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DETERMINATION OF WAYS OF IMPROVING THE PROCESS OF SEPARATION OF SEED MATERIALS ON THE WORKING SURFACE OF THE PNEUMATIC SORTING TABLE

Vadym Bredykhin[a], Taras Shchur[b*], Liliia Kis-Korkishchenko[c], Serhii Denisenko[d], Serhii Ivashchenko[e], Andrzej Marczuk[f], Oleg Dzhidzhora[g], Maciej Kubon[h,i]

[a] State Biotechnological University, Department of Reliability and Durability of Machines and Structures Named After V.Ya. Anilovich, Kharkiv, Ukraine, e-mail: vadimbr76@ukr.net, ORCID 0000-0002-5956-5458

[b] Cyclone Manufacturing Inc, Mississauga, Ontario, Canada, L5N 5S1, e-mail: shchurtg@gmail.com, ORCID 0000-0003-0205-032X

[c] State Biotechnological University, Department of Equipment and Engineering of Processing and Food Industries. Kharkiv, Ukraine, e-mail: e-mail: kisliliia1990@gmail.com, ORCID 0000-0001-5380-8052

[d] State Biotechnological University, Department of Equipment and Engineering of Processing and Food Industries, Kharkiv, Ukraine, e-mail: denisenkosergey.a@gmail.com, ORCID 0000-0002-6638-9763

[e] State Biotechnological University, Department of Equipment and Engineering of Processing and Food Industries, Kharkiv, Ukraine, e-mail: ivashenko_oipxv@ukr.net, ORCID 0000-0001-8234-1682

[f] University of Life Sciences in Lublin, Head of Department of Transporting and Agricultural Machinery, 28 Głęboka Street 20-612 Lublin, Poland, e-mail: andrzej.marczuk@up.lublin.pl, ORCID 0000-0002-2107-2068

[g] Manufacturing Innovations, US Foundry, 8351 NW 93rd Street, Medley FL, 33166, USA, e-mail: oleg.dzhidzhora@groupnei.com, ORCID: 0009-0005-8712-8086

[h] Department of Production Engineering, Logistics and Applied Computer Science, University of Agriculture in Krakow, 30-149 Krakow, Poland; e-mail: maciej.kubon@urk.edu.pl, ORCID 0000-0003-4847-8743

[i] Faculty of Technical Sciences and Design Arts, National Academy of Applied Sciences in Przemyśl, Książąt Lubomirskich 6, 37-700 Przemyśl, m.kubon@pansp.pl; ORCID 0000-0003-4847-8743

** Corresponding author: e-mail: shchurtg@gmail.com*

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ABSTRACT

The object of the study is the process of separation of seed material according to the seed density on the working surface of the pneumatic sorting table. The main defining design variables and linkage parameters of the equipment are analyzed, which realizes the process of separation of seed materials, and is coordinated with physical and mechanical variables of raw materials. The principles of modeling of seed material layer movement as a multiphase medium are provided. Under the effect of working surface vibrations and the power of an airstream the layer take on the properties of pseudoliquid. The criteria of chosen variables are presented, on which depend quality and quantity indicators of the separation process of seed materials according to the seed density. Optimal values of the separator linkage parameters are analytically determined and dependence diagrams are built. Secant lines of surfaces for a concrete crop (raw material) are performed. The "purity" of heavy fraction during the variation of indicated parameters is studied. It is proved that there are differences in types of the dependences: different decreasing of functions and increasing of airstream velocity. It is obvious that this nature is determined by difference in density of original raw materials. This way the smallest influence a change in the airstream velocity causes to soybean raw material, as soybean has the biggest density. At the same time, the biggest affect is provoked on sunflower seeds, which have the smallest density among the used types of raw materials, as well as a triangle form.

It is determined that the maximal frequency of the basic fraction, gained by the separation of wheat seed material on PST, is obtained under the airstream velocity in the range 1.3-1.5 $m \cdot s^{-1}$. For corn the rational airstream velocity falls in the range 1.3-1.6 $m \cdot s^{-1}$, for sunflower – 1.2-1.4 $m \cdot s^{-1}$, for soybean – 1.2-1.4 $m \cdot s^{-1}$. These figures are valid under the condition of using the relevant rational decisions of frequency and amplitude of vibrations of pneumatic sorting table deck during the separation of grain mixtures, as well as longitudinal and transverse angles of inclination. The veracity of experimental studying results is proved by the corresponding theoretical models of the process.

Introduction

Grain is a basis of human nutrition. Military actions, taking place in Ukraine during a long period of time, lead to an agricultural crisis. The area for agricultural needs becomes smaller. However, the increasing global demand on food products causes the search for innovative decisions for productivity development of the processes of manufacturing and preparing seed material (SM) (Dziki et al., 2023; Peniak and Nowacki, 2023).

For the solution of the objectives for the stable nutritional safety provision in the country it is necessary to improve the productivity of a grain manufacturing process. From (Olshanskii et al., 2016; Tishchenko et al., 2016) it is known that using the seed material, which has an increased biological potential (Bredykhin et al., 2023), for sowing allows the increase of energy of growing and, correspondingly, crop capacity to 60%.

In production of grain-crops seeds at the stage of final accurate processing of raw materials, separating machines showed great efficiency (Bredykhin et al., 2023), as they separate the material according to the seed density.

In realization of the raw materials separation process according to the seed density widespread are "wet" and "dry" methods (Nesterenko et al., 2017). However, "wet" method of separation requires additional energy consumption, which greatly increases prime cost of the final product, as well as time consumption for the preparation of seed material, in view of necessity for finish drying. The most widespread is "dry" method of the separation by separating machines of different configuration.

One of the main methods of "dry" separation is separation of the material according to the seed density by air-permeable, non-sifting working surfaces (decks). With the use of this method of separation, it is clear that the seed material, under the effect of working surface vibrations and airstream influence, takes on the properties of pseudoliquid and flakes off to fractions of different density. This allows obtaining a high frequency, as well as effective isolation of difficult-to-separate impurity (diseased and damaged seeds, or seeds of a non-main crop, etc.), which is impossible to isolate according to dimensional features, as they are close to features of the main crop.

Farmings, grain mills and seed plants have coordinated working operation lines. However, for the increase of efficiency and quality of the process there is a necessity to improve the working of lines machinery. Purchasing of a new machine is not always economically sound, as the cost is high. Thus, modernization of machines, which work on a farm or an enterprise, for increasing its efficiency (without a significant change in construction) is an actual way to solve this problem. Manufacturers, who specialize on producing machines and equipment for seed processing, are in constant searching for ways of improving machines, which are produced in lots. This process is stable, and takes place simultaneously with development of new models.

Existing machines and processes on preparing the seed material satisfy the growing demands not in full size, which makes the studies on determination optimal linkage parameters and design variables of separating machines, as well as coordination with physical and mechanical properties of raw materials. The results of the studies are actual for modernization of existing separating machines, which are used by farmings for processing own seeds and isolation of seed materials from grain heap.

Analyses of literature data and problem definition

There is a list of engineering, technical and scientific decisions for realizing the material separation process according to the seed density (Anders et al., 2023; Kaliniewicz et al., 2022). The most widespread are separating machines, the operation mode of which is based on transferring the seed material to pseudorarefied layer, in which assembly of particles takes on the properties of pseudoliquid.

To improve prediction of the processes, which take place on pseudorarefied layer, the method of mechanical and mathematical modeling of the motion and interaction of multiphase media showed great efficiency (Piven et al., 2018; Bredykhin et al., 2021). In work (Kroulik et al., 2016) the authors examined the separation of the material in pneumatic tubes, and provided graphical curve lines, which characterize motion paths of particles of different density. They also determined critical velocities of grain-crops seeds movement. The authors studied the process of material particles interaction not taking into account intralayer processes and interaction of particles with each other and working surface.

Physical and mathematical models of processes of precision separation of the seed materials are studied in work (Aliiev et al., 2019). However, this physical and mathematical model studies separation of sunflower seeds and for its usage the prediction of separating processes of other grain-crops is complicated. In work (Duan et al., 2017) the authors made the modeling of the material separation process by an impact air separator. The received results included design variables and linkage parameters of impact air separator, the operation mode of which greatly differs from generally used machines for material separation according to the seed density. The authors determined the interconnection between properties of pseudorarefied layer and a separate particle with design variables, linkage and aerodynamic parameters of machines, in presence of certain factors. The influence of accidental action of power under any pressure is also studied, in presence of airstream pulsation. However, separating machines of this type have not received a widespread occurrence. In work (Havrylenko et al., 2021) the authors reviewed movement of a separate particle on pseudorarefied layer and interconnection between design variables and linkage parameters of a dresser. The authors of scientific studies (Piven, 2017; Stepanenko and Dnes, 2021) examined the interaction of a separate particle with pseudorarefied medium in a pneumatic align separator. Analytical dependences of the influence of airstream on the particle were received. Mathematical models in works do not take into account interaction of particles, which differ according to the density. The authors of studies (Havrylenko et al., 2021; Lezhenkin et al., 2021) made a further step in developing physical and mathematical model of the material particle movement in a vibropneumatic rarefied medium. The authors examined the ways of improving the process quality with mechanical intensification under the additional influence of external factors of the intensification process on the layer. The paths of material particles under the influence of pulsating airstream were determined. In work (Stepanenko and Kotov, 2018; Zubko et al., 2022) the authors provided the results of theoretical studies on interaction of a material particle with a counterflow airstream. The curve lines of velocity projection alteration on Y-axis were determined. It was also determined that the change of airstream velocity influences the increase of the material separation process efficiency. The design of pneumatic separator with a loading machine for multilayer feeding of seeds is provided in work (Nesterenko et al., 2017). The influence of multilayer material feeding on the quality of cleaning is also studied. In work (Olshanskiy et al., 2018) the authors reviewed the systems with one freeness grade in applying to a particle of the seed material. A non-linear solution of Cauchy problem for the case of non-linear positional friction grade was built. In work (Clark, 1983) a further development received the method of modeling separation process of particles on pneumatic rarefied layer. However, the author did not take into account intralayer interactions of particles. The researchers (Salemi et al., 2010) reviewed the elastic particles separation based on gravity separation in the field of airstream action. The attention must be paid to work (Wang et al., 2019), where the authors conducted a study on the conception of seed production under conditions of climate changes. The influence of the quality of seeds on the seed production was studied, and the influence of working parts of separating machines on material particles damage was also reviewed.

Special attention must be paid to work (Linenko et al., 2021), in which the authors examined an experimental separator with a linear asynchronous electrical drive. The facts are proved that there is a positive influence on the separating process of seed material by changing frequency of working surface vibrating. The researchers (Duan et al., 2017) provided the method of modeling the process of particles movement for a liquid, which is incompressible. In (Li et al., 2018) the authors made a study on separating rice seeds. They also reviewed the interaction of a particle with a working surface. The authors in study (Karaiev et al., 2021) conducted reasoned studies on the theory of particles movement in seed mixture during an aspiration separation.

The analysis of the work shows that the authors primarily examined the movement of a separate particle and its interaction with particles, which are moving by. Such a simplification allows an adequate modeling of movement and intralayer processes, which take place on the layer of seed material. High accuracy of process prediction is possible by using the method of multiphase media movement, where the interaction of seed material components and air-stream is examined. The use of this method allows an adequate modeling of the process and obtaining the optimal linkage parameters and design variables of the separator working process according to physical and mathematical properties of raw materials, which are processed.

Purpose and objectives of study

The purpose of the study is to determine the ways of improving the process of seed materials separation according to the seed density on the working surface of the pneumatic sorting table. The optimization of the process variables allows effective and in short time choosing the separator linkage parameters depending on the grain crop, that is provided for processing, to ensure improvement of efficiency and productivity of the process of seed material separation according to the seed density, in the way of improving purity of the basic fraction and quality of isolation of difficult-to-separate impurities.

To reach this purpose, the following objectives were set:

- to determine interconnection of linkage parameters and design variables of the pneumatic sorting table with physical and mechanical properties of seeds, using developed theoretical dependences, and to conduct a testing on their adequacy, in the way of coordinating them with received results of experimental decisions;
- to perform an analysis of secant lines of surfaces;
- to conduct an optimization of process variables with recommendations making.

Materials and methods

The linkage parameters of the process of separation of seed material in a vibropneumatic rarefied layer and their relationship with physical and mechanical properties of raw materials were studied. The developed mechanical and mathematical model of the process of separation was used for calculations (Bredykhin et al., 2021).

Experimental studies were conducted on the pneumatic sorting table (PST) of Khorol Mechanical Plant (Khorol) (https://mehzavod.com.ua/ua/ (date of application 13.06.2023)), which was obtained under the contract for production tests. Experimental studies were carried out on the training and research fields of the State Biotechnological University (Kharkiv).

The principle of operation of the table: the seed material falls through the feeder onto the working surface (deck), where under the action of vibrations of the deck it starts to move to the discharge trays. The material layer comes into contact with the air stream and gains the properties of pseudoliquid. Particles of material are flaked off by their own density into heavy (4), medium (3), mixed (2), light fractions (1) and stones (5), if any (Figure 1 (https://mehzavod.com.ua/ua/_(date of application 13.06.2023))). Moreover, the heavy fraction includes the most biologically active seeds with high germination energy, and the light fraction includes affected, broken and pest damaged grain. The working surface has longitudinal and transverse adjustment angles and its own vibration amplitude. The optimum ratio of the mentioned linkage parameters, selected for the specific raw materials, allows obtaining high purity and productivity of the process.

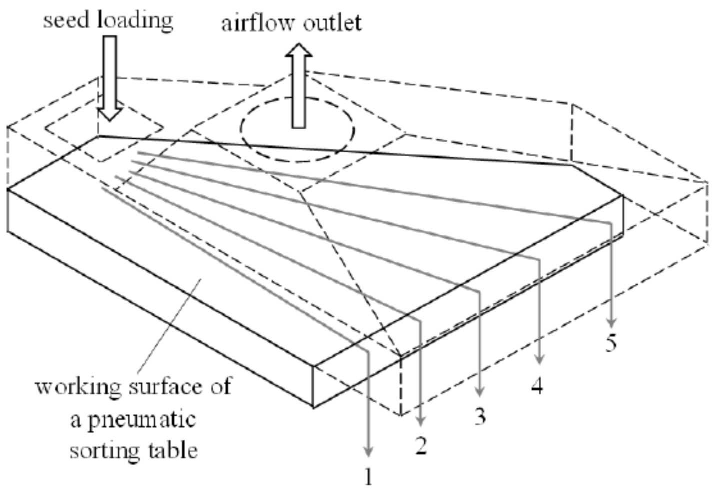


Figure 1. Technological scheme of separation of seed material on the working surface of a pneumatic sorting table (https://mehzavod.com.ua/ua/_(date of application 13.06.2023))

The most widespread in Ukraine seed materials of the corresponding crops were used in the experimental studies:

1. Winter wheat of "Kharkivska-99" variety. The mass of 1000 grains is 38 g, unit is 0.750 kg·dm^{-3}, density of particle is 780 kg·m^{-3}, moisture content is 13%.
2. Triple modified corn hybrid "Donor MV". The mass of 1000 grains is 300 g, unit is 0.790 kg·dm^{-3}, density of particle is 760 kg·m^{-3}, moisture content is 14%.
3. Confectionery sunflower of SPK variety, mass of 1000 grains is 43 g, unit is 0.360 kg/dm^{3}, density is 440 kg·m^{-3}, moisture content is 7%.
4. Soybean of Fortuna variety, mass of 100 grains is 142 g, density of the particle is 800 kg·m^{-3}, moisture content is 11%.

The parameters of the pneumatic sorting table, which have a determining influence on the efficiency of the process of separation of seed material are: frequency and amplitude of deck vibrations, longitudinal and transverse angle of inclination of the deck and airstream velocity at the entrance to the seed layer.

One of the important indicators of seed quality, namely the purity of the basic fraction, is accepted as a criterion of efficiency of the process of separation with the use of the pneumatic sorting table. The purity of the basic fraction of seeds means the content of the main crop in them, which is determined as a percentage of the sample taken for analysis.

When separating the material under production conditions, the sample of the final product (seeds at the entrance of the pneumatic sorting table) was manually disassembled, separating two groups: seeds of the main crop (heavy fraction) and different types of impurities (medium and light fractions).

Generalized values of average density of the material at theoretical modeling of the process of its separation and at separation of these raw materials under production conditions are given in Table 1.

Table 1
Average Density of Seed Materials

Raw materials	Caryopsis form	Average density, ($kg \cdot m^{-3}$)
Wheat	elliptical	780
Corn	triangular	760
Sunflower	triangular	440
Soybean	oval	800

Ranges of initial data for theoretical modeling of the process of material separation on the pneumatic sorting table are given in Table 2.

Table 2
Ranges of Initial Data for Theoretical Modeling of the Process of Seed Separation on the Pneumatic Sorting Table

Parameter	Parameter range
Deck vibration frequency, $(vibr \cdot min) \cdot s^{-1}$	800-1000/13.3-16.7
Deck vibration amplitude, (mm)	4-6
Longitudinal angle of inclination of deck, (deg.)	0-8
Transverse angle of inclination of deck, (deg.)	0-8
Airstream velocity, ($m \cdot s^{-1}$)	1-3

Since there are five factors that affect the efficiency of seed separation on the pneumatic sorting table, the following assumptions were made for the analysis. The rational frequency and amplitude of vibrations of the deck of the pneumatic sorting table were considered to be determined to a greater extent by the density of the original raw materials. Rational longitudinal and transverse angles of inclination of the deck are determined to a greater extent by the effective friction force between the layer of seeds (raw materials) and the table surface. The rational airstream velocity is determined by the aerodynamic characteristics of particles of original raw materials and, consequently, also by their average characteristic sizes. Based on this, the study is divided into two parts. That is, the values of rational frequencies and amplitudes of vibrations of the deck of the pneumatic sorting table, as well as the values of rational longitudinal and transverse angles of inclination of deck were studied as the result of a two-factor experiment. The rational value of airstream velocity may be found by extremes or asymptotes of the dependence on the given value of the purity of the basic fraction, as a parameter according to which the optimization is made.

Determination of rational modes was carried out step by step. Firstly, the ranges of rational frequencies and amplitudes of vibrations of the deck of the pneumatic sorting table at constant values of longitudinal and transverse angles of its inclination, as well as constant airstream velocity were determined. At the next stage, rational longitudinal and transverse angles of inclination of the deck at rational frequencies and amplitudes of its vibrations and constant airstream velocity were studied. At the final stage, the rational airstream velocity was determined while selecting rational values of all other parameters.

Results of studying parameters of the process of separation of seed material in the vibropneumatic rarefied layer

Study of linkage parameters and design variables of the pneumatic sorting table when working with seed material

At theoretical modeling of the process (Bredykhin et al., 2021) the method of hydrodynamics of multiphase media was used, according to which the pseudorarefied layer of seed material consists of two phases: discrete phase formed by solid particles of seed material and continuous phase – gaseous medium (air). The discrete phase is considered as a finite number N of discrete components, each formed by solid particles with density$\bar{\rho}_n, n = 1,2, \ldots N$.

The density of particles of n – component of the discrete phase is equal to:

$$\rho_n = \delta_n \bar{\rho}_n, \quad n = 1,2, \ldots, N, \tag{1}$$

where:

δ_n – is the volume fraction of particles of n – component in the pseudorarefied material.

In general, the density of the discrete phase is defined as:

$$\rho_P = \sum_{n=1}^{N} \rho_n.$$

The density of the continuous phase is defined as:

$$\rho = \bar{\rho}\left(1 - \sum_{n=1}^{N} \frac{\rho_n}{\bar{\rho}_n}\right) = \bar{\rho}\left(1 - \sum_{n=1}^{N} \delta_n\right), \tag{2}$$

where:

$\bar{\rho}$ – is the density of the gaseous medium (air).

Considering (1) and (2), in general, the density of the pseudorarefied material is equal to:

$$\rho_c = \rho + \rho_P. \tag{3}$$

The velocity of movement of pseudorarefied material is determined from the equation:

$$\rho_c \vec{V}_c = \sum_{n=1}^{N} \rho_n \vec{V}_n + \rho \vec{V}, \tag{4}$$

where:

$\vec{V}_n$ – is the velocity of n – component of the discrete phase,

$\vec{V}$ – is the velocity of the continuous phase.

In general, the mechanical and mathematical model of the process can be given as:

$$V_{n1} = A_n^S sh\left(\gamma_n\left(x_3 - \overline{h_n}\right)\right) + A_n^C ch\left(\gamma_n\left(x_3 - \overline{h_n}\right)\right) -$$

$$-\frac{g\sin\alpha(\rho_n+\rho)}{2(\mu_n+\mu)}x_3^2 + \frac{g\sin\alpha(\mu_n\rho-\mu\rho_n)}{\rho_n F_n(\mu_n+\mu)}, \quad (5)$$

$$V_1 = -\frac{\mu_n}{\mu}\left[A_n^S sh\left(\gamma_n\left(x_3 - \overline{h_n}\right)\right) + A_n^C ch\left(\gamma_n\left(x_3 - \overline{h_n}\right)\right)\right] -$$

$$-\frac{g\sin\alpha(\rho_n+\rho)}{2(\mu_n+\mu)}x_3^2, \quad n = 1,2,\ldots,N. \quad (6)$$

where:

$$A_n^S = \frac{fgh_1\rho_1}{\gamma_n\mu_n} ch\left(\gamma_1\overline{h}_1\right) + \frac{1}{\gamma_n\mu_n}\sum_{P=1}^{n-1} f_\rho^2, \quad (7)$$

$$A_n^C = \frac{fgh_1\rho_1}{\mu_1\gamma_1} sh\left(\gamma_1\overline{h}_1\right) + \sum_{P=1}^{n-1} f_\rho^1, \quad n = 2,3,\ldots,N,$$

$$A_1^C = 0, \quad A_1^S = 1, \quad (8)$$

$$f_P^1 = -\frac{g\sin\alpha\,\overline{h}_P^2}{2}\left(\frac{\rho_P+\rho}{\mu_P+\mu} - \frac{\rho_{P+1}+\rho}{\mu_{P+1}+\mu}\right) +$$

$$+g\sin\alpha\left(\frac{\mu_P\rho-\mu\rho_P}{\rho_P F_P(\mu_P+\mu)} - \frac{\mu_{P+1}\rho-\mu\rho_{P+1}}{\rho_{P+1}F_{P+1}(\mu_{P+1}+\mu)}\right), \quad (9)$$

$$f_P^2 = -g\sin\alpha\,\overline{h_P}\left(\frac{\mu_P(\rho_P+\rho)}{\mu_P+\mu} - \frac{\mu_{P+1}(\rho_{P+1}+\rho)}{\mu_{P+1}+\mu}\right),$$

$$\gamma_n = \left(\frac{\rho_n F_n(\mu_n+\mu)}{\mu_n\mu}\right)^{1/2}, \quad (10)$$

ρ_n, ρ – reduced densities of the n discrete phase and continuous phase,
μ_n and μ – effective coefficients of dynamic viscosity of the corresponding phases,
h_n – average thicknesses of the n layer,
$\overline{h_n} = \sum_{P=1}^{n} h_P$, α – angle of inclination of the working surface to the horizontal plane,
g – free fall acceleration.

The path of motion of the particle along axis x_3 has been considered, since the relative component of motion of the particle occurs exactly along axis x_3 (from the point of loading to unloading) and the value of the Coriolis force has a sufficiently small value and it can be neglected.

Thus, formulas (5) – (10) allow us to determine the distribution of velocities by the thickness of the pseudorarefied material in a steady-state mode of motion. The amplitude of the velocity of particles of the n discrete phase is from two summands. One summand depends quadratically on the coordinate x_3 (axis x_3, perpendicular to the cylindrical working surface of the vibropneumatic centrifugal separator.

The competition of these two summands determines the basic character of change of velocities of discrete phases by the thickness of the pseudorarefied layer of particles. Thus, for example, at the angle of inclination of the working surface to the horizontal plane close to zero, the summands with quadratic dependence on the coordinate x_3 can be neglected. When the coefficient of friction *f,* which is due to the working surface, is zero, the dominant summand will be the one with a quadratic dependence on the coordinate x_3. Finally, at $f \to 0$ and $\alpha \to 0$ the particle velocities of discrete phases become so small that they can be neglected. It should also be noted that the summand with quadratic dependence on the coordinate x_3 depends only on the physical parameters of particles of the corresponding discrete and continuous phases. The second summand, instead of the specified physical parameters, depends on the physical parameters of the below discrete phases.

Figure 2 shows the results of theoretical modeling of the process of separation of seed material, where the frequency and amplitude of vibrations of the deck of the pneumatic sorting table are the determining factors of the process, and the purity of the basic fraction is the assessment criterion. In this case, the longitudinal and transverse angles were equal to 1° and the airstream velocity was 1 m/s. The obtained results of the solution of the mathematical model were compared with the data of experimental studies carried out on the training and research fields of SBTU (State Biotechnological University, Kharkiv). The divergence of theoretical and experimental data is shown in Figures 4-8.

The surfaces shown in Fig. 2 have an extreme character. They have maxima of purity of the basic fraction, which correspond to rational values of amplitude and frequency of vibrations of the pneumatic sorting table.

Fig. 3 shows the results of theoretical two-factor modeling the process of separation of seed material, where the factors are longitudinal (α) and transverse (β) angles of inclination of the deck of the pneumatic sorting table, the assessment criterion is the purity of the basic fraction. In this case, the frequency and amplitude of vibrations of the deck of the pneumatic sorting table were selected based on the type of raw materials. For wheat, corn and sunflower seeds the frequency was 940 $vibr \cdot min^{-1}$, amplitude was 5 mm. For soybean seeds – frequency was 940 $vibr \cdot min^{-1}$, amplitude was 6 mm. The airstream velocity was equal to 1 $m \cdot s^{-1}$.

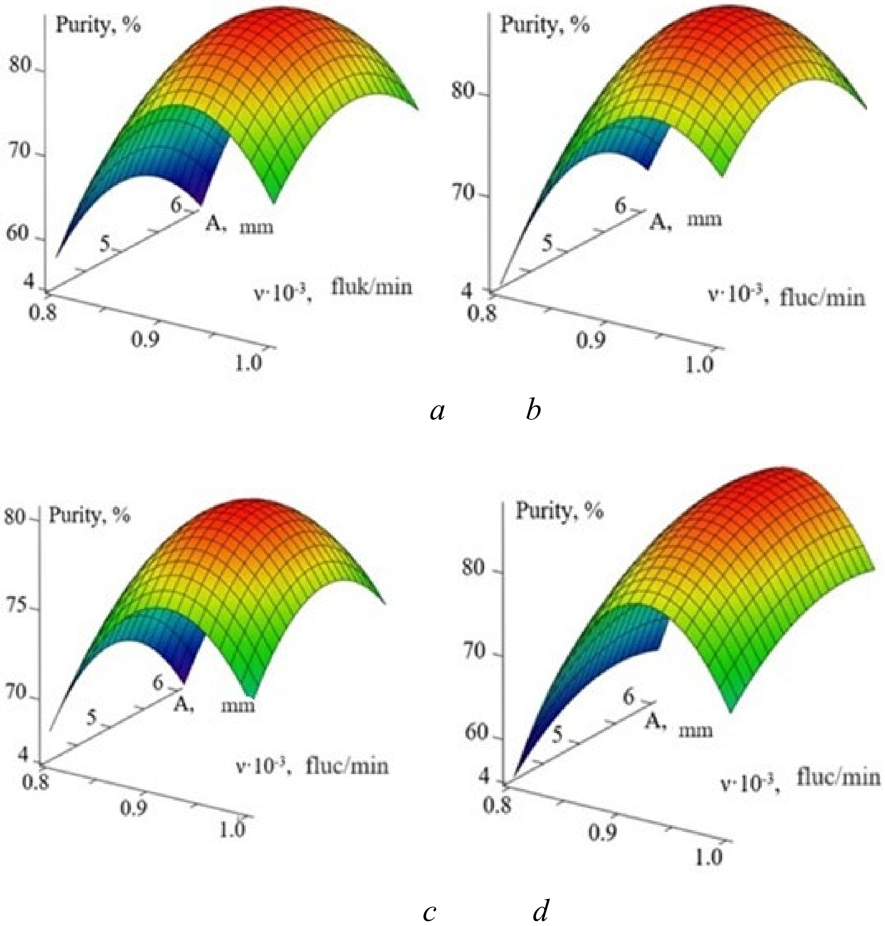
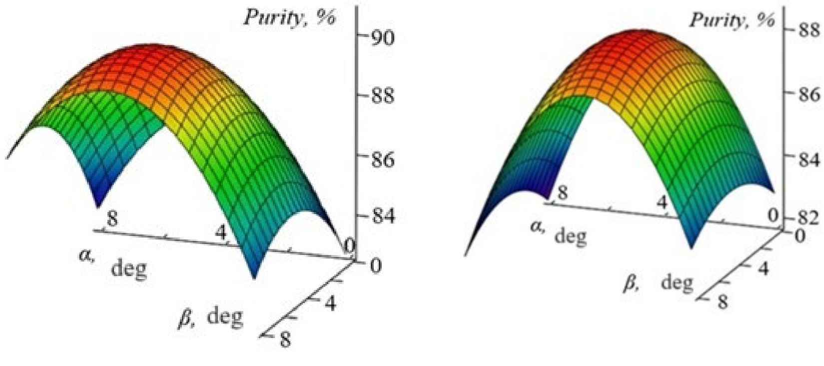
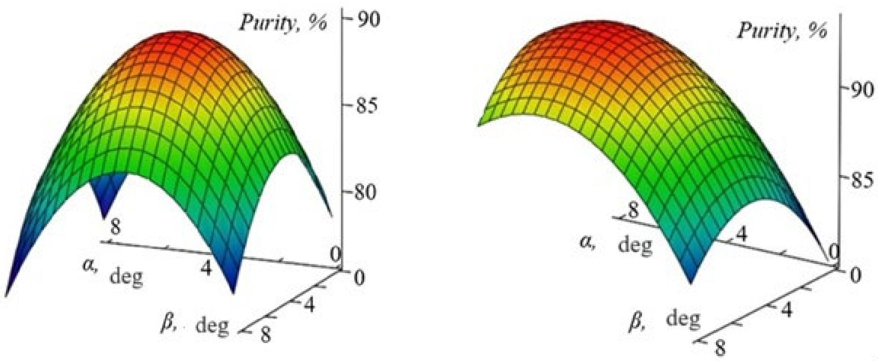


Figure 2. Results of theoretical modeling the change of purity of basic fraction of seed material depending on frequency (v) and amplitude (A) of vibrations of the pneumatic sorting table depending on raw materials: a – wheat; b – corn; c – sunflower; d – soybean

Dependences of the purity of the basic fraction on the values of longitudinal and transverse angles of inclination of the working surface (deck) have an extreme character. That is, the surfaces have a bend relative to the plane Oα×Oβ, which indicates the presence of values of longitudinal (α) and transverse (β) angles of inclination of the deck, at which there is a maximum value of purity of the basic fraction.



a *b*



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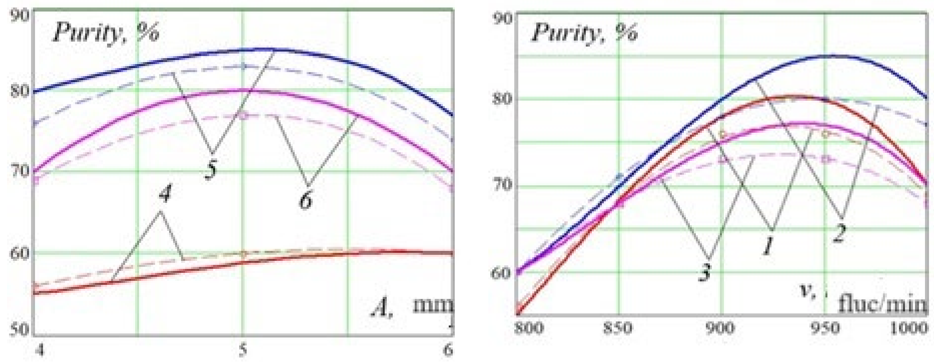
c *d*

Figure 3. Results of theoretical modeling the change of purity of basic fraction of seed material depending on the value of longitudinal (α) and transverse (β) angles of inclination of the deck of the pneumatic sorting table for raw materials: a – wheat; b – corn; c – sunflower; d – soybean

Analysis of plotted secant lines of surfaces

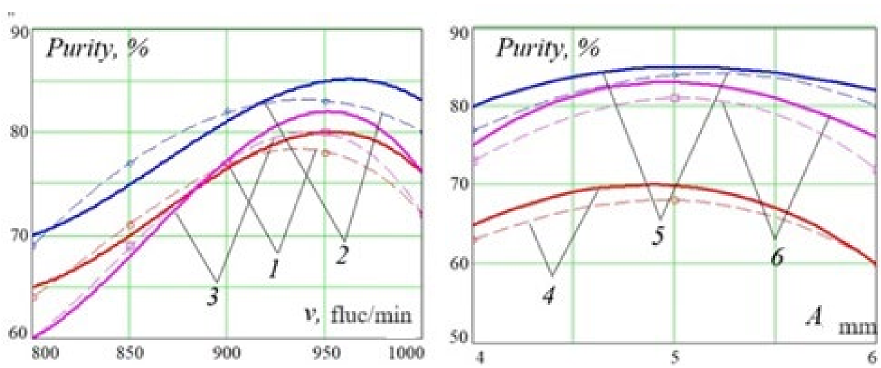
Figures 4-7 show the secant lines of surfaces for different raw materials and represent the dependence of the purity of the basic fraction on frequency (*a*) and amplitude (*b*) of vibrations of the pneumatic sorting table. The dots on these charts indicate the values of purity of the basic fraction depending on the frequency and amplitude of vibrations of the pneumatic sorting table, obtained under production conditions. For clarity, approximated curves of the corresponding color were plotted according to the points obtained under production conditions.



a *b*

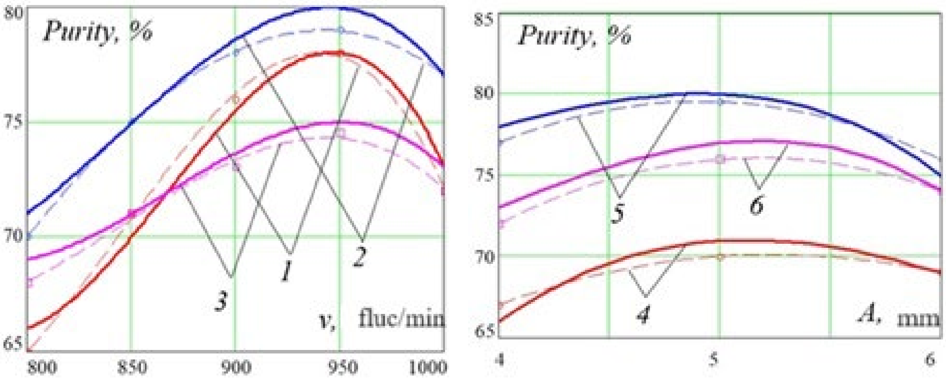
Figure 4. Change of purity of the basic fraction obtained by separation of wheat seed material on the pneumatic sorting table depending on changes of: a – frequency of vibrations (4 – 800 vibr·min^{-1}; 5 – 900 vibr·min^{-1}; 6 – 1000 vibr·min^{-1}); b – amplitude of vibrations (1 – 4 mm; 2 – 5 mm; 3 – 6 mm)

The secant lines shown in Figures 4-7, obtained theoretically, differ from the data obtained under production conditions. However, the differences in the values lie within the limits of error. Thus, for separation of grain mass from wheat (Fig. 4), the greatest deviation is observed at the frequency of vibrations of 950 vibr·min^{-1}and amplitude of 5 mm and is 6%.



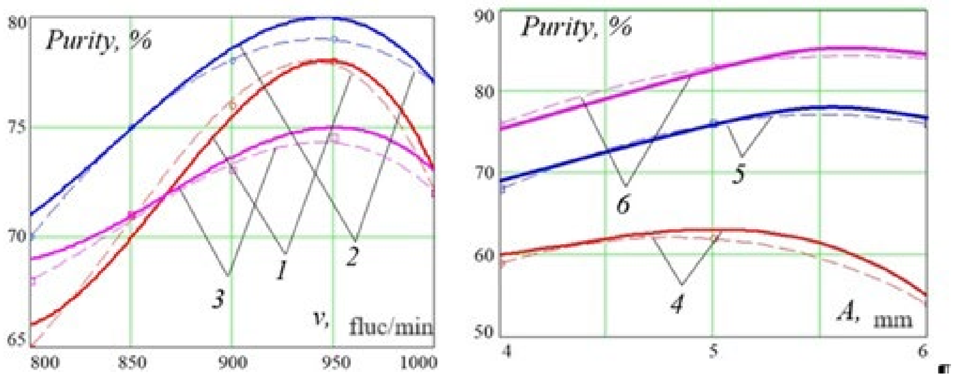
a *b*

Figure 5. Change of purity of the basic fraction obtained by separation of corn material on the pneumatic sorting table depending on changes of: a – frequency of vibrations (4–800 vibr·min^{-1}; 5–900 vibr·min^{-1}; 6–1000 vibr·min^{-1}); b – amplitude of vibrations (1–4 mm; 2–5 mm; 3–6 mm)



a *b*

Figure 6. Change of purity of the basic fraction obtained by separation of sunflower seed material on the pneumatic sorting table depending on changes of: a – frequency of vibrations (4 – 800 vibr·min^{-1}; 5 – 900 vibr·min^{-1}; 6 – 1000 vibr·min^{-1}); b – amplitude of vibrations (1 – 4 mm; 2 – 5 mm; 3 – 6 mm)



a *b*

Figure 7. Change of purity of the basic fraction obtained by separation of soybean seed material on the pneumatic sorting table depending on changes of: a – frequency of vibrations (4 – 800 vibr·min^{-1}; 5 – 900 vibr·min^{-1}; 6 – 1000 vibr·min^{-1}); b – amplitude of vibrations (1–4 mm; 2–5 mm; 3–6 mm)

For separation of soybean seeds (Fig. 7), the greatest deviation is observed at the frequency of vibrations of 950 vibr·min^{-1} and amplitude of 6 mm and is 5%. Based on the following values of deviations of the theoretically obtained results from the results obtained under production conditions (deviations lie within the error, i.e. do not exceed 10%).

To set the ranges of longitudinal and transverse angles of inclination of the pneumatic sorting table deck at which the maximum value of the purity of the basic fraction of the raw materials used in the study takes place, secant lines of surfaces should be given (Fig. 8).

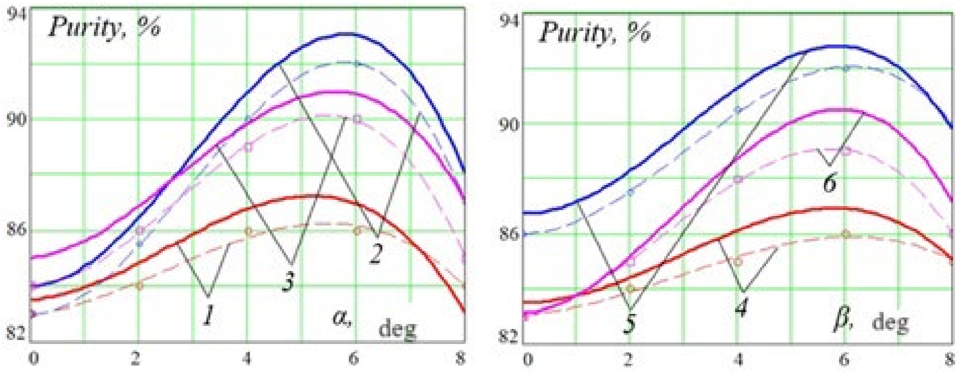


Figure 8. Change of purity of the basic fraction obtained by separation of wheat seed material depending on the angles of inclination of the pneumatic sorting table: a – longitudinal (1 – 0 deg.; 2 – 4 deg.; 3 – 8 deg.); b – transverse (4 – 0 deg.; 5 – 4 deg.; 6 – 8 deg.)

In addition to the secant lines representing functions of approximation of the theoretically obtained data, Fig. 8 shows data obtained at different longitudinal and transverse angles of inclination of the deck of the pneumatic sorting table obtained under production conditions using different raw materials. The data obtained under production conditions were determined for five values of longitudinal (0; 2; 4; 6; 8 deg.) and five values of transverse (0; 2; 4; 6; 8 deg.) angles. These values are given as dots of the corresponding color, combined by the function of approximation for clarity.

Determination of optimal values of process parameters

Optimal ranges should be considered the ranges of the specified parameters, at which the purity of the basic fraction will differ by no more than 10%. Such ranges of parameters of the raw materials under study, determined by the given dependences, are presented in Table 3.

Table 3.
Ranges of Rational Values of Pneumatic Sorting Table

Raw materials	Vibration amplitude, (mm)	Vibration frequency, (vibr·min^{-1})	α (deg.)	β (deg.)
Wheat	4.5-5.5	930-960	5-7	5-7
Corn	4.5-5.5	940-960	4-6	3-6
Sunflower	4.5-5.5	940-960	4-6	5-6
Soybean	5.5-6	930-950	5-7	4-6

The summary analysis of the ranges of rational values of linkage parameters of the pneumatic sorting table allowed determining that the longitudinal and transverse angles of inclination of the working surface have the greatest influence on the qualitative indicators of the process. Thus, by changing the longitudinal angle of inclination, the velocity of movement of the seed material along the upper edge, i.e. to the stone release valve, changes. At the optimum value determined for a particular crop, the thickness of the seed layer on the working surface gradually decreases from the loading zone to the unloading zone. The intrinsic velocity of the material is changed by adjusting the transverse angle of deck inclination.

The optimum values of the vibrations amplitude of the working surface vary slightly from crop to crop. By adjusting the amplitude, a uniform distribution of the material on the working surface is achieved.

By adjusting the frequency of vibrations of the working surface, the optimum velocity characteristics of the particle on the working surface are achieved.

Manual sorting of the selected samples allowed establishing the highest purity of the basic fraction when using optimal linkage parameters of the pneumatic sorting table when working with the seed material of the corresponding crop. The maximum release of hard-to-separate impurity (diseased, damaged grain and seeds of non-main crop) into the discharge trays (medium and light fractions), which are adjusted to release particles of appropriate density, was determined.

Such values are valid if appropriate rational values of frequency and amplitude of vibrations of the deck of the pneumatic sorting table and longitudinal and transverse angles of its inclination are used during separation of seed materials.

At the same time, differences in the nature of dependences should be noted: different decrease of functions when airstream velocity increases. Obviously, this nature is caused by different densities. That is, airstream velocity has the least influence on the seed material of soybean because soybean has the highest density. At the same time, sunflower seeds, which have the lowest density of the applied raw materials and triangular shape, are the most affected.

Discussion on the results of studying the optimization of the determining parameters of the process of separation of seed material on the pneumatic sorting table

Previous scientists considered the influence of a particular linkage parameter or design variable on the process (Lezhenkin et al., 2021; Karaiev et al., 2021). The intralayer interaction of the seed material was not taken into account. Implementation of the method, in contrast to the given and analyzed methods, allows an effective combination of linkage parameters and design variables of the pneumatic sorting table with physical and mechanical properties of raw materials. Thus, the influence of transverse and longitudinal angles of inclination, amplitude and frequency of vibrations of the deck of the pneumatic sorting table depending on the density of the most common grain crops was taken into account. The obtained model allows an adequate prediction of the trajectories of material particles of appropriate density and, accordingly, an adjustment of the linkage parameters of the pneumatic sorting table depending on the density of the material. This allows increasing purity of the basic fraction and productivity of the process of separation.

According to the dependences shown in Figures 3-6 it is possible to determine the ranges of rational values of amplitude and frequency of vibrations of the pneumatic sorting table for separation of seed material. Obviously, rational ranges should be considered the ranges of the specified parameters, at which the purity of the basic fraction will differ by no more than 10%. Such ranges of parameters of the raw materials under study, determined by the given dependences, are presented in Table 3.

In addition to the secant lines representing functions of approximation of theoretically obtained data, the presented data were obtained under production conditions using different raw materials for different longitudinal and transverse angles of inclination of the pneumatic sorting table deck. The data obtained under production conditions were determined for five values of longitudinal (0; 2; 4; 6; 8 deg.) and five values of transverse (0; 2; 4; 6; 8 deg.) angles. These values are given as dots of the corresponding color, combined by the function of approximation for clarity.

The difference, depending on the crop and the selected variable, ranges from 2 to 6 %, which is within a statistical error.

The given data are limited to studies of the narrowed list of the most common grain crops in Ukraine with optimization of linkage parameters of the pneumatic sorting table.

The disadvantage of the given data is a limitation of studies of the process of separation of seed materials by seed density using flat working surfaces and the development of recommendations for pneumatic sorting tables.

Further development of studies consists in studies of the process of separation of seed materials by seed density on cylindrical working surfaces with the creation of response surfaces and the development of recommendations for the optimization of design variables and linkage parameters for vibropneumatic centrifugal separators and pneumatic centrifuges.

Conclusions

1. The analysis of later sources showed that process of separation of seed materials and selection of biologically active seeds requires minimizing the mechanical impact of machines on the particle, which is ensured by processing the material on the PST.
2. For the solution of the set objectives with determination of optimal parameters of the process we used the general mechanical and mathematical model of the process of separation of seed material according to the seed density.
3. According to the set objective, we constructed dependence diagrams (response surfaces) of the interconnection between linkage parameters and design variables of the pneumatic sorting table with physical and mechanical properties of grain crops seeds, which are the most widespread in Ukraine.
4. We determined that the maximal frequency of the basic fraction, gained by the separation of wheat, is obtained at the airstream velocity in the range 1.3-1.5 $m \cdot s^{-1}$; for corn – 1.3-1.6 $m \cdot s^{-1}$, for sunflower – 1.2-1.4 $m \cdot s^{-1}$, for soybean – 1.2-1.4 $m \cdot s^{-1}$.
5. Ehe results of research on the production of wave-type intensifiers were implemented at PrJSC KhMZ (Khorol Mechanical Plant, Khorol) for the modernization and improvement of PST-3.5, as well as the development of PST-10.

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OKREŚLENIE SPOSOBÓW USPRAWNIENIA PROCESU SEPARACJI MATERIAŁU SIEWNEGO NA POWIERZCHNI ROBOCZEJ PNEUMATYCZNEGO STOŁU SORTOWNICZEGO

Streszczenie. Przedmiotem badań jest proces separacji materiału siewnego w zależności od gęstości nasion na powierzchni roboczej pneumatycznego stołu sortowniczego. Przeanalizowano główne definiujące zmienne projektowe i parametry powiązań sprzętu, który realizuje proces separacji materiałów siewnych i jest skoordynowany ze zmiennymi fizycznymi i mechanicznymi surowców. Przedstawiono zasady modelowania ruchu warstwy materiału siewnego jako medium wielofazowego. Pod wpływem drgań powierzchni roboczej i siły strumienia powietrza warstwa nabiera właściwości pseudopłynu. Przedstawiono kryteria wybranych zmiennych, od których zależą wskaźniki jakościowe i ilościowe procesu separacji materiałów siewnych w zależności od gęstości nasion. Wyznaczono analitycznie optymalne wartości parametrów powiązania separatora i zbudowano wykresy zależności. Wykonywane są linie odciętych powierzchni dla konkretnego zbioru (surowca). Badana jest "czystość" frakcji ciężkiej podczas zmiany wskazanych parametrów. Wykazano, że istnieją różnice w typach zależności: różne zmniejszanie funkcji i zwiększanie prędkości strumienia powietrza. Oczywiste jest, że charakter ten jest zdeterminowany różnicą w gęstości oryginalnych surowców. W ten sposób najmniejszy wpływ zmiana prędkości strumienia powietrza ma na surowiec sojowy, ponieważ soja ma największą gęstość. Jednocześnie największy wpływ ma na nasiona słonecznika, które mają najmniejszą gęstość spośród użytych rodzajów surowców, a także kształt trójkąta. Ustalono, że maksymalna częstotliwość frakcji podstawowej, uzyskana przez oddzielenie materiału siewnego pszenicy na PST, jest uzyskiwana przy prędkości strumienia powietrza w zakresie 1,3-1,5 $m \cdot s^{-1}$. Dla kukurydzy racjonalna prędkość strumienia powietrza mieści się w zakresie 1,3...1,6 $m \cdot s^{-1}$, dla słonecznika - 1,2-1,4 $m \cdot s^{-1}$, dla soi - 1,2-1,4 $m \cdot s^{-1}$. Liczby te są ważne pod warunkiem zastosowania odpowiednich racjonalnych decyzji dotyczących częstotliwości i amplitudy drgań pneumatycznego pokładu stołu sortowniczego podczas oddzielania mieszanek ziarna, a także wzdłużnych i poprzecznych kątów nachylenia. Prawdziwość wyników badań eksperymentalnych potwierdzają odpowiednie modele teoretyczne procesu.

Słowa kluczowe: proces separacji, gęstość nasion, pneumatyczny stół sortowniczy, pseudopłyn, zmienne fizyczne i mechaniczne, materiały siewne