ASSESSMENT OF AERODYNAMIC SCREEN EFFICIENCY OF VIBRO-FRICTIONAL SEED SEPARATOR IN PROCESSING SMALL SEED MATERIALS

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Abstract. A block of two adjacent, parallel working surfaces of the vibro-frictional seed separator form a flat air channel. When the vibro-friction separator is operating, these surfaces perform synchronous vibrations, causing complex spatial alternating air movement in a flat channel. The velocity field in the working region changes over time according to the periodic law. The superposition of areas of increased and lowered pressure and areas with non-zero air velocities along the end of the working surfaces generates a complex picture of an alternating velocity field inside the area, located between the working surfaces of the separator block. The alternating flow affects the dynamics of the seed movement relative to the working surfaces under the impact of vibration. For seeds with a round shape and relatively large mass and density, the impact of air upon the separation process is insignificant. However, for the seeds with pronounced aerodynamic properties and relatively small mass the impact of the air flow is significant. In some cases, this effect can almost completely eliminate the directed vibrational movement of the seed material, causing the seeds to hang above the working surface under the influence of the moving air. This reduces the support reaction force and, accordingly, the friction force. As a result, the quality of seed separation decreases and mixing of the seed fractions occurs. Thus, when separating small-seed materials, the harmful effect of the alternating air flow that takes place during the operation of the separator is caused. Increasing the efficiency of the separation process of small-seed crops, sensitive to the effect of the air flow onto the blocks of the vibro-frictional seed separator and substantiating its design and operating parameters is a relevant and promising scientific and applied task for agro-industrial production.

Keywords: seeds, vibro-frictional separation, efficiency, dynamics of movement, air flow, aerodynamic screen.

Introduction

The analysis of scientific investigations on vibro-frictional separation of small seed materials indicates that the negative impact of the aerodynamic forces upon the process of vibrational separation of the seed materials has not been sufficiently studied. In well-known studies analytical expressions have been proposed for the calculation of the magnitude of the impact of aerodynamics upon the parameters of the vibro-frictional movement of seeds [1-11]. However, this does not take into account the lateral aerodynamic forces and aerodynamic moments arising due to the uneven distribution of pressure over the surface of the seeds when the air flow is passing over them.

The authors of the research [2] point out the importance of taking into account the aerodynamic factor when processing the seed material. However, no numerical indicators for measuring these characteristics have been formulated. Another study provides an overview of the mechanism of interaction between the working parts of the separator and air [3]. However, numerical mathematical models for parametric investigations of the perspective machines are not presented. There has been developed a numerical model of the gas and particle flow in the cyclone separators [4]. However, the processes of interaction of the working bodies with air in the presence of devices for reducing the negative impact of the aerodynamic factor were outside the scope of the study. There was also studied interaction of air with wide-angle diffusers [5]. However, the nature of interaction of air with the devices, such as an aerodynamic screen, and the efficiency of their use were not considered.

A mathematical model has been developed of the oscillatory movement of ellipsoidal seeds on an inclined rough surface [6]. However, the influence of aerodynamic forces and moments is not taken into account. In addition, the presentation of the seeds as bodies of revolution does not allow their aerodynamic properties to be taken into consideration. In work [7] the processes of interaction of seeds with the working surfaces were studied considering the air vibrations, based on analytical flat gas-dynamic models. Based on the results of the investigation, there were created models of the air velocity distribution along the height of the interplane space at pre-set sections. There was assessed the impact

of the aerodynamic factor upon the oscillatory movement of seeds, associated with their transfer by the air flow.

An analysis of the method for increasing the efficiency of the process of cleaning sunflower seeds from impurities indicates a possibility to select the operating parameters of a vibratory seed separator, based on the criterion of reduction of the impact of air exposure [8]. And, as the research results show, the selection of the angles of inclination, the amplitude and frequency of vibrations of the working surfaces allows reducing the negative impact of air during separation of the oil seeds. However, for the small-seed light crops this method does not give satisfactory results since the seeds are not different from impurities in their parameters and aerodynamic properties.

Other authors propose a method for calculating the velocity field and air pressure in the interplane space of the separator block for a three-dimensional case [9]. As a result, there were obtained patterns of changes in the air dynamics in various phase positions of the working bodies.

Another investigation presents a numerical model of the oscillatory movement of seeds, taking into account: the force of the aerodynamic resistance, lateral aerodynamic forces and moments [10]. However, the proposed model is quite labour-intensive when used for designing vibration machines.

The authors of the investigation presented the results of constructing four-factor second-order regression models to assess the efficiency of separating mixtures of parsnip, dill and lettuce seeds, taking into account the dynamics of air between the working surfaces of the vibro-frictional seed separator block [11]. The regressions are constructed on the basis of numerical modelling of the vibro-frictional movement of the seeds, considering their interaction with an alternating air flow. However, the accuracy of the regression equations depends entirely on the degree of fitness of the mathematical model to be used. There is no comparative assessment of the results, obtained in a natural experiment.

So the analysis of other previously conducted studies allows to establish that:

- numerical models of vibro-movement of seeds during cleaning (sorting) of the seed mixtures on vibration machines have been created, taking into account the air dynamics inside the blocks of the working surfaces. These models provide a possibility of numerical simulation of the working processes of the vibration machines, taking into account measures to eliminate the aerodynamic factor for light seed mixtures;
- no comparative assessment of the efficiency of vibrational separation of light seeds based on numerical simulation of vibro-frictional separation processes has been made.

In this regard, there arises a problem of substantiating the numerical indicator of the efficiency of separation of finely dispersed materials on vibro-frictional seed separators with an aerodynamic screen.

The aim of the study is to substantiate a quantitative indicator, measuring the change in the separation quality depending on the design and operating parameters of the vibro-frictional seed separators with an aerodynamic screen. To achieve the set goal, it is necessary to solve the following specific problems: to construct an analytical expression for the quality indicator of the seed material separation; to develop a method for calculation of the quality indicator of separation on a vibro-frictional separator with an aerodynamic screen for the particular design and operating parameters.

Materials and methods

1. Analytical expression for assessment of the quality index of seed separation

The physical meaning of the quality indicator of seed separation on a vibro-frictional separator with an aerodynamic screen is illustrated, using Fig. 1. The seeds from different fractions move along the working surface of the separator under the action of the vibration impulses, gravity, resistance and aerodynamic forces and moments. Their probable trajectories of movement are within the boundaries of the probable trajectory sectors (Fig. 1). Compared to the seeds that are less sensitive to the action of the air flow (Fig. 1a), the sectors of probable trajectories of the light seeds that are sensitive to the action of the air flow increase and the degree of their overlap increases (Fig. 1b).

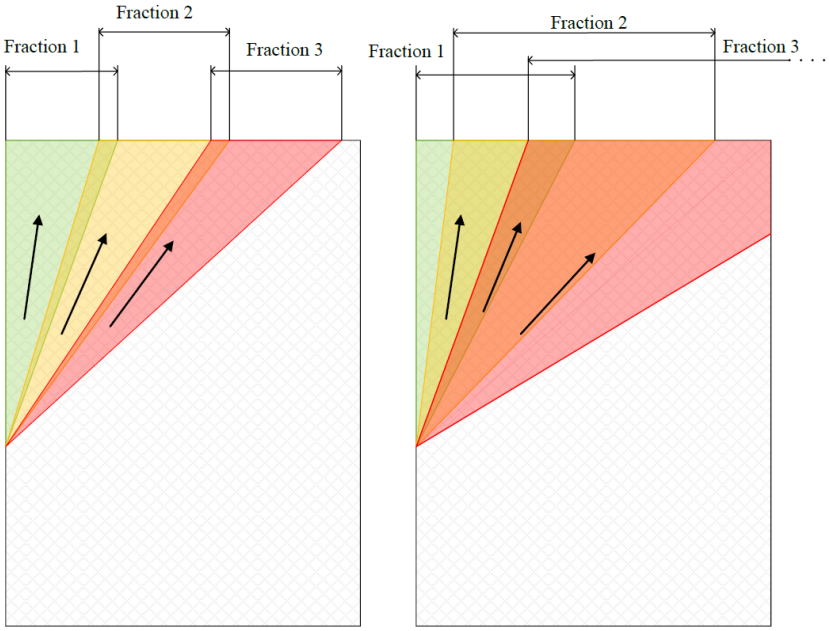

Fig. 1. **Efficiency of using the vibro-frictional seed separator in separating seed materials:** conventional (left); sensitive to the action of the air flow (right)

The analytical expression for the assessment of the numerical value of the separation quality indicator is:

$$K(\mathbf{X}) = \frac{\sum_{i=1}^{N^{\mathrm{fr}}}(\delta_i^{\mathrm{a}} + \Delta_i^{\mathrm{a}})}{\sum_{i=1}^{N^{\mathrm{fr}}}(\delta_i^{\mathrm{b}} + \Delta_i^{\mathrm{b}})}, \quad (1)$$

$$\Delta_i = \begin{cases} (\varphi_i + \delta_i) - (\varphi_{i+1} + \delta_{i+1}), if\ (\varphi_i + \delta_i) - (\varphi_{i+1} + \delta_{i+1}) \geq 0, \\ 0, if\ (\varphi_i + \delta_i) - (\varphi_{i+1} + \delta_{i+1}) < 0\ or\ i = N^{\mathrm{fr}}, \end{cases} \quad (2)$$

where Δ_i – angle of the overlap sector of the adjacent sectors of probable trajectories of seeds of the *i*-th and *i* + 1-th fractions of the seed material;

φ_i - mathematical expectation of the angle of deviation of the average axis of the vibro-frictional movement of seeds of the *i*-th fraction relative to the *Y* axis of the coordinate system, associated with the working surface;

δ_i – half-angle of the sector of probable trajectories of seeds of the *i*-th fraction;

N^{fr}– number of fractions of seed material being examined;

X – vector of design and operating parameters of a vibro-frictional separator with an aerodynamic screen.

Marks “b” and “a” in the expression define the parameters, obtained without and with the effect of aerodynamic forces and moments, respectively.

That is, the indicator (1) shows how many times the relative overlap of sectors of probable trajectories of seeds of different fractions increases relative to similar sectors, obtained in the absence of aerodynamic forces and moments. If the harmful effect of the alternating flow is reduced to zero, the index (1) is equal to one. When the quality of separation deteriorates due to mixing of the seed fractions, the value of the indicator (1) increases and becomes greater than one.

2. Methodology for calculating the quality indicator of seed separation on the vibro-frictional seed separators with an aerodynamic screen

A methodology for calculating the quality indicator is based on statistical processing of quasi-random trajectories of the seed movement relative to the working surface of the separator. Step-by-step integration of trajectories is implemented, using a numerical model of the vibro-frictional movement of

seeds of a particular shape, with established physical and mechanical characteristics, with specified design and operating parameters of a vibro-frictional seed separator with a screen.

The algorithm for integrating the vibrational movement of a seed of a certain shape with established physical and mechanical characteristics is shown in Fig. 2.

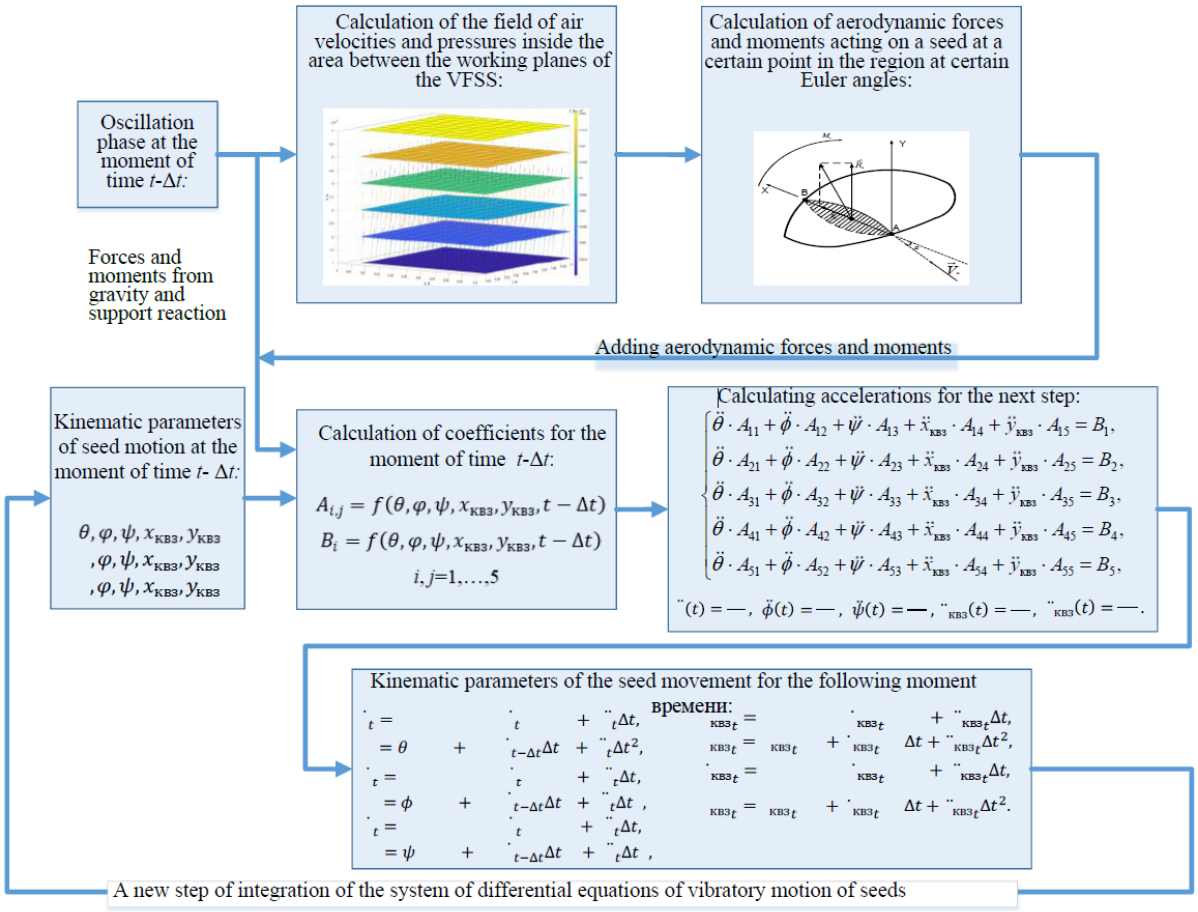

Fig. 2. **Algorithm for calculation of kinematic parameters of movement of a seed taking into account the impact of the air flow**

When entering the algorithm, the initial values of the kinematic parameters of the seed are set. Next, for the current phase of oscillations of the working surface, the field of the air velocities and pressures in the middle of the region is calculated [12].

For the air velocity vector corresponding to the location of the seed, corresponding to the point of its spatial orientation, the aerodynamic characteristics are calculated [13].

Instantaneous aerodynamic forces and moments, acting on the seed surface, are added to the system of equations of vibrational movement. The basic model used is a model of continuous movement of a solid body, rolling and sliding along a rough inclined surface and performing vibrational oscillations [10]. The body moves under the action of:

- force of gravity;
- support reactions;
- aerodynamic forces and moments arising from the movement of air.

The created model allows to take into account the influence of aerodynamic forces and moments upon the kinematic parameters of the vibrational movement of the seed, depending on the phase of the vibration of the vibro-frictional separator and the location of the seed in the area between two working surfaces. The influence of the air movement is manifested as a deviation of the approximating axis of the vibrational movement of the seed and an increase in the sector of possible trajectories, constructed relative to this axis.

Results and discussion

The seed separation efficiency index (1) is relative. It shows how many times worse the separation of the seed material, sensitive to the action of air flow, is in relation to some standard separation conditions. This includes the condition when the processing of the seed material on the vibro-friction seed separators occurs under vacuum conditions. In practice such conditions are unattainable. However, when using a mathematical model, reference conditions are obtained by equating to zero the aerodynamic forces and moments, acting upon the seed, the trajectory of which is integrated.

The method for calculating the seed separation efficiency indicator is implemented through the use of separation techniques for the mathematical models. First, the air velocity field in the working space is calculated, based on the phases of vibration of the working surfaces, and then a seed is introduced into this field, performing a vibrational movement relative to the working surface. This approach simplifies the numerical solution of the problem since the influence of the seed material on the parameters of the alternating air flow is not taken into account. The problem dimension is reduced. However, this introduces some error into the results of simulation. This is an overestimate of the degree of impact of the aerodynamic effects upon the separation quality, compared to real processes. This error is explained by neglecting the viscosity of air and the processes in its boundary layer near the working surfaces of the separator.

However, the developed mathematical model does not distort the nature of the dependence parameters of the vibro-frictional seed separator with an aerodynamic screen That is, it allows to carry out with its help analysis and quantitative comparison of alternative design options and operating modes of the separator.

Conclusions

1. As an indicator for measuring the quality of separation of the seed material there was used the ratio of the sums of the angles of opening and overlapping of the sectors of probable trajectories of seeds of various fractions, obtained under conditions of action and absence of the alternating air flow. The value of this indicator is sensitive to changes in the design and operating parameters of the vibro-frictional seed separator with an aerodynamic screen and, therefore, on its basis, an optimality criterion can be formed to justify the design and operating parameters of perspective separators.
2. The method for calculation of the values of the quality indicator of seed separation is implemented as an algorithm for integrating the trajectory of the continuous vibro-frictional movement of the seed relative to the working surface of the vibro-frictional seed separator under the action of an alternating air flow. The assumptions, made in mathematical models, (neglect of the impact of the air viscosity, air flow gradients in the boundary layer) reduce the dimensionality of the computational problem without distorting the nature of the dependence of the separation quality indicator upon the design and operating parameters.

Author contributions

Conceptualization, V.B.; methodology, S.I. and V.N.; software, Y.I.; validation, A.A. and V.B; formal analysis, V.B and J.O..; investigation, V.B., S.I., V.N. and J.O.; data curation, A.A., V.B. an J.I.; writing – original draft preparation, V.B.; writing – review and editing, A.A. and V.B.; visualization, Y.I., V.N.; project administration, V.B.; funding acquisition, H.B. All authors have read and agreed to the published version of the manuscript.

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