the surface in the negative direction of the axis *X* under the assumption that the motion began at a phase angle δ_{0-}. The dependence of the dimensionless velocity is obtained by integrating equation (2) in the range from δ_{0-} up to the current value of the phase angle δ and from $x' = 0$ up to the current value of the velocity $x' < 0$

$$x' = \sin\delta - \sin\delta_{0-} + 0{,}25\left(\sin 2\delta - \sin 2\delta_{0-}\right) - z_{-}\left(\delta - \delta_{0-}\right). \tag{9}$$

At the moment of stopping the slip, the velocity of the particle turns to zero. Consequently, the value of the phase angle $\delta_{2-}^{(1)}$ corresponding to the end of the slip of the particle in the negative direction can be calculated from equation

$$\sin\delta_{2-}^{(1)} - \sin\delta_{0-} + 0{,}25\left(\sin 2\delta_{2-}^{(1)} - \sin 2\delta_{0-}\right) - z_{-}\left(\delta_{2-}^{(1)} - \delta_{0-}\right) = 0. \tag{10}$$

Solving the last equation by the method of successive approximations with respect to $\delta_{2-}^{(1)}$, we determine the value of the phase stop angle.

As noted above, checking for the presence or absence of a pause before starting the motion in the positive direction consists in comparing the values of the phase angles $\delta_{2-}^{(1)}$ and δ_{0+}. If $\delta_{2-}^{(1)} \geq \delta_{0+}$, then there is no pause and the movement in the positive direction begins at a phase angle $\delta_{1+} = \delta_{2-}^{(1)}$. If $\delta_{2-}^{(1)} < \delta_{0+}$, as in the case under consideration, the movement in the positive direction is preceded by a pause. Consequently, the particle begins to slide in the positive direction at the phase angle $\delta_{1+} = \delta_{0+}$.

To determine the velocity dependence, we integrate equation (2) in the range from $\delta_{1+} = \delta_{0+}$ up to the current value of the phase angle δ and from $x' = 0$ up to the current value of the velocity $x' > 0$

$$x' = \sin\delta - \sin\delta_{1+} + 0{,}25\left(\sin 2\delta - \sin 2\delta_{1+}\right) - z_{+}\left(\delta - \delta_{1+}\right). \tag{11}$$

At the moment when the particle slips in the positive direction at the phase angle, the velocity vanishes

$$\sin\delta_{2+} - \sin\delta_{1+} + 0{,}25(\sin 2\delta_{2+} - \sin 2\delta_{1+}) - z_{+}(\delta_{2+} - \delta_{1+}) = 0. \quad (12)$$

Solving equation (12) with respect to δ_{2+} the method of successive approximations, we determine the value of the phase angle δ_{2+} of the cessation of the slip of the particle in the positive direction of the axis *X*.

If $\delta_{2+} - 2\pi < \delta_{0-}$, then the motion of the particle in the negative direction is preceded by a pause. In this case, the motion in the negative direction begins at a phase angle $\delta_{1-} = \delta_{0-}$.

It should be noted that the presence of pauses before the movement in each direction means that the steady motion is obtained.

If $\delta_{2+} - 2\pi > \delta_{0-}$, as is the case in the present case, then a pause before the particle motion in the negative direction is absent. Then the particle starts to move in the negative direction is not at the phase angle δ_{0-}, as it was made before the first stage of integration, because by the time corresponding to the phase angle δ_{0-}, the particle has not stopped moving in a positive direction. Therefore, in the second stage of integrating the equations of motion of the particle, correction of the phase angle of the origin of motion in the negative direction is necessary. Since the time corresponding to the phase angle $\delta_{2+} - 2\pi$, the ratio of the driving force and the resistance force correspond to the condition of movement in the negative direction, then $\delta_{1-} = \delta_{2+} - 2\pi$.

After correcting the phase angle of the beginning of the particle's slip in the negative direction of the axis *X*, the velocity dependence has the form

$$x' = \sin\delta - \sin\delta_{1-} + 0{,}25(\sin 2\delta - \sin 2\delta_{1-}) - z_{-}(\delta - \delta_{1-}). \quad (13)$$

The phase angle δ_{2-} of the end of the particle's slip in the negative direction in the second stage of integration is determined by solving by the method of successive approximations the equation

$$\sin\delta_{2-} - \sin\delta_{1-} + 0{,}25(\sin 2\delta_{2-} - \sin 2\delta_{1-}) - z_{-}(\delta_{2-} - \delta_{1-}) = 0. \quad (14)$$

Note that $\delta_{2-} < \delta_{2-}^{(1)}$ (see figure 2).

Thus, as a result of adjusting the phase angle of the beginning of the movement in the negative direction, the duration of the pause before the motion of the particle in the positive direction increases. Therefore, the values of the phase angles of the beginning and the end of the motion of the particle in the positive direction remain unchanged. Consequently, steady motion is obtained.

The statement that the condition $\delta_{2-} < \delta_{1+} = \delta_{0+}$ is satisfied in the case under consideration can be explained as follows. The intervals of motion of the particle in each direction contain two subintervals: the subinterval of the accelerated motion (the driving force exceeds the resistance force); subinterval of slow motion (the force of resistance exceeds the driving force). The boundaries of the subintervals of the accelerated motion are determined by the values of the parameters z_{-} and z_{+}. The parameter z_{-} defines the boundaries of the subinterval of the accelerated motion of the particle in the negative direction of the axis *X*. The parameter z_{+} is in the positive direction. The search for steady motion is associated with the need to correct the phase angle of the beginning of the motion, whose value either corresponds to the beginning of the subinterval of the particle's accelerated motion, or belongs to this subinterval, and then determines the phase angle of the end of the motion in this direction. In our case, when investigating the motion of a particle in the first period of oscillations of the support surface, it is established that slip in the negative ends before the particle can begin to move in the positive direction ($\delta_{2-}^{(1)} < \delta_{0+}$), and the motion in the positive direction ends later than the particle can begin to move in the negative direction

($\delta_{2+} - 2\pi > \delta_{0-}$). This means that when studying the motion of a particle in order to find the steady motion, it should be assumed that in the subsequent oscillation period of the reference surface, the particle begins to move in the negative direction at the phase angle $\delta_{1-} = \delta_{2+} - 2\pi$, that is, at a larger value of the phase angle than in the previous oscillation period. Note that correcting the condition of the beginning of the motion in the negative direction leads to an increase in the value of the phase angle of the beginning of the motion. Obviously, in this case, at the stage of particle motion in the negative direction, in the second period of surface oscillations, the duration of the subinterval of the accelerated motion is reduced. Consequently, the particle ends the motion in the negative direction earlier than it was determined in the first stage of the particle motion study, that is, the condition $\delta_{2-} < \delta_{1+} = \delta_{0+}$ is satisfied.

After finding the phase angles of the beginning and end of the particle's slip relative to the surface in each of the directions in the steady motion, we determine the particle movements in the negative and positive directions.

To determine the displacement of the particle relative to the surface in the negative direction, we integrate equation (13) in the range from δ_{1-} to δ_{2-} and from $x = 0$ to x_-

$$x_- = (z_-\delta_{1-} - \sin\delta_{1-} - 0{,}25\sin 2\delta_{1-})(\delta_{2-} - \delta_{1-}) - (\cos\delta_{2-} - \cos\delta_{1-}) - 0{,}125(\cos 2\delta_{2-} - \cos 2\delta_{1-}) - \\ - z_- \frac{\delta_{2-}^2 - \delta_{1-}^2}{2}. \quad (15)$$

To determine the displacement of the particle in the positive direction, we integrate equation (11) in the range from δ_{1+} to δ_{2+} and from $x = 0$ to x_+

$$x_+ = (z_+\delta_{1+} - \sin\delta_{1+} - 0{,}25\sin 2\delta_{1+})(\delta_{2+} - \delta_{1+}) - (\cos\delta_{2+} - \cos\delta_{1+}) - 0{,}125(\cos 2\delta_{2+} - \cos 2\delta_{1+}) - \\ - z_+ \frac{\delta_{2+}^2 - \delta_{1+}^2}{2}. \quad (16)$$

The value of the average dimensionless velocity of a particle during the period of surface oscillations is determined by the formula

$$x'_m = \frac{x_- + x_+}{2\pi}. \quad (17)$$

As noted above, the dimensionless velocity is obtained by differentiating the dimensionless coordinate $x = \frac{X}{B}$ from the dimensionless time $\delta = \omega t$, that is, $x' = \frac{dx}{d\delta}$. Therefore, the transition from the dimensionless displacement x to the dimensional displacement s can be carried out by the formulas: to move in the negative direction - $s_- = Bx_-$; to move in the positive direction - $s_+ = Bx_+$. The dimensionless instantaneous velocity x' is related to the dimensional instantaneous velocity $\dot{X}$ by the following relation $x' = \frac{dx}{d\delta} = \frac{dX}{Bd\delta} = \frac{dX}{B\omega dt} = \frac{\dot{X}}{B\omega}$. Then the value of the dimensional average speed Vm can be determined by the formula

$$V_m = \frac{B\omega(x_- + x_+)}{2\pi} = B\omega x_m. \quad (18)$$

The following conclusions can be drawn from the presented solution for determining the steady motion. Investigation of the motion of a particle relative to an oscillating surface can be carried out in the following sequence. We determine the phase angles δ_{0-} and δ_{0+} corresponding to the conditions of the maximum possible start of the motion in each direction. At the first stage of the study of particle motion, we assume that it starts moving, for example, in the negative direction at a phase angle δ_{0-}. Determine the dependence of the velocity of the particle as it slides relative to the surface in the negative direction. We determine the value of the phase angle $\delta_{2-}^{(1)}$ of the end of the slip of the particle in the negative direction, provided that the velocity is zero. If $\delta_{2-}^{(1)} < \delta_{0+}$, as in the case under consideration, then after moving in the negative direction until the time corresponding to the value of the phase angle δ_{0+}, the particle is in a state of relative rest (motionless relative to the surface), that is, there is a pause. After a pause, the particle begins to move relative to the surface in the positive direction at a phase angle δ_{0+}. Next, we determine the dependence of the velocity of the particle as it slides relative to the surface in the positive direction and the phase angle δ_{2+} of the end of this motion. If $\delta_{2+} - 2\pi < \delta_{0-}$, therefore, steady-state motion is obtained, since the previously assumed assumption that the particle starts to move in the negative and positive directions, respectively, at phase angles δ_{0-} and δ_{0+} turned out to be correct. If $\delta_{2+} - 2\pi > \delta_{0-}$, as in the case under consideration, then the correction of the condition for the beginning of the motion of the particle in the negative direction is required. Therefore, the particle begins to move in the negative direction at a phase angle $\delta_{1-} = \delta_{2+} - 2\pi$. Further, taking into account the new value of the phase angle of the beginning of the relative particle's slip, we determine the dependence of its velocity on this stage of the motion and the phase angle δ_{2-} of its termination. In the case under consideration, the condition $\delta_{2-} < \delta_{1+} = \delta_{0+}$ is satisfied, and this means that a steady motion is obtained.

Conclusion. The presented graph-analytical method for studying transient and steady-state processes of the particle's vibrational motion with non-harmonic oscillations of the working support surface will allow the design engineers to calculate the kinematic parameters of the separation process of the grain mix, and also design the parameters of the separating organ of the grain cleaning machines.

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БӨЛШЕКТІҢ СИММЕТРИАЛДЫ ЕМЕС ДЕНЕНІҢ ТЕРБЕЛМЕЛІ БЕТПЕН ВИБРАЦИЯЛЫҚ ОРЫН АУЫСТЫРУЫ

Аннотация. Өндірісте симметриалды емес тербелістерді қолдану симметриалды тербелістермен салыстырғанда технологиялық, сонымен қатар конструктивті ерекшелігі болады. Бұл деген күрделі қозғалтқыш механизмдерден бас тартуға әкелуі мүмкін. Мысалы, гармоникалық емес тербелісті қолданумен дәндіқоспаны елекпен сұрыптауды горизонтал електі жұмыс органында жүзеге асыруға болар еді. Бұл кезде дәндіқоспаның електен өтетпей бөлімін бағытты орта жылдамдықпен қозғалтуға болар еді.

Мақалада айналмалы гармоникалық емес тербелетін горизонтал бетпен материалды дене вибрациалық тербелісінің теориялық зерттеулер нәтижелері келтірілген. Дененің симметриалды емес тербелетін бетте вибрациялық орын ауыстыруының аналитикалық есептерін кезеңмен интегралдау әдісімен шешу жолы ұсынылады. Дененің бағытты орта жылдамдықпен салыстырмалы орын ауыстыратын тірек бетінің кинематикалық және қалыпты параметрлерінің облысы анықталды.

Түйін сөздер: жұмыс бетінің гармоникалық емес тербелісі, дененің (сусымалы заттың) тербелмелі бетпен вибрациялық орын ауыстыруы, дәнді қоспаларды вибрациялық сұрыптау.

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ВИБРАЦИОННОЕ ПЕРЕМЕЩЕНИЕ ЧАСТИЦЫ ПРИ НЕСИММЕТРИЧНЫХ КОЛЕБАНИЯХ РАБОЧЕЙ ПОВЕРХНОСТИ

Аннотация. Применение на практике несимметричных колебаний дает существенные технологические, а иногда и конструктивные преимущества по сравнению с гармоническими колебаниями. Это может привести отказу от более сложных приводных устройств. Например, с использованием негармонических колебаний процесс ситового сепарирования зерносмесей мог бы осуществлен на горизонтальной ситовой рабочей поверхности. При этом обеспечивалось бы направленное в среднем движение сходовой части зерносмеси по сите. В статье представлены результаты теоретического исследования вибрационного перемещения материальной частицы по горизонтальной поверхности, совершающей горизонтальные негармонические колебания. Предложено аналитическое решение задачи вибрационного перемещения частицы при несимметричных колебаниях опорной поверхности методом поэтапного интегрирования. Определена область кинематических и установочных параметров опорной поверхности, при которых возможно направленное в среднем перемещение частицы относительно колеблющейся поверхности.

Ключевые слова: негармонические колебания рабочей поверхности, вибрационное перемещение частицы (сыпучего тела) по колеблющейся поверхности, вибрационное сепарирование зерновых смесей.

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