Cleaning of grain sowing material from weed seeds for the sustainable development of agriculture

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Abstract. The article deals with the optimization of cleaning grains and seeds of agricultural crops from weed seeds. The process of cleaning grain material by one-dimensional horizontal vibrations depends on the friction coefficients of the seeds against each other. It is optimized by selecting the amplitude and angle, relative to the vertical, under which the cylindrical container containing the grain mixture is located. Experiments were carried out with almost all types of seeds most widely used in the domestic agricultural industry. The cleaning process was investigated only at amplitudes smaller than the seed size. The seeds of cultivated plants and weeds move upward or downward, depending on the specific gravity. Calculations show that with correctly selected values of the amplitude and angle, the average trajectories of the grains are practically straight lines parallel to the generatrix of the cylinder containing the seeds. Studies have shown that the maximum cleaning speed is achieved under the condition that the angle of inclination of the cylindrical vessel is equal to the natural slope of the seeds with the highest specific gravity.

1. Introduction

One of the most important stages of clearing fields from clogging is cleaning the seeds. Separation of grain mixtures is an integral part of various technological processes, including the preparation of seed material and plant materials [1, 2]. This is a preventive phase that is important in the integrated control of weed. Even though the seeds of weed grasses are not completely released when the sowing material is cleaned, the cleaning is very effective [3]. Many weed plants that have severely clogged crops have almost come to naught with an improvement in the quality of seed purification. The quality of the separation process can be improved by a combination of vibration and additional factors such as rising air flow [4] and electrification of the sorted seeds [5], etc. In various variations during cleaning, the physical and mechanical properties of seeds of cultivated and weed plants are involved - geometric dimensions, windage, specific gravity, degree of surface roughness, etc.

This, however, leads to the fact that technologies and equipment become more complex. Almost all of the currently known cleaning methods have (with various variations) basically a vibrating trier (cellular) surface on which seeds are poured in a thin layer. And since the processes of cleaning seeds
entail certain economic costs, the problem of increasing the efficiency and optimizing the methods of vibration separation of the seed remains urgent [6].

The analysis shows that the vibrational component of mechanical energy in the total energy consumption when cleaning grain mixtures is predominant. Therefore, in terms of optimization, it seems most preferable to determine the optimal conditions for vibration impact on the seed. Here, the most significant is the selection of the direction, frequency and amplitude of oscillations for each specific grain mixture with its physical and mechanical characteristics. In this regard, the article discusses aspects of the behavior of grain material in one-dimensional, horizontal, low-frequency oscillations for various angles of inclination of cylindrical vessels containing planting material.

2. Materials and methods

Practically without using any idealizations, the seeds of cultivated plants and weeds can be attributed to a certain kind of bulk materials. And bulk materials under the influence of vibrations and vibrations, under certain conditions can behave both as a solid and as a liquid [7, 8, 9]. In this work, an attempt is made to use the above-mentioned properties to describe aspects of the process of cleaning planting seed material from weed seeds [10]. Let’s consider a vibrating cylindrical container of seed material.

Oscillation energy from the cylinder is also transmitted to individual seeds in the mixture. As a result of making up the system with vibration energy, under certain modes, a certain state occurs (analogue of the "phase" transition) that the entire volume of planting seed material starts to move. The grains begin to "flow" through the vessel, as in a liquid. Averaged over the oscillation period, the values of the coordinates of the seeds make it possible to calculate a certain average speed of their "drift" relative to the cylindrical container vessel. It is important that, unlike a liquid, in this case, there is dry friction in the interaction between seeds in the mixture. Collisions are not always elastic and, unlike a liquid, there are no forces of attraction [11]. This can lead to instability with respect to the separation of seeds into fractions or clustering [12]. That is, if a weed seed or a seed of another variety appears next to the grain of a cultivated plant, then the resulting forces acting on them are different.

The seeds move in different directions. Conversely, when the seed gets to itself like this the forces are such that the relative movement becomes minimal but they continue to move relative to the cylindrical vessel. So the seeds of the same type unite and, uniformly filling the space, push out seeds of other types.

The following forces act on each seed in the mixture: gravity, inertial force, reaction force from the surrounding seeds, friction force. In this work we will neglect the effects of seed electrification due to friction. When seeds are poured onto a horizontal surface, they form a cone. The angle of the generatrix of the cone and the normal to the surface depends on the coefficient of friction between the seeds. Let’s consider a seed on an inclined surface and the angle of inclination is such as \( \mu = \tan \alpha \). Let \( \hat{i} \) be the unit vector (ort) in the direction of the greatest descent (gradient), let \( \hat{j} \) be the unit vector of the tangent to the trajectory of the seed and let \( \hat{k} \) be the unit vector of some averaged force \( F \) acting from the surrounding seeds. First, we write down the condition of quasi-static equilibrium, when the seed practically does not move:

\[
\vec{F} + mg \sin \alpha \hat{i} + \vec{F}_f = 0,
\]

where \( F_f \) is friction force.
As far as $\vec{F}_f = -\mu mg \cos \alpha \hat{j}$, and $\mu = \tan \alpha$ we have

$$\vec{F} + mg \sin \alpha \hat{i} = \tan \alpha \ mg \cos \alpha \hat{j}. \hspace{1cm} (2)$$

Squaring both parts and simplifying:

$$F^2 + m^2 g^2 \sin^2 \alpha + 2Fmg \sin \alpha \cos \delta = m^2 g^2 \sin^2 \alpha,$$

$$F(F + 2mg \sin \alpha \cos \delta) = 0, \hspace{1cm} (4)$$

here $\cos \delta = (\hat{k}, \hat{i})$.

It follows from equation (4) that at values from the range $90 \leq \delta \leq 180$ we have $F = -2mg \sin \alpha \cos \delta > 0$. If $\delta$ takes values from the range $0 \leq \delta \leq 90$ then from (4) it follows that $F = 0$. The seed trajectory determines the resulting force

$$\vec{R} = \vec{F} + mg \sin \alpha \hat{i} = mg \sin \alpha (\hat{i} - 2 \cos \delta \hat{k}) =$$

$$= mg \sin \alpha (\hat{i} + 2 \cos \delta (\sin \delta \hat{i} - \cos \delta \hat{k})) =$$

$$= mg \sin \alpha \cos 2\delta (\tan 2\delta \hat{i} - \hat{i}), \hspace{1cm} (5)$$

where $\hat{i}$ is axis eagle $Oy$.

We got that under certain conditions, the seed moves, sliding down or rising up along the vector $\hat{i}$. If it is necessary to obtain a trajectory for other conditions, for example, for $90 \leq \delta \leq 180$ then from (5) it follows

$$\frac{dy}{dx} = -\tan 2\delta = -\frac{2 \sin \delta \cos \delta}{\cos^2 \delta - \sin^2 \delta} = \frac{2xy}{x^2 - y^2}, \hspace{1cm} (6)$$

that is, the seed moves in an arc of a circle.

Thus, from (4) and (6) there follows a deterministic relationship between the efficiency of the seed cleaning process by one-dimensional horizontal oscillations on the value of the angle of natural friction. Let’s consider a two-component blend of peeled and unpeeled millet seeds. When such a mixture is poured onto a flat surface a complex cone is formed. This is a figure consisting of a truncated cone on which another cone is located. The different values of the angles between the generatrices and the bases are due to different natural slope angles. The more the angles of repose differ, the more pronounced the effect. The shape of the cone and kink depend on the ratio of the components. Table 1 shows the dynamics of the angles of the cones depending on the proportion ($\nu$) of the components that make up the mixture. For untreated seeds, the angle is 36.2° and for cleaned millet seeds, is 31.4°. Analysis of the data in the table shows that the most statistically significant for describing the dependence is the dependence $f(\nu) = 0.14 \ln(\nu) + 36.19$, that is, as the proportion of unrefined seeds in the mixture increases, the angle corresponding to the upper cone increases according to the logarithmic law from 31° to 36°.
Table 1. Changes the corners of the cone generatrix to the horizontal when the percentage of components changes.

| The proportion of unrefined seeds in the mixture (v) | Upper cone, ° | Bottom cone, ° |
|-----------------------------------------------------|---------------|---------------|
| 0.125                                               | 34.4          | 33.0          |
| 0.250                                               | 34.5          | 31.4          |
| 0.375                                               | 34.7          | 31.0          |
| 0.500                                               | 35.1          | 26.6          |
| 0.625                                               | 35.6          | 28.6          |
| 0.875                                               | 36.1          | 44.9          |

In order to study the features of the separation of a two-component mixture of bulk materials, an experimental setup was made. The setup consists of a cylindrical container, the angle of the axis of which relative to the horizontal can be changed by means of a rotary mechanism. The cylinder itself is fixed to the platform, oscillating in a horizontal plane with an adjustable frequency.

The directions of all forces, except for gravity and inertia are constantly changing due to the chaotic movement of seeds relative to each other due to vibration. The resulting gravity and inertia force is constant at a given vibration frequency. Under certain conditions in the oscillatory system, the resulting force allows seeds with a large specific gravity to reduce their potential energy by moving downward relative to seeds with a lower specific gravity.

3. Results and discussion

For an experimental study of the optimal cleaning conditions buckwheat and millet seeds containing impurities and weed seeds were selected. This choice is mainly due to the clarity of the demonstration of the cleaning process - a good color difference in seeds with a small difference in size. In addition, the considered not the smallest seed sizes make it possible to neglect the influence of electrostatic forces arising from electric charging of seeds due to mechanical contact. The characteristics of the components of the studied mixtures are presented in Table 2.

The studied mixtures of seeds were placed in a cylindrical vessel made of transparent material with an adjustable angle of inclination. The vessel was rigidly connected to the vibrator.

The stages of the cleaning process are shown in Figure 2. As mentioned above, the amplitude of fluctuations did not exceed the average linear dimensions of the seeds. This is due to the fact that at which amplitudes and frequencies, instead of the process of cleaning seeds in a mixture into components, on the contrary, their intensive mixing begins. The vibration frequency varied from 5 to 10 Hz. Under these conditions making measurements is not difficult. The ability to use a high frame rate when recording video on modern smartphones (up to 960 frames per second) allows to determine both the average and instantaneous speed of movement of seeds in the cylinder.

Table 2. Characteristics of materials to be separated.

| Seeds   | Angle of natural slope, ° | Density, kg/m³ |
|---------|---------------------------|----------------|
| Buckwheat | 31.1                  | 530            |
| Millet   | 34.7                  | 760            |
The results of measurements of the dependence of the average "drift" speed during the cleaning process in the form of graphs of dependence on the angle of inclination of the cylindrical vessel to the horizon are shown in Figure 3.

![Figure 2. Mixture separation process.](image)

![Figure 3. Dependence of the average speed of "drift" of millet and buckwheat seeds on the angle of orientation of the axis of the vertical cylindrical bunker (vibration frequency \(\nu = 10\) Hz).](image)

4. **Conclusion**
The manufacture and use of the experimental setup made it possible to collect sufficient material for statistical verification and confirmation of the theoretical premises for describing the process of cleaning seeds of cultivated plants from weed seeds. The relationship between the average speed of the "drift" of seeds in a mixture poured into a cylindrical container with the frequency and amplitude of
oscillations has been investigated. For all the used samples the extremum of the function was found - the maximum value of the average "drift" speed corresponding to the angle of inclination of the cylinder approximately equal to the natural angle of slope of these seeds with a higher specific weight. The maximum scatter of the measurement results relative to the average values turned out to be no more than 8-12%. It is also important that this approach to cleaning among other things allows to separate whole seeds from damaged ones - broken and eaten. As a supplement to the research, it should be noted that it is necessary to improve the experimental setup to eliminate the effect of electrifying seeds. In order to save energy and time further research on this problem should be directed to the study of the critical values of the amplitude and frequency of oscillations.

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