Pre-Fractionation as a Way to Improve the Efficiency of Grain-Cleaning Systems

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Abstract. In most ordinary farms, the seed production share in the structure of the post-harvest processing and storage cost reaches 40 %, which is largely determined by the low productivity and operating quality of grain cleaners of existing grain-cleaning units. In farms, the required quality is achieved by repeatedly passing seed through grain cleaners, which leads to increased production costs, losses, and seed damage. Designing grain-cleaning lines based on the conventional flow sheet construction principles does not allow reducing the seed material damage and the production cost and leads to the cost of units increasing almost directly proportional to their productivity.

One way to solve the issue of improving the grain-cleaning system efficiency while reducing material and labor costs is the development and implementation of the grain mixture pre-fractionation technology based on the physical and mechanical characteristics of particles. Fractionation on an inclined plane with a curved surface (trampoline) increases the efficiency of grain cleaners by 20–30 % due to obtaining fractions of different quality before further processing.

1. Introduction
Most of the existing grain-cleaning units and complexes in ordinary farms of the Kurgan region do not allow achieving the required grain cleaning quality during post-harvest processing; as a result, only about 45-50 % of the 1st and 2nd class seeds are sown [1, 2]. Off-spec grain makes a third of the total seed volume. Due to the low cleaning efficiency, the seed should re-pass through the grain cleaners, which leads to increased grain damage. Grain-cleaning costs also increase, reaching 30-40 % of the total production costs. Ultimately, this leads to the infeasibility of obtaining high-quality seed material for farms.

2. Relevance and Research Objective
The low efficiency of the existing flow grain cleaning technology using cleaners with flat separating surfaces for post-harvest seed processing is associated with their uneven loading, low orienting ability, increased content of impurities in the source material, and a lack of modern engineering and constructive solutions in this area in general [3].

To increase the separating ability of flat sieves and reduce the number of the grain material passes through the tools, it is advisable to separate different-quality grain fractions at the pre-cleaning stage for their subsequent separate processing. Numerous studies in this area [4-10] show that to improve efficiency, the fractionation should be performed by several features: shape, friction coefficient, and
particle surface condition. Devices allowing the grain mixture pre-fractionation before feeding for further processing with the least material and energy costs include static gravity surfaces [11, 12].

3. Theoretical

To separate the grain mixture into fractions by several features, the largest difference in the trajectories of particle motion in space should be determined [13-15].

The study has been performed for an ellipsoid particle when moving along an inclined plane passing into a spherical surface depending on various physical and mechanical properties of the particle and the device parameters. When a particle moves on an inclined plane, it is affected by gravity \( G \), normal pressure force \( N \), and friction force \( F \). The particle-plane friction force is affected by the shape, friction coefficient \( f \), and the particle surface condition.

An analysis of the particle velocity change theoretical study results has shown that the velocity increases sharply at the initial stage of motion from zero and continues increasing with the inclined plane length. With an increase in the plane inclination angle, the velocity \( \upsilon \) also increases. However, an increase in the inclination angle above \( \alpha = 40^\circ \) is not advisable since it will not affect the particle acceleration because an increase in velocity gradually stabilizes. For the same reason, the optimal working plane length \( S \) is within 1.2-1.8 m [16].

Let us consider the motion of an individual particle along a curved ABC section of a chute plane with a central angle of \( 2\alpha \) (Figure 1, a). In this case, the particle is affected by the same forces as when moving along an inclined plane. On the arc (trampoline), the \( \tau \) natural trihedron axis is drawn tangentially to the spherical surface through the arbitrarily chosen point D, and the \( n \) axis is drawn perpendicularly to the tangent.

\[
\begin{align*}
\sin^2 \alpha & = \frac{1}{R} \sin \varphi \gamma \\
\sin^2 1 & = \frac{1}{R} \sin \varphi \gamma \\
\end{align*}
\]

\[
\begin{align*}
v_c &= \sqrt{v_b^2 - 2 \cdot g \cdot R \cdot \sin \alpha \cdot \tan \varphi} \\
&= \sqrt{1 + 2 \cdot \tan \varphi \cdot \sin \alpha}. \\
\end{align*}
\]

Figure 1. The Design Particle Motion Scheme.

Since in the AB section of the curved surface, the horizontal components of the gravity and friction forces are directed in different directions and in the BC section, their directions are the same, the particle motion is considered separately in each section. By the known velocity in the inclined plane end (the A point) \( v_A \), the velocity \( v_B \) at the B point and then, by the \( v_B \) velocity, the \( v_C \) velocity (the C point) are determined.

The particle velocity at the C point is determined using a theorem on the kinetic energy change equal to the sum of all forces applied to the particle at a given displacement depending on the surface radius \( R \) (curvature) and the angle of the particle descent on the curvilinear trampoline \( \varphi \):

\[
\begin{align*}
v_c &= \sqrt{\frac{v_b^2 - 2 \cdot g \cdot R \cdot \sin \alpha \cdot \tan \varphi}{1 + 2 \cdot \tan \varphi \cdot \sin \alpha}}. \\
\end{align*}
\]
where $\rho$ is the particle friction angle, $\rho=\arctg(f)$.

An analysis of the results obtained has shown that with an increase in the curvature radius $R$, the particle velocity decreases due to an increase in the arc length, and at a certain $R$ value tends to zero.

In the BC curved surface section, the dominant factor affecting the particle motion after it descends at the C point is not so much the curvature radius as the angle $\phi_2$ measured from the B point. The particle descent angle with the friction surface determines both the velocity at which the particle passes into free motion (flight) and its direction to the horizon.

After the particle leaves the gravitational surface, it is affected by gravity and aerodynamic drag force $P$, which is proportional to velocity and opposite to the particle’s flight direction.

As a result of the substitution of the initial values, separation of variables, and integration, the equation for the particle motion (flight) trajectory after leaving the surface is obtained:

$$y = x \cdot \tan \gamma + \frac{g \cdot x}{k \cdot v_0 \cdot \cos \gamma} + \frac{g}{k^2} \cdot \ln \left(1 - \frac{k}{v_0 \cdot \cos \gamma} \cdot x \right),$$

where $k$ is the resistance coefficient; $\gamma$ is the velocity vector to the horizon inclination angle (Figure 1, b).

The analysis of the motion trajectories of various particles, obtained as a result of the theoretical study confirms the hypothesis of the possibility to separate the grain mixture particles using a surface for pre-fractionation. Installing a separating bar allows removing part of the impurities from the grain mixture (Figure 2).

4. Study Results

The use of high-speed video recording when observing the particle motion on a section of an inclined plane $S=0.9-1.0$ m until it leaves the plane edge confirms the theoretical study results indicating the inefficiency of increasing the inclined surface length to more than 1.2 m. Thus, rational gravitational plane parameters are an inclination angle of 35-40°, length $S=1.0-1.2$ m, and the curvature radius $R=0.01-0.05$ m.

Figure 2. Particle Motion Trajectories after Leaving the Friction Surface ($\phi_2=20^\circ$, $R=0.01$ m).
In the experimental study, empirical forms of the grain motion trajectory have been obtained depending on various physical and mechanical properties of particles, i.e. dependences 5 and 6 (Figure 3).

![Comparison of the Particle Trajectory Study Results.](image)

1 - theoretical wheat grain motion range; 2 - theoretical feeble grain motion range; 3 - the averaged wheat grain motion trajectory; 4 - the averaged feeble grain motion trajectory; 5 - experimental wheat grain motion trajectory; 6 - experimental feeble grain motion trajectory

**Figure 3.** Comparison of the Particle Trajectory Study Results.

Theoretical dependencies 1–4 obtained by solving equations 1 and 2 correspond to the dependencies obtained in the experimental study, i.e. curves 5 and 6 (Figure 3). The convergence of the study results is confirmed by the Pearson criterion calculations.

Comparative tests performed on a K-531 Gigant grain cleaner while feeding the contaminated source grain mixture and pre-fractioned grain mass to processing have indicated an increase in separation efficiency due to preliminary separation of a part of the impurities (Figure 4).

![Comparative Test Results.](image)

1 and 3 – the separation completeness E and the grain loss P when cleaning fractionated grain mass, 2 and 4 - the separation completeness E and the grain loss P when cleaning the contaminated source grain mixture

**Figure 4.** Comparative Test Results.
During the test use of the pre-fractionation device within the ZAV-20 grain-cleaning unit process line in Glinka CJSC in the Kurgan Region, when cleaning the initial grain mixture by only the process line machines, seeds meeting the standard requirements could be obtained if processed at least twice. When processing pre-fractionated grain mixture at the same productivity \( q = 8 \, \text{t/h} \), seeds with a purity of 97 % corresponding to the requirements of the 3rd class of the sowing standard were obtained in a single pass.

The calculation of the economic efficiency of pre-fractionation has shown that when cleaning equal grain mixture amounts during the same period and at the same experimental line productivity, the reduced costs and the specific energy consumption decrease by 203 RUB/t (24 %) and 47 %, respectively, and energy savings is 1,100 GJ/season.

5. Conclusions
Since the existing continuous flow technology for post-harvest grain processing does not ensure the required cleaning quality at a single pass of material along the process lines, the grain cleaning system efficiency can be improved by using static gravity surfaces for pre-fractionation of the grain mixture.

Pre-fractionation of the grain mixture on an inclined plane with a curved surface improves the grain cleaner efficiency by 20-30 % due to obtaining fractions of different quality before further processing.

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