Substantiation of basic scheme of grain cleaning machine for preparation of agricultural crops seeds

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Abstract. The article presents data on the feasibility of the concept of a high-efficiency seed cleaner with the consistent use of the air flow in aspiration and the multi-tier placement of the sorting grids in grating mills. As a result of modeling, the directions for further improvement of air-screen seed cleaning machines have been identified: an increase in the proportion of sorting grids in the mills up to 70 ... 80% and an increase in the speed of the air flow in the channel of the pre-filter cleaning up to 8.0 m / s. Experiments have established the competence of using mathematical modeling of airflow in the pneumatic system with the use of a finite-volume method for solving hydrodynamic equations for substantiating the basic parameters of the pneumatic system.

1. Introduction

A common approach to post-harvest processing and cleaning of grain heaps, in which at each stage a part of impurities and defective grains is extracted from it, resulted in a large length of production lines, the use of identical machines duplicating the work of the previous ones, numerous physical impacts on the future seeds and their consequent damage. This principle does not fully take into account the ultimate goal of purification – to obtain seeds.

This shortcoming is inherent in both Russian and high-performance foreign-made production lines. After-harvest processing of grain, the heap irrespective of its final destination passes the stage of primary cleaning (sometimes preliminary) on air-screening machines to separate large, lightweight and fine impurities [2, 3]. Primary cleaning is completed by bringing the grain heap to the standard moisture and its laying for temporary storage [6].

The second stage of seed preparation begins with the unloading of the grain heap from its temporary storage facilities and its transfer to air-screening machines that differ from the machines used for primary cleaning by operating mode [2, 3].

The authors hypothesize that it is possible to achieve the required completeness of isolation (80%) with a single skipping of the heap by air-screen grain cleaners working on fractional technology with the separation of forage fraction in both aspirations and the balanced ratio of sieves in the sieve mill.

2. Materials and methods

The aim of the study is to substantiate the concept of a high-efficiency seed-cleaning machine with a consistent use of air flow in aspiration and multi-tier placement of sorting gratings in grating mills.
The object of the study is the working process of an air-sieve seed-cleaning machine with the sequential use of air flow in a two-aspirated pneumatic system.

The theoretical part of the research was carried out using the main provisions of the probability theory and the finite-volume method for solving the equations of hydrodynamics. The experimental part was carried out using modern methods of collecting and processing initial data and substantiating the choice of objects for conducting experiments.

3. Results and Discussion
The grain heap of various grain crops was conventionally divided into classes, if possible, by sieves, depending on the width of their holes, and by pneumatic separating channels, depending on the speed of the air flow [1, 2, 4, 5, 7, 8, 10].

Using basic principles of relativity theory, the authors determined the probability of separation of components of each class into forage fraction. The highest probability of content and the lowest probability of extraction can be observed in two classes. The class with heap components has width exceeding the width of holes of the seed screen and hovering velocity exceeding air-flow rate that is set in the canal of after-screen aspiration. Heap components of that class can only be separated by the sorting screen.

Heap components of the class with the width that is more than the size of the holes of sorting screen and hovering velocity exceeding air-flow rate that is set in the canal of pre-screen refinement, but less than air-flow rate set in the canal of after-screen refinement can be separated only by the canal of after-screen refinement.

There are two ways to lessen the load on these operative parts: by increasing air-flow rate in the canal of pre-screen refinement in order to separate heap components that are only separated by the canal of after-screen refinement and in the canal of pre-screen refinement; by increasing quantity of sorting screens in shoes alongside rearrangement of all screens.

An increase in quantity of sorting screens in shoes from 33% (60% separation completeness) to 80% (Figure 1 and Figure 2) considerably enhances the probability of heap components separation by screens, while minimizing heap quantity coming from sorting screens into the canal of after-screen refinement, which also heightens the probability of heap components separation by aspiration systems.

Figure 1. Dependence of the completeness of the separation of forage fractions ($\varepsilon$) on the proportion of sorting screens ($Fc$) in the shoes by the following classes: 1 - completeness of the forage fraction separation by aspirations; 2 - completeness of separation of forage fractions by screens; 3 - total completeness of forage fractions separation..

Figure 2. Dependence of the total completeness of the separation of forage fractions ($\varepsilon'$) on the proportion of sorting screens in the shoes at different speeds in the pre-screen refinement canal ($Vd$): 1 - $Vd = 6.7$ m/s; 2 - $Vd = 7.4$ m/s; 3 - $Vd = 8.0$ m/s.
The increase in the proportion of sorting screens in the shoes has a greater impact on the increase in separation of all components in the forage and waste fraction than the increase in airflow rate in the pre-screen refinement canal (Figure 1). This can be explained by a larger proportion of components contained in the heap, which can be separated only by sorting screens.

The smaller increase in the completeness of the separation by aspiration systems at a higher airflow rate in the pre-screen refinement canal is explained by the fact that with increasing speed, the proportion of heap components released by the pre-screen refinement canal increases, and the total supply of heap to sorting screen decreases, which reduces the increase in the completeness of the separation.

This can also explain the fact that an increase in the airflow rate in the pre-screen refinement canal has a greater effect on the increase in the completeness of the heap component separation by the aspiration systems than the increase in the proportion of sorting screens in the shoes does. If the airflow rate in the pre-screen refinement canal reaches 8.0 m/s, the completeness of the separation by screens exceeds 90% with the proportion of sorting screens over 70% (Figure 2).

Thus, it is possible to achieve high efficiency of separation of such components only due to a simultaneous increase in the airflow rate in the canal of pre-screen refinement and the proportion of sorting screens in the shoes.

As a canal for pre-screen aspiration, the authors considered a horizontal canal with a sectional sedimentary chamber, which was located on the path of airflow from the sedimentary chamber of after-screen aspiration to the radial fan. The principle of successive use of air flow in aspiration systems made it possible to exclude the resistance of such elements of the pneumatic system as turns and turnabouts of the air flow and to reduce the air expenditure to the values necessary for the operation of the after-screen aspiration canal.

To substantiate the basic parameters of a dual aspiration pneumatic system with the sequential use of airflow in aspiration, a finite-volume method of solving hydrodynamics equations was used and a rectangular adaptive grid with local grid refinement [10]. A hollow model of a pneumatic system with sedimentary chambers created in CAD Solid Works was used as the geometry of the calculated area (Figure 3).

As a mathematical model, taking into account the operating mode of the pneumatic separating canals and the average statistical data on the geometric parameters of the grain heap components, a model of a turbulent incompressible fluid was chosen. To close the equations, the authors chose the simplest standard k-ε model of turbulence. To analyze the simulation results and visualize the results on the plane, the authors used a vector velocity field and filling from the pressure (Figure 4).

As can be seen from the vector field obtained from the simulation results (Figure 3), the after-screen refinement sedimentary chamber allows obtaining in the lower part close to zero values of air flow rate, which indicates the possibility of precipitation of forage impurities. The structure of the air flow in the sectional sedimentary chamber and the pre-screen refinement canal can provide for the removal of most of the lightweight impurities outside the forage section. In the lower part of the forage section, an inverse turbulence of the air flow is observed with a speed of up to 2.4 m/s, which will carry from the chamber into the main air flow lightweight impurities, which have low hovering velocity.

Lower resistance (no more than 60 Pa) is demonstrated by a pneumatic system of pre-screen refinement, which is caused by the absence of canal turns and a baffle plate in the sedimentary chamber. The resistance of the pneumatic system of after-screen aspiration with a vertical pneumatic separating canal of relatively large length and three smooth turns of the air flow is more than 90 ... 95 Pa.

The results of the simulation made it possible to come to conclusion about the reduction of the overall dimensions of the sedimentary chambers, which made it possible to install additional screen layers in screen shoes without increasing the height of the machine. To assess the possibility of using simulation results in the design of the pneumatic system of machines, the velocity field on the pneumatic system itself has been checked out. The actual distribution of air flow rates along the
section of the sedimentary chambers confirms the general nature of the distribution obtained as a result of modeling, and also the validity of the conclusions drawn about the reduction in the dimensions of the chambers.

![Figure 3. The design model of the pneumatic system: 1-delivering heap; 2 - the wall; 3 - delivering heap; 4 - air inlet; 5 - output of forage; 6 - access to the screen shoe; 7 - output of forage; 8 - air outlet.](image1)

![Figure 4. The vector field of air flow rate on the longitudinal axis.](image2)

The obtained results of modelling and experimental studies have allowed substantiating the basic scheme of a universal air-screen seed cleaner with a dual aspiration pneumatic system serviced by one air flow (Figure 5).

![Figure 5. Schematic diagram of the machine: 1 - a pneumoseparating canal of after-screen refinement; 2 - a sedimentary chamber of a pneumo-canal; 3 - a directing peak; 4 - horizontal canal of pre-screen refinement; 5 - section of the main fraction of the sedimentary chamber of the pre-screen refinement canal; 6 - partition wall with valve; 7 - forage collection section; 8 - feeding device; 9 - canal to the cyclone and fan; 10 - upper screen shoe; 11 - lower screen shoe; 12 - delivering device; 13 – output of forage aspiration; 14 - trays for large impurities removal; 15 - screen forage outlets; 16 - output of purified main fraction grain; 17 - the sieve screens; 18 - sorting screens of the lower shoe; 19 - sorting screens of the upper shoe.](image3)
The machine includes a pneumatic system with canals of pre-screen 4 and post-screen 1 refinement, feeder 8, top 10 and lower 11 screen shoes, device 12, delivering main fraction into the post-screen aspiration canal, radial fan and dust separator installed outside the machine. The canal of pre-screen aspiration 4 has a horizontal arrangement and ends with a sectional sedimentary chamber, divided by wall 6 with a valve into two sections: main fraction collecting section 5 and forage collection section 7. Section 5 has a closed canal with a gravity valve to feed heap to screen refinement upper shoe 10. Forage collection section 7, like sediment chamber 2 of after-screen refinement canal 1, comprises aspirating forage output devices 13. The distribution along the width and the supply of heap to the pre-screen refinement canal is performed by feeding device 8, which includes a hopper with a gravity distributor. After-screen refinement canal 1 includes a lower part that expands toward the screen shoe and is divided by a vertical partition into the preliminary fluidization zone and the main one. Upper screen shoe 10 has a grain separator dividing the grain into two parts to feed the grain heap in equal proportions into two upper tiers 17 with the sieve screens. The lower tier of the upper screen shoe is installed with a reverse slope and equipped with sorting screens.

The grain heap from the screens of the lower tier of the upper shoe is delivered to the grain separator of lower shoe 11, which includes three tiers 18 with sorting screens. The main fraction of the heap that passed through the screen refinement is, by means of device 12, directed into the canal of after-screen aspiration, where biologically inferior feed grain and remaining impurities are released.

Depending on the required productivity for the implementation of fractional seed preparation technology, recommendations have been developed for completing machines with fans, electric motors and screens with a layout scheme.

4. Conclusion
As a result of modeling, the guidelines for upgrading air-screen seed-cleaning machines have been worked out: increasing the proportion of sorting screens in shoes up to 70…80%, increasing air flow rate in the canal of pre-screen refinement to 8.0 m/s.

Experimental research has established the validity of using mathematical modeling of airflow in the pneumatic system with the use of a finite-volume method for solving hydrodynamic equations to substantiate the basic parameters of the pneumatic system.

The developed universal air-screen seed cleaner will make it possible to realize the possibility of seed preparation with a single heap skipping and a minimum number of mechanical impacts.

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