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CONTENT

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IMPROVEMENT OF THE SUNFLOWER SEED SEPARATION PROCESS EFFICIENCY ON THE VIBRATING SURFACE

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The study of the sunflower seed separation process during its movement on the vibrating surface has been carried out in two stages. The first (theoretical) stage has been implemented in the software package STAR-CCM + using the corresponding physical models. The second stage is the conduct of experimental research on a pilot sample with a base of vibrating pneumatic PVS table. As a result of numerical simulation and experimental studies of the sunflower seed separation process during its movement on the vibrating surface, we have determined the dependences of the change in the distribution coefficient, productivity and power consumed by the vibrating pneumatic separator from the seed supply, the inclination angles of the vibrating surface, the frequency and amplitude of its oscillation and the velocity of the airflow V. The statistical analysis has shown that the correlation coefficient between the theoretical and experimental dependencies in the variation of the values of the factors in the given range is 0.88-0.92. The technological and constructive scheme of the adaptive vibrating pneumatic separator with rationally defined regime parameters (seed supply, airflow velocity, deck oscillation frequency, deck inclination angle) has been developed basing of the obtained theoretical and experimental dependencies, using the software which is based on the created algorithm, allowing to perform the technological process of sunflower seed mixtures separating by volume density with higher productivity and quality.

Keywords: seed, sunflower, purification, vibration, separator

INTRODUCTION

The task of the revision of the seed material of the sunflower hybrids parent components and seed of primary seed elements requires the use of the most advanced technical approaches. For obtaining homogeneous parent components genetic seed material we need to take into account all signs in complex, including signs of achene. Sunflower seeds have a large variety in size, shape, weight and color (Kirichenko, 2005; Vedmedeva, Soroka, 2015). For the confectionery used sunflower, the achene volume weight is a quantitative indication, which affects the plant productivity.

One of the methods for separating seed material by density or volume weight is its separation in a fluidized layer. The separation in fluidized layer can be done in different ways: vibrating (only the supporting surface's vibration effects on the seed layer); pneumatic (pulsating or constant air flow effects on seed layer); vibrating pneumatic (supporting surface's vibration and pulsating air flow effect on seed layer simultaneously); pneumatic and centrifugal (field of centrifugal forces and air flow effects the seed layer) (Zaika, 2006; Tishchenko et al., 2010). The most effective way of separating sunflower seed material is vibrating pneumatic. It is implemented in vibrating pneumatic separators and pneumatic sorting tables. In this case, the general scheme of division is carried out as follows: the mixture enters the perforated vibration surface (deck), which is blown by air flow. It results into grouping and layering (segregation) of the mixture in the layers of

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particles with similar physical characteristics. After the layering, the mixture is separated by various means. By choosing the frequency of oscillation and the angle of the deck, the particles are arranged to be located at different levels and have different densities in different places (Tishchenko, 2004; Saitov, 2012, Kharchenko, 2017). Due to the high heterogeneity of the seed material, we need to adjust the setup of the vibration and pneumatic separators constantly, this causes reduction of machines' productivity, decline of the seed material separation quality and increases the complexity of the process implementation.

Therefore, the purpose of the research is to improve the efficiency of the mechanical and technological process of the sunflower seed material precision separation by volume using the vibrating surface by substantiating its rational regime parameters.

EXPERIMENTAL

Numerical simulation method

Study process of sunflower seeds separation during its movement on a vibrating surface has been carried out in two stages.

The first (numerical simulation) stage is implemented in the software package STAR-CCM+ using the corresponding physical models: k-ε model of separated flow turbulence, gravity field, Van der Waals real gas model, model of discrete elements, model of multiphase interaction (Aliev et al., 2018). Accepted on the assumption that the seeds are represented as ellipsoids with the same defined density and effective diameter. Physical and mechanical properties of seeds have been adopted for implementation of simulation (Aliev, Yaropud, 2017): Poisson's coefficient is 0.5; Jung's module – 0.2 MPa; density – 200-1000 kg/m^3; coefficient of resting friction – 0.8; normal recovery factor – 0.5; tangential recovery factor – 0.5; coefficient of rolling resistance – 0.3. Properties of the environment are as follows: environment – air; dynamic viscosity – 1.85508 · 10^{-5} Pa·s; Prandtl turbulent number is 0.9; acceleration of free fall – 9.8 m/s^2; temperature – 293 K; pressure – 101325 Pa. The size of the grid cell modeling is 0.001 m.

For the implementation of numerical simulation, we have complied the calculated scheme of the oilseed material movement process on a vibrating surface (Figure 1).

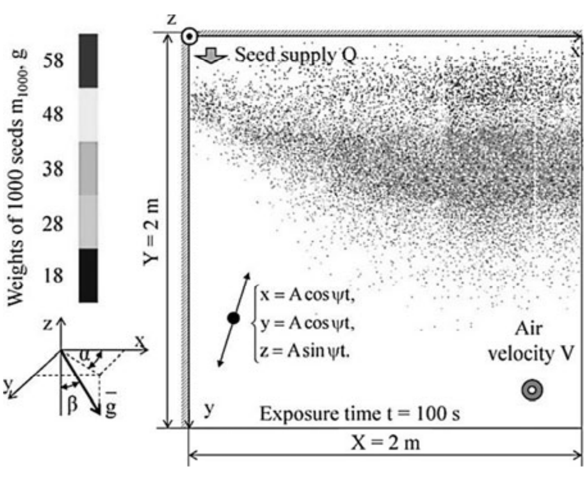

Figure 1. Scheme of the oilseed material movement process on a vibrating surface

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The vibrating surface has a square shape with a side of 2 m. The surface performs periodic motion in three coordinates according to the law:

$$x = A\cos\psi t, \quad y = A\cos\psi t, \quad z = A\sin\psi t, \qquad [1]$$

where A – amplitude of oscillations, m; ψ – frequency of oscillations, s^{-1}.

The angles of the separator inclination α and β are determined by changing the angles of the acceleration of free fall $\overline{g}$, which is absolutely identical. The mass flow of seeds is represented by 5 fractions of seeds of the same number with different weights of 1000 seeds m_{1000} in the range 18-58 g with 10 g step.

The following technological parameters have been adopted for numerical modeling factors: seeding Q, sieve angle α and β, sieve oscillation frequency ψ, amplitude of oscillations of Sieve A and air flow velocity V (range of variation are presented in Table 1).

Table 1. Levels of variations of the factors of numerical simulation of the process of moving the seeds of oilseed crops under the action of the vibratory surface

Levels of factors variations	Factors					
	Seed supply Q, kg/h	Angle of inclination α, °	Angle of inclination β, °	Fluctuation frequency ψ, s^{-1}	Amplitude of oscillations A, m	Air velocity V, m/s
Lower level	1000	1	1	5	0.005	3
Basic level	1400	3	3	7.5	0.01	3.5
Upper level	1800	5	5	10	0.015	4
Interval of variations	400	2	2	2.5	0.005	0.5

A complete numerical factor experiment for 6 factors and 3 levels of variation contains $3^6 = 729$ experiments, which is limited by the power of the personal computer and time for data processing. Therefore, it has been decided to carry out numerical simulations using the non-composite Box-Behnken plan for 6 factors. The exposure time is 100 seconds.

The productivity at the output q has been taken as the quantitative criterion of the sunflower seed separation on the vibrating plate process. In order to evaluate the quality of the separation process, the criterion of the quality of fraction distribution in the receptacles has been introduced – the distribution coefficient δ, which is defined as follows. If the input material is divided into N fractions, then the number of grab areas must be N. For each grab area, the fractional composition of the seed mixture is determined, which can be mathematically represented in the form of a square matrix N × N (Aliev et al., 2018):

$$\begin{pmatrix} w_{11} & w_{12} & \cdots & w_{1N} \\ w_{21} & w_{22} & \cdots & w_{2N} \\ \cdots & \cdots & \cdots & \cdots \\ w_{N1} & w_{N2} & \cdots & w_{NN} \end{pmatrix} \qquad [2]$$

where w_{ij} is the mass part of fraction i in the collection j:

$$w_{ij} = \frac{m_{ij}}{\sum_{i=1}^{N}\sum_{j=1}^{N} m_{ij}} \cdot 100\% \qquad [3]$$

m_{ij} is the mass of fraction i in the collection j.

The coefficient of distribution δ is defined as the largest sum of the diagonal elements of the matrix (2):

$$\delta = \max\left(\sum_{k=1}^{N} w_{kk}, \sum_{k=1}^{N} w_{k(k+1)}, \ldots, \sum_{k=1}^{N} w_{k(k+N-1)}, \sum_{k=1}^{N} w_{(k+1)k}, \ldots, \sum_{k=1}^{N} w_{(k+N-1)k}\right); \qquad [4]$$

where k is a natural number.

Experimental research method

The second stage was the conduct of experimental studies on the stand (figure 2), consisting of a bunker 1 for loading seed material for separation, a vibrating pneumatic table PVS 2, fraction collections 3 (I-III). The seed supply has been changing with the calibrated valve 4 on the bunker 1. The angles of inclination of the vibrating pneumatic table deck 2 are set with the adjusting of corresponding levers 5 and controlled by the Digital inclinometer. The frequency of oscillations of the vibrating pneumatic table separator 2 is directly proportional to the frequency of the rotation of the shaft of the asynchronous motor 6 and can be changed with the control unit based on the frequency converter Danfoss VLT Micro Drive 7. The air flow generator is a fan 8 driven by an asynchronous electric motor 9. The flow rate of the air coming through the vibrating pneumatic table deck 2 has been detected with the damper 10, and controlled using the anemometer 11 (Benetech GM-816). Electric power supply to asynchronous electric motors 6 and 9 has been provided through electric wires through the electricity meter 12.

The source material during the experimental research is seeds of confectionery sunflower “Smak”, selection of the Institute of Oilseed Crops of NAAS, which is calibrated to the fraction 3.2-3.4 mm and contains plant additives, the mass fraction of which is 12.3 %. Humidity – 8,2±0,6 %, bulk mass – 263±17 kg/m^3, mass of 1000 seed – 88±5 g, purity – 98,9±0,5 %. One experiment has been conducted by passing a 100 kg seed material sample through a pilot sample.

The factors for experimental research are the seed supply Q, the deck inclination angles α and β, the frequency of oscillations ψ, the air velocity V. According to the results of numerical simulation, it has been found that the oscillation amplitude of the deck A does not significantly affect the performance q (factor effect – 7.4 %). However, the filling factor θ and the distribution coefficient δ have an optimum for the oscillation amplitude of the deck A = 0.013 m, which is accepted as a condition for conducting experimental studies. The intervals and levels of variation by these factors are the same as for numerical simulations.

The following optimization criterias have been set: productivity – q, power consumption – P and distribution coefficient – δ.

The productivity of the vibrating pneumatic table q has been determined by measuring the mass of the seed M passing through it and the corresponding time τ. The calculation has been made by the formula:

$$q = M/\tau \qquad [5]$$

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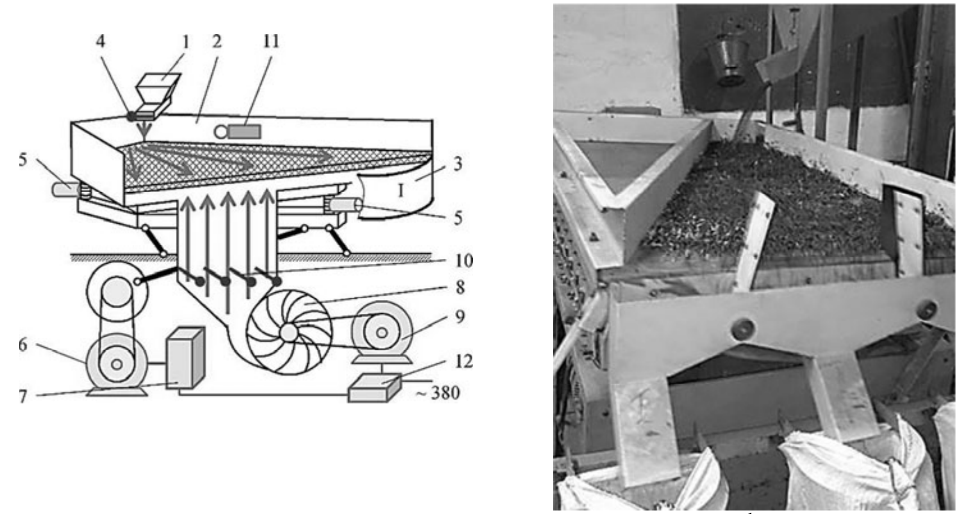
The power consumed by the installation has been measured using an authorized electric meter and calculated using the formula:

$$P = \Delta E / \tau \quad [6]$$

where ΔE – meter readings, W·h; τ – time of experiment, h.



a b

1 – bunker; 2 – vibrating pneumatic table; 3 – fraction collections; 4 – calibrated valve; 5 – levers for adjusting the angle of the deck; 6 – asynchronous electric motor; 7 – Danfoss VLT Micro Drive frequency converter; 8 – fan; 9 – asynchronous electric motor; 10 – damper; 11 – anemometer Benetech GM-816; 12 – electricity meter

Figure 2. Structural and technological scheme (a) and general view (b) of a pilot sample for studying the process of sunflower seeds separation by volume density

Since the task of separating sunflower seeds during movement on a vibrating surface is a division of it into 3 fractions (the bare core, fully executed, incompletely executed and empty), experimental installation has 3 fringe areas. For each experiment, for each fringe area, fractional composition is determined according to the generally accepted methodology (GOST 10854-88, 2010) and the corresponding distribution coefficient δ is calculated according to the formula [2-4] (Aliev et al., 2018).

Experimental studies have been conducted on the D-optimal Second-Order Boxing Box for 5 factors (45 trials) in triple repetition. The processing of the studies results has been carried out by the method of mathematical factor planning of experiments using the Mathematica software program. The mathematical model is determined by each optimization criterion.

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RESULTS AND DISCUSSION

Numerical simulation

According to the first stage, the data array has been defined as a result of numerical simulation, processed via Mathematica software package. This allows us to compile a mathematical expression that linked the productivity of q with the research factors in the form:

$$q = -3448.66 + 482.402\,\alpha - 51.0518\,\alpha^2 + 138739\,A - 8373.72\,\alpha A - 3.54768\cdot 106\,A^2 - \\ - 18.1987\,\beta + 3746.37\,A\beta - 0.00755229\,Q + 0.094723\,\alpha Q + 15.8784\,AQ + 509.047\,V - \\ - 28.0576\,\alpha V + 385.786\,\psi - 8697.01\,A\psi + 0.0276348\,Q\psi - 48.721\,V\psi - 9.15336\,\psi^2 \quad [7]$$

According to the data, obtained using Mathematica software package, a mathematical expression has linked the coefficient of distribution δ to the factors of research in the encoded form:

$$\delta = -38.1368 - 6.35462\,\alpha - 4184.99\,A + 20.0425\,\beta - 0.222365\,\alpha\beta - 0.668868\,\beta^2 - \\ - 0.0329178\,Q + 0.434932\,AQ + 0.00114068\,\beta Q + 0.000012024\,Q^2 + 107.519\,V - \\ - 4.26185\,b V - 13.6016\,V^2 - 25.6235\,\psi + 0.700329\,\alpha\psi + 376.926\,A\psi - 0.188064\,\beta\psi - \\ - 0.00080786\,Q\psi + 0.841809\,V\psi + 0.969268\,\psi^2 \quad [8]$$

Experimental research

This resulted into a model of each stage in the Mathematical model of factors productivity influence of the vibrating pneumatic table q, which looks like this:

$$q = -1901.46 + 159.113\,\alpha - 60.3788\,\alpha^2 + 136.126\,\beta - 12.7299\,\beta^2 + 0.461994\,Q + \\ + 0.136598\,\alpha Q + 0.04875\,\beta Q - 0.000329705\,Q^2 - 208.153\,V + 42.6091\,\alpha V + \\ + 0.185833\,QV + 74.1\,V^2 + 370.192\,\psi - 7.06667\,\alpha\psi - 13.7667\,\beta\psi - 51.6543\,V\psi - \\ - 9.56714\,\psi^2 \quad [9]$$

Analyzing equations [7] and [9], it can be stated that the productivity of the vibrating pneumatic table q is influenced by all factors of research. At the same time, with increasing of the seed supply Q and the deck inclination angle α, the productivity q increases as parabola; the velocity of the air flow V and the deck inclination angle β are directly proportional to the productivity q; with the increase of the oscillation frequency ψ, the productivity q decreases as parabola.

The productivity of the vibrating pneumatic table q by equation [5] is maximal at the following optimal values of the factors of research:

$$q = Q = 1800 \text{ kg/h},\ \alpha = 4.5\,°,\ \beta = 5\,°,\ \psi = 5 \text{ Hz},\ V = 4 \text{ m/s}. \quad [10]$$

Graphical interpretation of the obtained theoretical [7] and experimental [9] dependencies at A = 0.013 m are shown in Figure 3. The statistical analysis showed that the correlation coefficient between the theoretical [7] and experimental [9] dependencies in the variation of the values of the factors in the given range is 0.88.

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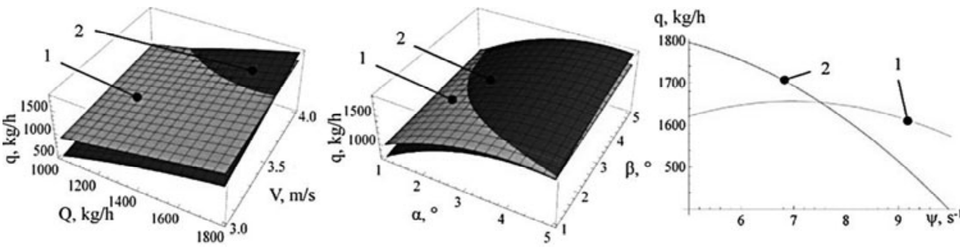


1 – theoretical dependence [7]; 2 – experimental dependence [9]

Figure 3. The dependence of the vibrating pneumatic table productivity q on the seed supply Q, the air flow velocity V, the frequency of the deck oscillations ψ and the deck inclination angles α and β at optimal values [10]

The criterion for the quality of separation is coefficient of distribution δ, which is determined from the mass part of fraction [2-4]. There has been defined the mathematical model of the influence of the investigated factors on the coefficient of distribution δ:

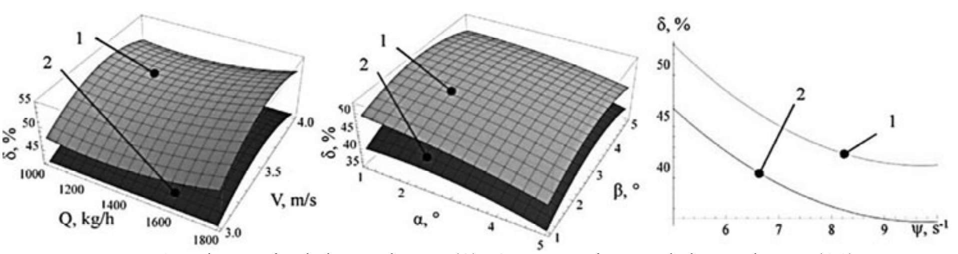
$$\delta = -147.163 - 4.8605\,\alpha - 0.460969\,\alpha^2 + 28.1812\,\beta - 1.04909\,\beta^2 + 105.827\,V + 1.82315\,\alpha V - 5.3159\,\beta V - 13.3333\,V^2 - 10.1229\,\psi - 0.472683\,\beta\psi + 0.6\,V\psi + 0.493084\,\psi^2 \quad [11]$$

Analyzing equations [8] and [11], it can be stated that the distribution coefficient δ does not significantly affect the seed supply Q. In this case, for the airflow velocity V and the deck inclination angles α and β there is an optimum in which the coefficient of distribution δ assumes the maximum value; and with increasing the frequency of the deck oscillations ψ, the distribution factor δ decreases as parabola.

The coefficient of distribution δ is maximal with the following optimal values of the research factors:

$$\delta = 45.7\%,\ \alpha = 1.7\ °,\ \beta = 3.4\ °,\ \psi = 5\ \text{Hz},\ V = 3.5\ \text{m/s}. \quad [12]$$

Graphical interpretation of the received theoretical [8] and experimental [11] dependences at A = 0.013 m are shown in Figure 4. Statistical analysis as shown that the correlation coefficient between the theoretical [8] and experimental [11] dependencies in the variation of the values of the factors in the given range is 0.92.



1 – theoretical dependence (8); 2 – experimental dependence (11)

Figure 4. The dependence of the distribution coefficient δ on the seed supply Q, the airflow velocity V, the deck oscillation frequency ψ of the deck inclination angles α and β at optimal values [12]

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The mathematical model of the influence of the investigated factors on the power P, consumed by the experimental installation, has the form:

$$P = 1.19276 - 0.300625\,\alpha - 0.00630208\,\alpha^2 - 0.0780208\,\beta - 0.011093\,\beta^2 + 0.0007892\,Q + 0.00006041\,\beta Q - 3.3463\cdot10^{-7}\,Q^2 - 0.0525\,V + 0.06\,\alpha V + 0.000195833\,Q V + 0.0936667\,\psi - 0.0101667\,\beta\psi \quad [13]$$

The power P is minimal with the following optimal values of the research factors:

$$P = 1.16 \text{ kW},\ Q = 1000 \text{ kg/h},\ \alpha = 5\ °,\ \beta = 5\ °,\ \psi = 5 \text{ Hz},\ V = 3 \text{ m/s} \quad [14]$$

The graphic interpretation of the obtained dependence (13) is presented in Figure 5. Analysis of Fig. 5 allows us to determine that the seed supply Q, the air flow velocity V and the deck oscillation frequency ψ directly proportionally affect the power P, consumed by the experimental installation. However, with increasing the deck inclination angles α and β decreases the power P.

Provided that the seed separation process is effective, during the vibrating surface movement, it is necessary to keep its productivity q maximal and equal to the seed supply value q = Q, with the distribution coefficient δ being the largest, and the power P consumed by the pneumatic breaker – the smallest, that is:

$$\begin{cases} \delta(Q,\alpha,\beta,\psi,V) \to \max, \\ P(Q,\alpha,\beta,\psi,V) \to \min, \\ q(Q,\alpha,\beta,\psi,V) = q. \end{cases} \quad [15]$$

Solving the problem [15] using Mathematica software package has led to optimal technological regimes of separation of sunflower seeds during its movement on a vibrating surface:

$$q = Q = 1029 \text{ kg/h},\ \alpha = 3.8\ °,\ \beta = 4.0\ °,\ \psi = 5 \text{ Hz},\ V = 4 \text{ m/s},\ \delta = 40.4\ \%,\ P = 1.94 \text{ kW}. \quad [16]$$

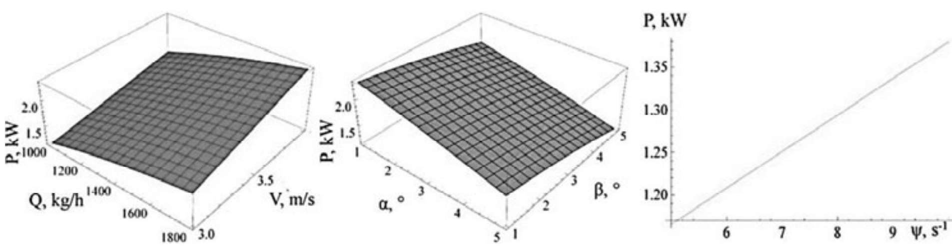

Figure 5. The dependence of the power P consumed by the experimental installation, on the seed supply Q, air flow velocity V, deck oscillations frequency ψ of deck inclination angles α and β at optimal values [14]

The adaptive vibrating pneumatic separator

Observation of the vibrating pneumatic table PVA and analysis of the results prove the hypothesis that for the high efficiency of the process of separation heterogeneous

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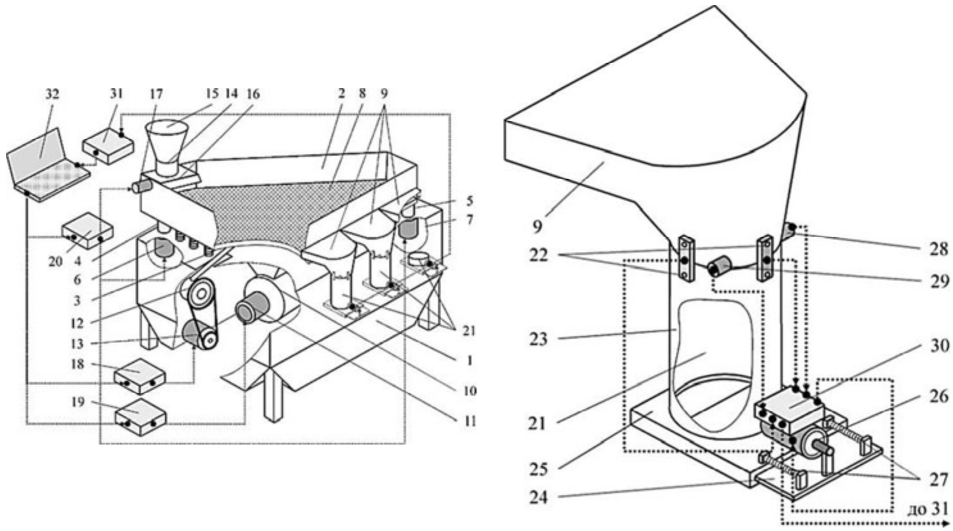
mixture of sunflower seed by volume weight it is necessary to readjust regime parameters constantly. This leads to a decrease in machine performance, a deterioration in the quality of material separation into fractions and an increase in the process execution complexity. To solve this problem the constructive and technological scheme of the adaptive vibrating pneumatic separator has been developed (Figure 6) with efficiently coordinated operational parameters (seed supply Q, airflow velocity V, the deck oscillation frequency ψ, deck inclination angles α and β) by using software based on the generated algorithm (Figure 7) and the established dependencies [9], [11], [13], [15].



1 – frame; 2 – deck; 3 – springs; 4, 5 – adjusting screws; 6, 7 – stepper electric motors; 8 – air penetrating working surface; 9 – unloading windows; 10 – fan; 11 – electric motor; 12 – crank mechanism; 13 – electric motor; 14 – seed supply unit; 15 – neck; 16 – valve; 17 – stepper electric motor; 18, 19 – electric motors control blocks; 20 – stepper motor control unit; 21 – volume measurement unit; 22 – stretching strain gauges; 23 – empty cylinder; 24 – damper; 25 – bracket; 26 – pushing electromagnet (solenoid); 27 – stretch springs; 28 – infrared diode; 29 – infrared photodetector; 30 – measurement control unit; 31 – general measuring block; 32 – a personal computer on which the appropriate software is installed

Figure 6. A general view of an adaptive vibrating pneumatic separator

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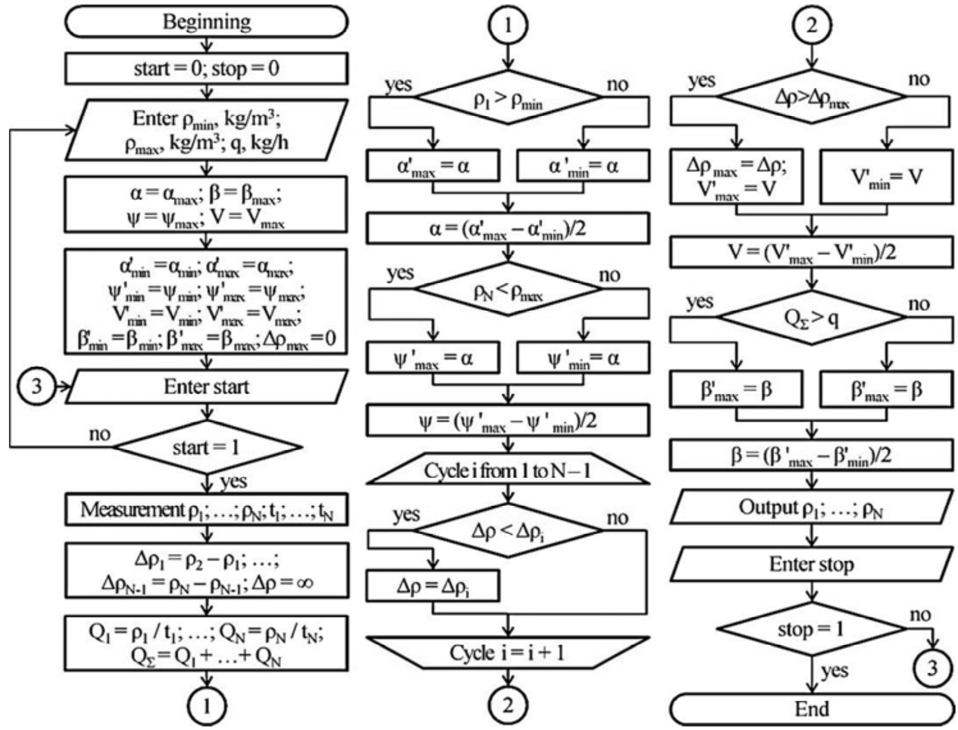

Figure 7. Software Algorithm

CONCLUSIONS

As a result of numerical simulation of the process sunflower seed material movement on the vibrating surface, we have obtained the dependencies of the change in the distribution coefficient δ and the productivity q from the seed supply Q, the deck inclination angles α and β, the oscillation frequency ψ, the oscillations amplitude A and the airflow velocity V.

As a result of experimental studies of the sunflower seed material separation by volume on the vibrating surface, we have obtained the dependencies of the change in the coefficient of distribution δ, of the productivity q and on the power P consumed by the vibrating pneumatic separator, on the seed supply Q, airflow velocity V, deck oscillations frequency ψ, deck inclination angles α and β. Provided that the seed separation process is effective, it is necessary for the productivity q to be maximal and equal to the seed supply value q = Q = 1029 kg/h, with the distribution coefficient δ = 40.4% to be the largest, and the power P = 1.94 kW, which is consumed by a pneumatic breaker – the smallest. The following values have been determined according to the aforementioned: α = 3.8, β = 4.0, ψ = 5 Hz, V = 4 m/s. Statistical analysis has shown that the correlation coefficient between the theoretical and experimental dependency by varying the values of the factors in a given range is 0.88-0.92.

Based on the theoretical and experimental dependencies, we have developed the structural and technological schemes of adaptive vibrating pneumatic separator with effi-

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ciently coordinated operational parameters (seed supply Q, airflow velocity V, the deck oscillation frequency ψ, deck inclination angles α and β) using software based on the created algorithm, which allows to perform the technological process of separation of sunflower seed mixtures in volume density with higher productivity and quality.

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