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ELABORATION AND RESEARCH OF VIBROSHAKERS WITH ELECTROMAGNETIC DRIVE FOR CLASSIFICATION OF DRY MATERIALS

There are schemes of various vibroshakers for classification of dry materials for construction, agriculture, food and processing industry, in mining and transport, examined in this article. As a result, of the analysis the authors came to conclusion about low efficiency and reliability of known vibroshakers. In course of their functioning significant part of consumed energy is spent for bringing in movement of massive driving elements. Actually, each of these vibroshakers realizes only one scheme of loading with relatively narrow range of change of its main parameters (amplitude, frequency, transmitting energy). Besides, intensive dynamic loadings make a negative influence on supporting elements of these machines and that leads to their rapid wear. With examination of these disadvantages of known vibroshakers, authors elaborated schemes of improved vibroshakers with electromagnetic drive for classification of dry materials. The proposed vibroshakers provide complex schemes of loading of processed material and that promotes to increase of efficiency of the working process. In one of these schemes foreseen possibilities of change of location of electromagnetic vibro-exciters relatively of foundation. Later allows to change a scheme of loading of the processed material depending from its physical-mechanical characteristics. An electromagnetic drive of the improved vibroschakers gives possibility of a separate and accurate adjustment of the main parameters of the loading of material in wide range. In the constructions of the vibroschakers are absent elements of friction and massive inertia masses therefore they have an increased reliability and efficiency. There are differential equations of the movements of the executive elements of the vibroschakers are proposed in the article that allow to determine their main working parameters in course of different stages of a working cycle. These equations can be used for creation of methods of design calculation of the proposed vibroschakers.

Kee words: *vibroshakers, electromagnetic drive, classification, dry material, schemes of loading, mathematic model.*

Problem formulation. Vibroshakers are a type of wide spread equipment for classification of dry and humid materials: rocks in mining; gravels and siftings in building; grains and legumes in agriculture; weeds and small stones in threshing-floors, elevators, mills; for dehydration of cleaned coals and ores; at bread, confectionery, canning and food concentrates enterprises, in laboratories for fractional analysis of dry materials [1 – 3]. Therefore, an actual task is improvement of equipment for classification in order to increase its productivity and reliability, to widen of technological possibilities and to minimize of energy expenses of machines for classification.

Analysis of last researches and publications. There are different schemes of

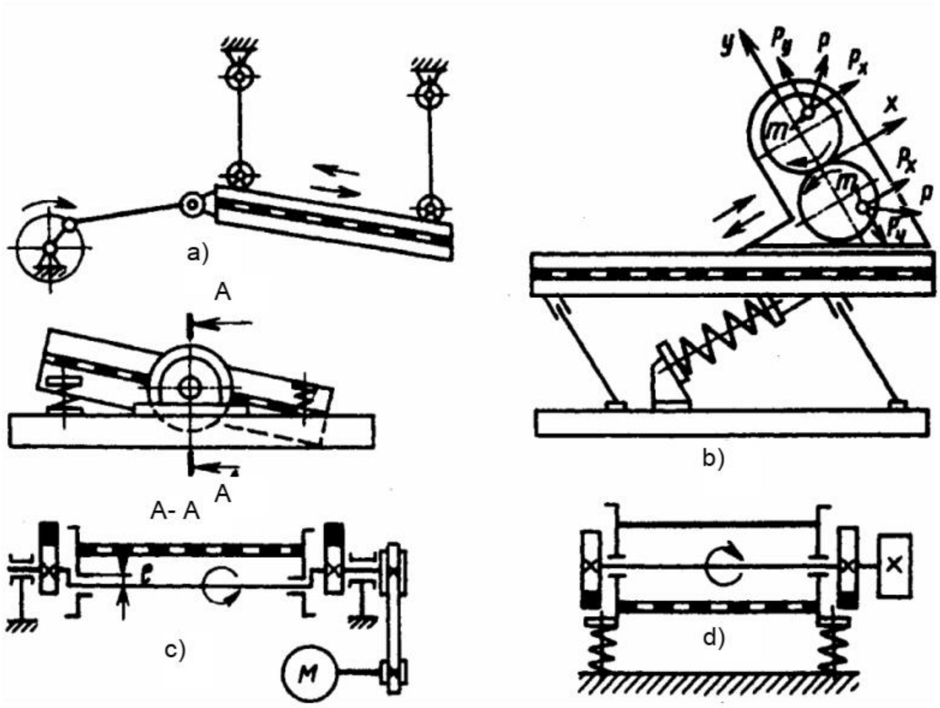

Figure 1 – Schemes of vibroshakers: a – rocking; b – gyratory; c – with directional fluctuations; d – vibratory inertial

vibroshakers, presented on fig. 1 [4]. In the whole, it is a simple and inexpensive equipment, which has versatile use in different branches and under processing of various materials [1]. One of main and general disadvantages of this equipment is availability of details that are underwent intensive

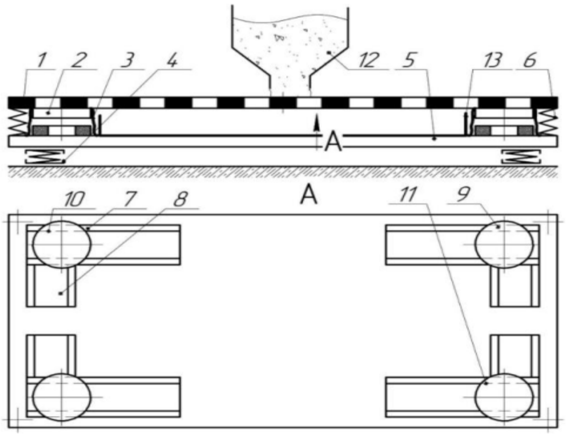

Figure. 2 – Scheme of an improved vibroshaker with an electromagnetic drive for classification of dry materials: 1 – sieve; 2, 9, 10, 11 – electromagnetic vibro-exciters; 3 – dust shield; 4 – vibroinsulator; 5 – foundation; 6 – spring; 7, 8 – holders; 12 – bunker with initial material; 13 – container for small fraction fines

dynamical loading in course of realization of a working process: bearings and shafts, levers of suspension, crank shafts and other. This leads to accelerative wear of the details and to decrease of reliability of the machines. One more substantial disadvantage is availability of inertia movable elements (debalances and levers) that cause additional ineffective expenses of energy. Besides, there is not provided a possibility of independent regulation of sieve fluctuations by frequency and amplitude and has narrow enough limits of their regulation (for frequency – 10 – 20 Hz, for amplitude – 0 – 3 mm [2, 3]).

Purpose formulation. The purpose of this article is elaboration and research of schemes of improved vibroshakers with electromagnetic drive for classification of dry materials where avoided fully or partially shortcomings of the known equipment of the similar designation.

Presentation of main material. There is the first scheme of the improved vibroshaker, presented on the fig. 2.

An executive element of the vibrosheker is the sieve 1, elastically installed with the help of the springs 6 on the foundation 5. The latter is based on the vibroinsulators 4. Driving elements of the vibroshaker are four electromagnetic vibro-exciters 2, 9 that can install and fix in different positions in slots of longitudinal 7 and transversal 8 holders. The vibro-exciters 2, 9 are closed with dust shields 3. In order to realize functioning of the vibroshaker provide periodical feeding of voltage at limbs of the vibro-exciters. As a result, their armatures fulfil vertical reciprocal movements with frequency up to 100 Hz and with amplitude up to the 4 mm (the amplitude can be changed by way of installation of the armatures of various thickness). These movements are transmitted to the sieve 1, so, processed material that is loaded down on the sieve from the bunker 12 is effectively separated at fractions. The fraction with more small particles goes through the sieve 1 and gets into container 13. The fraction with large particles remains on the surface of the sieve. There is realized constant or periodical unloading of the separated fractions from the sieve 1 and from the container 13.

The proposed vibroshaker does not contain elements of friction with intensive wear of executive surfaces. Also, there are absent massive inertia elements and that provides more effective use of consumed energy, which is transmitted from the vibro-exciters 2, 9. Possibility of change of a position of the vibro-exciters 2 relatively the sieve 1 provides a lot of variants of loading schemes. Besides, there can be adjusted a mode of feeding of voltage at winding of the vibro-exciters 2 and 9 when their armatures fluctuate in the same phase or in an opposite phase. That still more widen technological possibilities of the elaborated vibroshaker. There is a lot of standard, reliable and inexpensive electromagnetic vibro-exciters of different capacity and with wide range of parameters of fluctuations [5], so their selection as driving elements of the vibroshaker is quite reasonable. All this allows us to make a conclusion about successful elimination of main disadvantages of known machines for classification in the construction of the proposed vibroshaker.

By our notion, the most effective variants of loading of the material on the sieve are provided when both the working (upwards) and the idle (downwards) strokes of the sieve are fulfilled under the impact of the electromagnetic vibro-exciters. This will promote to maximal frequency of oscillations of the sieve 1 and to high productivity of the working process.

So, the first main variant of loading is realized when the vibro-exciters 2, 9 provide working strokes of the sieve 1 and vibro-exciters 10, 11 – idle strokes. In this case, the sieve will fulfill vertical reciprocal movements parallel to a surface of the foundation 5.

The second main variant of loading is carried out when the vibro-exciters 2, 10 provide working strokes and vibro-exciters 9, 11 – idle strokes. In this case, the sieve 1 will fulfill wobbling movements relatively own transverse axis.

The third main variant of loading is carried out when the vibro-exciters 2, 11 provide working strokes and vibro-exciters 9, 10 – idle strokes. In this case, the sieve 1 will fulfill wobbling movements relatively own longitudinal axis. The second and the third variants of loading provide both tossing of processing material particles perpendicularly to the sieve surface and their rolling across or along of the sieve. In our opinion, these regimes will secure higher productivity of the working process.

These variants of regimes can adjust by selection a corresponding difference of phases of movements of executive elements of the vibro-exciters 2, 9 relatively movements of the vibro-exciters 10, 11 – for the first regime, the vibro-exciters 2, 11 relatively movements of the vibro-exciters 9, 10 – for the second regime, the vibro-exciters 2, 10 relatively movements of the vibro-exciters 9, 11 – for the third regime.

The working cycle of movements of the executive elements of the vibro-exciters for the first regime of loading can be divided on two stages: I stage – a movement of the executive element from a top initial position in a lower final position; II stage – a movement of the executive element from the lower final position in the top initial position.

We can consider that durability of the I stage (T_I) of the cycle is equal to durability of the II stage (T_{II}) of the cycle of movements of the executive elements.

T_I, T_{II} can be calculated, depending from frequency ν of vertical reciprocal fluctuations of the executive elements of the vibro-exciters by a formula

$$T_I = T_{II} = \frac{1}{2 \cdot \nu}. \quad (1)$$

There are schemes of loading of the sieve and of the portion of processed material on the sieve surface in course of the I stage and the II stage of the working cycle of the sieve presented on the fig. 3.

There are parameters designated on the schemes (fig. 3):

m_s, m_m – masses of the sieve 1 (see also fig. 2) and of the portion of processed material on the sieve surface;

x_s, x_m – coordinates of movements of the masses m_s, m_m;

F_e – nominal driving force, creating by pair of the vibro-exciters of the vibroshaker [5];

$F_{spI}(t)$, $F_{spII}(t)$ – variable elasticity force of the springs 6 in course of the loading cycle at the I stage and at the II stage respectively [6];

$F_{m.fin}$ – driving force, creating by the sieve on the portion of processed material in the initial moment of the I stage and corresponding to the value of the $F_m(t)$ in the final moment of the II stage $t = \frac{1}{2 \cdot \nu}$. The portion of processed material is thrown upwards in course of this stage under impact of the

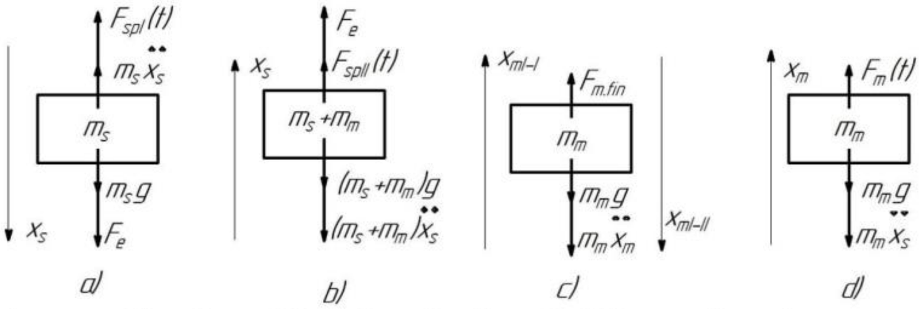

Figure. 3 –Schemes of loading of the sieve (*a, b*) and of the portion of processed material on the sieve surface (*c, d*) at the I stage (*a, c*) and at the II stage (*b, d*) of the sieve's working cycle

force $F_{m.fin}$. The sieve is beginning a movement downwards in this moment. Then the portion realizes an uniformly retarded free motion in a top position to a complete stopping in it and an uniformly accelerated free motion under influence of gravity in a lower position up to the interaction with the sieve, that fulfils the next movement upwards in course of the II stage of the cycle.

$F_m(t)$ – variable driving force, creating by the sieve at the portion of processed material at the II stage [7]. In course of this stage the portion of processed material moves together with the sieve, therefore on the scheme for the II stage (fig. 3, d) acceleration of the portion of the processed material corresponds to acceleration of the sieve - $\ddot{x}_s$;

Forces $F_{sI}(t)$, $F_{sII}(t)$ can be determined by formulas

$$F_{sI}(t) = 4 \cdot c_s(x_{s0} + x_s);\ 0 \le t \le \frac{1}{2\cdot\nu}. \qquad (2)$$

$$F_{sII}(t) = 4 \cdot c_s\left(x_{s0} + x_{s.fin} - x_s\right);\ \frac{1}{2\cdot\nu} < t \le \frac{1}{\nu}, \qquad (3)$$

where c_s – coefficient of hardness of the spring 6;

$x_{s.fin}$ – coordinate of a movement of the mass m_s in the final moment of the I stage: $t = \frac{1}{2\cdot\nu}$;

x_{s0} – preliminary compression of the spring 6 under impact of gravitation of the sieve in the initial moment of the cycle, that can be determined as

$$x_{s0} = \frac{g\cdot(m_s+m_m)}{4\cdot c_s}. \qquad (4)$$

On basis of the schemes on the fig. 3, *a, b* and with consideration of the formulas (1 – 4) differential equations of sieve movements at the I and at the II stages of the cycle have an appearance:

$$-m_s\ddot{x}_s = F_e + m_sg - F_{spI}(t);\ 0 \le t \le \frac{1}{2\cdot\nu}. \qquad (5)$$

$$-\ddot{x}_s(m_s+m_m) = F_e - g(m_s+m_m) + F_{spII}(t);\ \frac{1}{2\cdot\nu} < t \le \frac{1}{\nu}. \qquad (6)$$

On basis of the schemes on the fig. 3, *c, d* differential equations of the portion of processed material at the I and at the II stage of the cycle:

$$-m_m\ddot{x}_m = -m_mg;\ 0 \le t \le \frac{1}{4\cdot\nu}; \qquad (7)$$

$$m_m\ddot{x}_m = m_mg;\ \frac{1}{4\cdot\nu} \le t < \frac{1}{2\cdot\nu}; \qquad (8)$$

$$-m_m\ddot{x}_s = F_{m.fin} - m_mg;\ t = \frac{1}{2\cdot\nu}; \qquad (9)$$

$$-m_m\ddot{x}_s = F_m(t) - m_mg;\ \frac{1}{2\cdot\nu} < t \le \frac{1}{\nu}. \qquad (10)$$

The force $F_m(t)$ in the equation (10) can be found with help of the equation (6):

$$F_m(t) = F_e + (m_s+m_m)(\ddot{x}_s - g) + F_{spII}(t);\ \frac{1}{2\cdot\nu} < t \le \frac{1}{\nu}. \qquad (11)$$

There is one more scheme of an improved vibroshaker with electromagnetic drive, presented on the fig. 4.

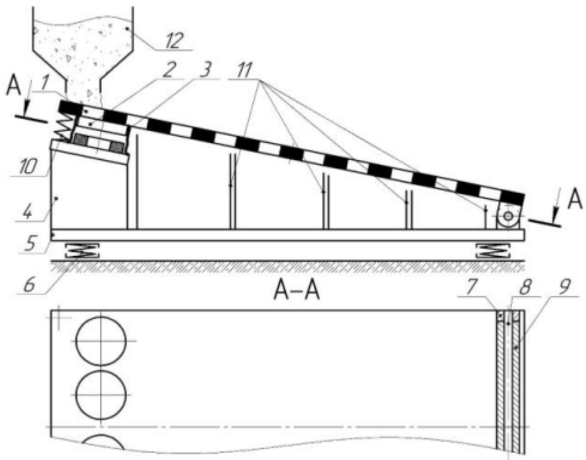

Figure. 4 –Scheme of improved vibroshaker with electromagnetic drive of wobbling motion of the sieve for classification of dry materials: 1 – sieve; 2 – electromagnetic vibro-exciter; 3 – dust shield; 4 – holder; 5 – foundation; 6 – vibroinsulator; 7 – immovable hinge; 8 – pin; 9 – movable hinge; 10 – spring; 11 – containers for different fractions fines; 12 – bunker with initial material

A feature of this scheme is a wobbling motion of the sieve 1, which provided in the very construction of the vibroshaker. The sieve 1, installed with some incline to the foundation 5 creates by one of its ends a movable connection with the foundation. There are armatures of the four electromagnetic vibro-exciters 2, attached from below to the other end of the sieve 1. There are limbs of the vibro-exciters installed on the holders 4. The springs 10, fastened on the left end of the sieve, create an elastic bound with the foundation 5. A working surface of the sieve consists over its length several sections with different sizes of sells (these sizes are increased from the left section to the right section of the sieve).

In case of periodical feeding of voltage at the limbs of the electromagnetic vibro-exciters 2 the sieve 1 fulfils wobbling reciprocal movements. In order to provide maximal frequency of fluctuations of the sieve, feeding of voltage at the limbs of a pair of the external electromagnetic vibro-exciters is realized in the moments of switching off the limbs of a pair of the internal vibro-exciters (see also the section A – A on the fig. 4). So, a working stroke and an idle stroke of the sieve are fulfilled under impact of the vibro-exciters. As a result, particles of initial material spill out from the bunker 12 at the sieve surface and fulfil stick-slip motions from the left to the right of the sieve. Particles with minimal sizes separate at the first left section of the sieve 1 and go through it in the first left container 11. Similarly, particles of the next size range separate through the second left section of the sieve in the second from the left container 11 and in the same way – to the particles of the largest size range, that separate through the first right section of the sieve in the first right container 11.

The proposed scheme of the vibroshaker (fig. 4) has almost all advantages of the previous scheme (fig. 3): the simple and reliable design, effective use of consumed energy, wide utilization in the construction of standard elements. Additional advantages of this scheme are: a possibility of wide range and independent change of the above indicated parameters of loading of processed material, a possibility of classification of its particles by size at several fractions, an utilization of energy of gravitation of the materials particles for realization of the working process.

The working cycle of the vibroshaker can be divided at the same two stages as for the previous scheme (fig. 2): the I stage – a movement of the sieve 1 from a top initial position in a lower final position; the II stage – a movement of the executive element from the lower final position in the top initial position.

There are schemes of loading of the sieve (a, b) and of the portion of processed material on the sieve surface (c, d) at the I stage (a, c) and at the II stage (b, d) of the sieve working cycle (fig. 5).
There are parameters designated on the schemes (fig. 5):

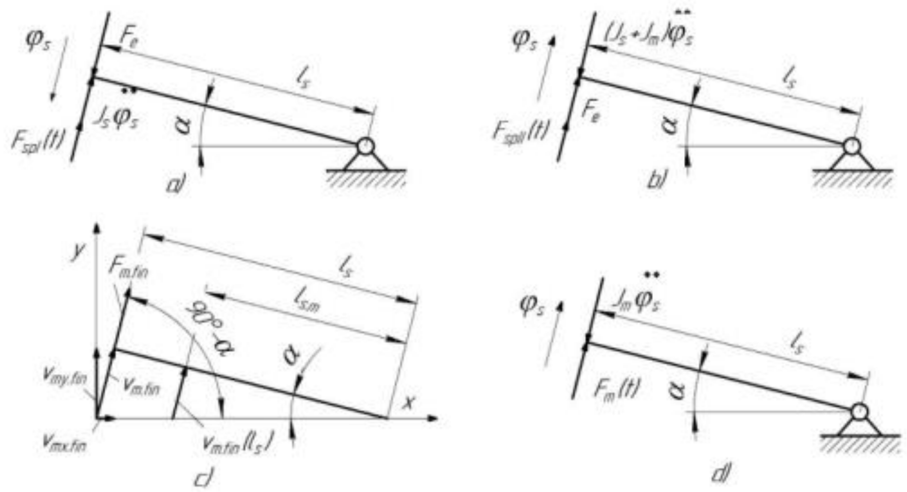

Figure. 5 – Schemes of loading of the sieve (*a, b*) and of the portion of processed material on the sieve surface (*c, d*) at the I stage (*a, c*) and at the II stage (*b, d*) of the sieve's working cycle

J_s, J_m – moments of inertia of the sieve 1 (see also fig. 4) and of the portion of processed material on the sieve surface;

φ_s, φ_m – turn angles of the sieve 1 and of the portion of processed material;

F_e – nominal driving force, creating by pair of the vibro-exciters of the vibroshaker;

l_s – working length of the sieve;

$F_{spI}(t)$, $F_{spII}(t)$ – variable elasticity force of the springs 10 in course of the loading cycle at the I stage and at the II stage respectively;

$F_m(t)$ – variable driving force, creating by the sieve at the portion of processed material at the II stage. In course of this stage the portion of processed material moves together with the sieve, therefore on the scheme for the II stage (fig. 5, d) the angle acceleration of the portion of the processed material corresponds to the angle acceleration of the sieve - $\ddot{\varphi}_s$;

$F_{m.fin}$ – driving force, creating by the sieve at the portion of processed material in the initial moment of the I stage and corresponding to the value of the $F_m(t)$ in the final moment of the II stage $t = \frac{1}{2\cdot\nu}$. The portion of the processed material is thrown upwards and right by the scheme in course of this stage under impact of the force $F_{m.fin}$ and under angle 90º - α to the horizon, where α – is the angle of an incline of the sieve in the top initial position (fig. 5, c);

$v_{m.fin}$ – initial speed of particles of the portion of processed material in the initial moment $t = \frac{1}{2\cdot\nu}$ of the I stage in the extreme left point of the working surface of the sieve;

$v_{mx.fin}$, $v_{my.fin}$ – components of the speed $v_{m.fin}$ relatively x-axis and y-axis.

Forces $F_{spI}(t)$, $F_{spII}(t)$ can be determined by formulas [8]

$$F_{spI}(t) = 2\cdot c_s(x_{s0}+\varphi_s l_s);\ 0 \le t \le \frac{1}{2\cdot\nu}; \qquad (12)$$

$$F_{spII}(t) = 2\cdot c_s\left(x_{s0}+\varphi_{s.fin}-\varphi_s\right);\frac{1}{2\cdot\nu} < t \le \frac{1}{\nu}, \quad (13)$$

where c_s – coefficient of hardness of the spring 10;

$\varphi_{s.fin}$ – angle coordinate of movement of the sieve 1 in the final moment of the I stage: $t = \frac{1}{2\cdot\nu}$;

x_{s0} – preliminary compression of the springs 6 under impact of gravitation of the sieve in the initial moment of the cycle, that can be determined by formula (4), where m_s, m_m – masses of the sieve 1 (see also fig. 5) and of the portion of processed material on the sieve surface.

On basis of the schemes on the fig. 5, *a, b* and with consideration of the formulas (4, 12, 13) differential equations of the movements of the sieve at the I and at the II stages of the cycle have an appearance:

$$-J_s\ddot{\varphi}_s = \left(F_e - F_{spI}(t)\right)l_s;\ 0 \le t \le \frac{1}{2\cdot\nu}. \qquad (14)$$

$$-\ddot{\varphi}_m(J_s+J_m) = \left(F_e + F_{spII}(t)\right)l_s;\frac{1}{2\cdot\nu} < t \le \frac{1}{\nu}. \quad (15)$$

The speed $v_{m.fin}$ can be found from the known formula [9]

$$\ddot{x}_s = \frac{v_{m.fin}-v_{m.in}}{t};\ t = \frac{1}{2\cdot\nu}, \qquad (16)$$

where $v_{m.in}$ – initial speed of the portion of processed material in the moment t = 0:

$$v_{m.in} = 0. \qquad (17)$$

Then by formulas (16, 17)

$$v_{m.fin} = \ddot{x}_s t = \frac{\ddot{x}_s}{2\cdot\nu};\ t = \frac{1}{2\cdot\nu}. \qquad (18)$$

The speed $v_{m.fin}$ (l_s) of the particles of the portion of processed material in the initial moment $t = \frac{1}{2\cdot\nu}$ at the distance $l_{s.m}$ from the extreme right point of the working surface of the sieve (see fig. 5, c) is

$$v_{m.fin}(l_{s.m}) = \frac{l_{s.m}}{l_s}v_{m.fin};\ 0 \le l_{s.m} \le l_s. \qquad (19)$$

The acceleration $\ddot{x}_s$ in the moment $t = \frac{1}{2\cdot\nu}$ can be determined from the equation of movement of the portion of processed material

$$\frac{1}{2}(m_s+m_m)\ddot{x}_s = F_e - \frac{1}{2}(m_s+m_m)g + 2\cdot c_s x_{s0};$$
$$t = \frac{1}{2\cdot\nu}. \qquad (20)$$

Then the acceleration $\ddot{x}_s$ is

$$\ddot{x}_s = \frac{F_e - \frac{1}{2}(m_s+m_m)g + 2\cdot c_s x_{s0}}{\frac{1}{2}(m_s+m_m)};\ t = \frac{1}{2\cdot\nu}. \qquad (21)$$

Putting $\ddot{x}_s$, calculated by formula (20) in the formulas (18, 19), we can determine $v_{m.fin}(l_{s.m})$.

The components of the speed $v_{m.fin}(l_{s.m})$ can find by formulas [9]

$$v_{mx.fin}(l_{s.m}) = v_{m.fin}(l_{s.m})cos(90° - α) =$$
$$= v_{m.fin}(l_{s.m})sinα;\ 0 \le l_{s.m} \le l_s; \qquad (22)$$
$$v_{my.fin}(l_{s.m}) = v_{m.fin}(l_{s.m})sin(90° - α) =$$
$$= v_{m.fin}(l_{s.m})cosα;\ 0 \le l_{s.m} \le l_s. \qquad (23)$$

Equations of free movement of the particles of the portion of processed material relatively x- and y-axis at the I stage of the cycle have an appearance [9]:

$$x = v_{mx.fin}(l_{s.m})\cdot t;\ 0 \le l_{s.m} \le l_s;\ 0 \le t \le \frac{1}{4\cdot\nu}; \quad (24)$$

$$y = v_{my.fin}(l_{s.m})\cdot t - \frac{g\cdot t^2}{2};$$
$$0 \le l_{s.m} \le l_s;\ 0 \le t \le \frac{1}{4\cdot\nu}. \qquad (25)$$

On basis of the scheme on the fig. 5, *d* a differential equation of the portion of processed material at the II stage of the cycle has an appearance:

$$-J_m\ddot{\varphi}_c = F_{m.fin};\frac{1}{2\cdot\nu} < t \le \frac{1}{\nu}. \qquad (26)$$

There is a scheme of a vibroshaker with swinging movement of the sieve presented at the fig. 6. The sieve 1 is installed on a foundation 5 with help of four springs 2. The foundation is based on vibroinsulators 6. The sieve 1 is brought in movement from four electromagnetic vibro-exciters 8, 10, 11, 12, that are fixed at holders 3, so as a bunker 12 with processed material.

Under switching on of a winding of vibro-exciters 8, 12 their armatures are gravitated to the limbs and through livers 9 provide a turn of the sieve to the right with pressing of springs 7. In the

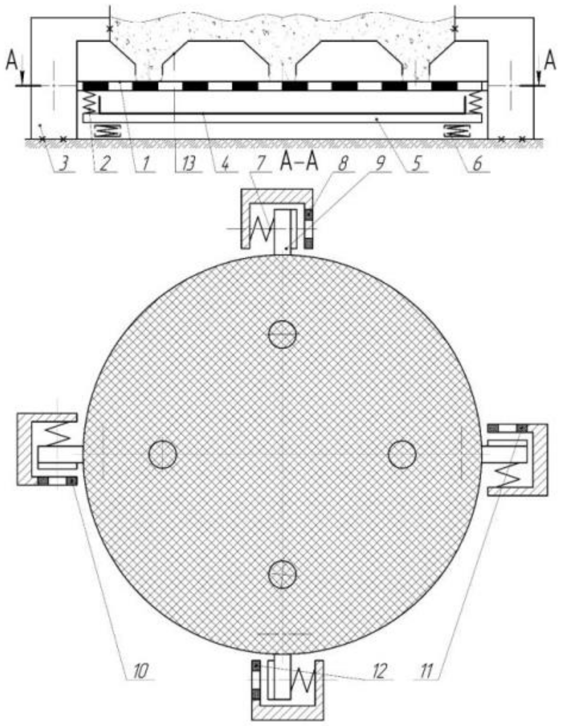

Figure. 6 – Scheme of an improved vibroshaker with an electromagnetic drive of swinging motion of the sieve for classification of dry materials: 1 – sieve; 2, 7 – springs; 3 – holder; 4 – containers for classified material; 5 – foundation; 6 – vibroinsulator; 8, 10, 11, 12 – electromagnetic vibro-exciters; 9 – lever; 13 – bunker with initial material

end of this turn the winding of the vibro-exciters 8, 12 is switched off and the winding of the vibro-exciters 10, 11 is switched on. As a result, the sieve under the impact of the vibro-exciters 10, 11 and the compressed springs of the vibro-exciters 8, 12 turns left in the initial position with the compression of the springs of the vibro-exciters 10, 11. After that, the working cycle of the sieve's movements repeat itself. So, the sieve fulfils swinging motions around own vertical axis. Processed material under influence of own gravitation spills out through the four sockets of the bunker 13 on the upper surface of the sieve. As a result of vibrations fine particles of materials go through the sieve in a container 4 and large particles remain on the sieve surface.

This vibroshaker also has relatively simple and reliable construction. Unified electromagnetic vibro-exciters, using in the sieve's drive, provide wide range change of amplitude and frequency of vibration of executive element, with their accurate and separate regulation. Besides, the proposed machine creates a complex spatial regime of vibro-loading of processed material, that has proved its high efficiency in different technological processes [10, 11].

The sieve's working cycle can divide at two stages: the I stage – a turn of the sieve from an initial position to the right; the II stage – a turn of the sieve in the initial position to the left.

There are schemes of loading of the sieve (a) and of the portion of processed material on the surface of the sieve (b) at the I stage and at the II stage of the sieve's working cycle (fig. 7).

There are parameters designated on the schemes (fig. 7):

J_s, J_m – moments of inertia of the sieve 1 (see also fig. 6) and of the portion of processed material on the sieve surface;

φ_s, φ_m – turn angles of the sieve 1 and of the portion of processed material;

F_e – nominal driving force, creating by a pair of the vibro-exciters of the vibroshaker;

$F_{m.fin}$ – driving force, creating by the sieve at the portion of processed material, in the final moment of the I stage $t = \frac{1}{2 \cdot \nu}$ and in the final moment of the II stage $t = \frac{1}{\nu}$. The portion of the processed

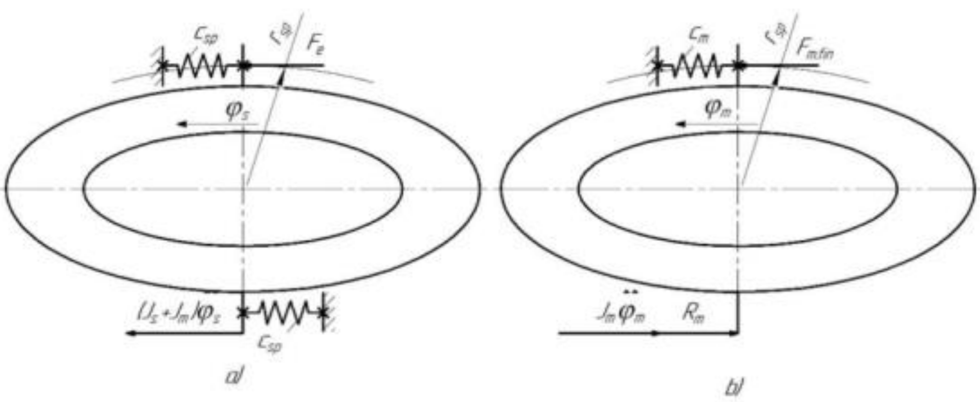

Figure. 7 – Schemes of loading of the sieve (a) and of the portion of processed material on the surface of the sieve (b) at the I stage and at the II stage of the sieve's working cycle

material turns in these moments under impact of the force $F_{m.fin}$ and by own inertia relatively the sieve in a direction, opposite to the sieve next turn;

R_m – force of dry friction of particles of processed material upon the sieve's surface and between of layers of other particles of material [1, 10, 11];

c_m – coefficient of hardness of particles of processed material [1, 10, 11];

c_{sp} – coefficient of hardness of the spring 7 (we may not consider hardness of the springs 2);

r_{sp} – radius of a circle of fastening of the springs 7.

On basis of the schemes on the fig. 7 differential equations of movements of the sieve and of the portion of processed material on its surface at the I and at the II stages of the cycle have an appearance:

$$-(J_s + J_m)\ddot{\varphi}_s = r_{sp}\left[F_e - 2 \cdot c_{sp}\left(x_{sp0} + \varphi_s r_{sp}\right)\right];$$
$$0 \le t \le \frac{1}{2\cdot\nu}; \qquad \frac{1}{2\cdot\nu} < t \le \frac{1}{\nu}; \qquad (27)$$

$$-J_m\ddot{\varphi}_m = \left(F_{m.fin} - c_m\varphi_m r_{s.h} - R_m\right)r_{s.h};$$
$$t = \frac{1}{2\cdot\nu};. \qquad (28)$$

$$-J_m\ddot{\varphi}_m = \left(-c_m\varphi_m r_{s.h} - R_m\right)r_{s.h};$$
$$0 \le t < \frac{1}{2\cdot\nu}; \frac{1}{2\cdot\nu} < t \le \frac{1}{\nu}; \qquad (29)$$

where x_{sp0} – preliminary compression of the springs 7.

Driving force $F_{m.fin}$ for equation (27) can be found with help of the formula, received from the equation (26)

$$F_{m.fin} = r_{sp}\left[F_e - 2 \cdot c_{sp}\left(x_{sp0} + \varphi_s r_{sp}\right)\right] +$$
$$+(J_s + J_m)\ddot{\varphi_s}; t = \frac{1}{2\cdot\nu}. \qquad (30)$$

Conclusions. 1. Known equipment for classification of damp and dry dispersive materials demands of improvement in a direction of widening of its technological possibilities (realization of various schemes and regimes of loading of processed material with accurate and independent regulation of parameters of loading), increase of efficiency (minimization of expenses of energy for fulfilment of classification, raise of productivity), increase of reliability of the equipment.

2. Authors propose schemes of improved vibroshakers with an electromagnetic drive of vertical reciprocal, wobbling or swinging movements of executive elements. In the drive of the vibroshakers are used efficient, powerful, compact and reliable electromagnetic vibro-exciters, which have standard characteristics and provide wide range accurate and separate change of frequency, amplitude and intensity of loading of processed material. The proposed equipment has simple and reliable design, high versatility for utilization in different branches and technological processes of classification of various materials with effective use of consumed energy.

3. The schemes of loading of executive elements of the elaborated equipment, schemes of loading of processed material in course of its classification in the vibroshakers for different stages of their working cycle, are also proposed in the article. On basis of these schemes were elaborated differential equation of movement of executive elements of the vibroshakers and processed material that connect main constructive and working parameters of the proposed equipment and can be used for creation of its methods of design calculation.

References

1. Sevostianov, I. (2020) *Technology and equipment for vibro-blowing dehydration of damp dispersive materials. Monograph*. Vinnytsia: VNAU [in Ukrainian].

2. Cherevko, O. I., Poperechny, A. M. (2019) *Procesy i aparaty harchovyh vyrobnycztv [Processes and apparatuses of food productions]* Harkiv.: Svit Knyg [in Ukrainian].

3. Martseniuk, O. S. (2021) Protsesy i aparaty kharchovykh vyrobnytstv Osnovni poniattia i zakony *[Processes and apparatuses of food productions. Main lows and conceptions]*. Kyiv : NUKhT, [in Ukrainian].

4. Kaletnik, H., Sevostianov, I., Bulgakov, V., Holovach, I., Melnik, V., Ihnatiev, Ye., Olt, J. (2020) *Development and examination of high-performance fluidisedbed vibration drier for processing food production waste. Agronomy Research.* 18(4), P. 2391 – 2409.

5. Bulgakov V., Sevostianov I., Kaletnik G., Babyn I., Ivanovs S., Holovach I., Ihnatiev Y. (2020) *Theoretical Studies of the Vibration Process of the Dryer for Waste of Food*. *Rural sustainability research* 44 (339).

6. Sevostianov I., Tokarchuk O., Pidlypna M. (2021) Automated technological projection of classification processes of dry dispersive materials. *Tekhnika, enerhetyka, transport APK*,. 2 (113). 15-21.

7. Sevostianov I.V., Melnyk O.S., Pidlypna M.P. (2021) Doslidzhennia parametriv efektyvnosti protsesiv klasyfikatsii sukhoi zernovoi syrovyny pry vykorystanni riznykh skhem yii navantazhennia [Study of parameters of effectiveness of processes of classification of dry grain raw materials under using of different schemes of loading]. *Vibratsii v tekhnitsi ta tekhnolohiiakh*,. 3(102). 109-117. [in Ukrainian].

8. Sevostianov I.V., Ivanchuk Ya.V., Pidlypna M.P. (2021) Rozrobka variantiv tekhnolohichnykh skhem pererobky osnovnykh vydiv zernovoi

syrovyny [Development of variants of technological schemes for the processing of the main types of grain raw materials]. *Tekhnika, enerhetyka, transport APK*. 4 (115). 128-135. [in Ukrainian].

9. Sevostyanov I., Ivanchuk Y. (2022) Modelling of working process of equipment with hydraulic drive for separation of damp dispersive materials. *Tekhnika, enerhetyka, transport APK*. 1 (116). 77-82.

10. Sevostyanov I., Ivanchuk Y. (2022) Elaboration and researches of a vibro-press for dehydration of damp dispersive materials. *Vibratsii v tekhnitsi ta tekhnolohiiakh*. 1(104). 5-11.

11. Sevostyanov I., Melnyk O. (2022) Elaboration and researches of apparatus of control for hydroponic installations. *Vibratsii v tekhnitsi ta tekhnolohiiakh*. 1(104). 57-62.

РОЗРОБКА ТА ДОСЛІДЖЕННЯ ВІБРОГРОХОТІВ З ЕЛЕКТРОМАГНІТНИМ ПРИВОДОМ ДЛЯ КЛАСИФІКАЦІЇ СУХИХ МАТЕРІАЛІВ

У цій статті розглянуто схеми різних віброгрохотів для класифікації сухих матеріалів на будівництві, у сільському господарстві, у харчовій та переробній промисловості, у гірничодобувній промисловості та на транспорті. У результаті проведеного аналізу автори дійшли висновку про низьку ефективність і надійність відомих віброгрохотів. У процесі їх функціонування значна частина споживаної енергії витрачається на приведення в рух масивних рушійних елементів. Фактично кожен з цих віброгрохотів реалізує лише одну схему навантаження з відносно вузьким діапазоном зміни його основних параметрів (амплітуди, частоти, енергії, що передається). Крім того, інтенсивні динамічні навантаження негативно впливають на опорні елементи цих машин, що призводить до їх швидкого зносу. З огляду на ці недоліки відомих віброгрохотів, авторами розроблено схеми вдосконалених віброгрохотів з електромагнітним приводом для класифікації сухих матеріалів. Запропоновані віброгрохоти забезпечують комплексні схеми завантаження оброблюваного матеріалу, що сприяє підвищенню ефективності робочого процесу. В одній із цих схем передбачені можливості зміни розташування електромагнітних вібрoзбуджувачів відносно фундаменту. Останнє дозволяє змінювати схему завантаження оброблюваного матеріалу в залежності від його фізико-механічних характеристик. Електромагнітний привід удосконалених віброгрохотів дає можливість роздільного і точного регулювання основних параметрів завантаження матеріалу в широкому діапазоні. Конструкції віброгрохотів не містять елементів тертя і масивних інерційних мас, тому мають підвищену надійність і ефективність. У статті запропоновано диференціальні рівняння рухів виконавчих елементів віброгрохотів, які дозволяють визначити їх основні робочі параметри на різних етапах робочого циклу. Ці рівняння можуть бути використані для побудови методики конструктивного розрахунку запропонованих віброгрохотів.

***Ключові слова**: віброгрохот, електромагнітний привід, класифікація, сухий матеріал, схеми завантаження, математична модель.*

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